The Geographic Sources of Innovation in the Multinational Enterprise: U.S. Subsidiaries and Host Country Spillovers, 1980-1990

by

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Abstract

This dissertation is about multinational firms and the geography of technological innovation. It addresses a series of questions about the spatial location of the knowledge sources that underpin and inform innovations developed by foreign subsidiaries.

Where foreign subsidiaries draw their scientific, technical, and commercial ideas from during the process of generating knowledge is a central concern in current debates about the nature of foreign direct investment and the multinational enterprise. An emerging notion in the literature is that the multinational firm may be evolving toward an institution specializing in the assimilation, diffusion, and, ultimately, creation, of knowledge on a worldwide scale. A key conjecture in this perspective is that what makes the multinational unique as a learning organization is its structural position spanning heterogeneous institutional environments. To date there exists little in the way of systematic evidence that foreign subsidiaries assimilate knowledge originating in the host countries in which they are located – much less that this knowledge is actually being utilized, either locally by the subsidiary or elsewhere within the multinational firm.

This study seeks to advance this debate through an empirical investigation of the subsidiary-environment interface in the context of technological innovation. Three research questions are addressed:

1. Where, geographically, do foreign subsidiaries derive their scientific and technical ideas from during the process of technological innovation?

2. Under what conditions do innovations generated by foreign subsidiaries build upon sources of science and technology in the home and/or host country?

3. To what extent and under what conditions do other parts of the multinational firm derive a learning benefit from a foreign subsidiary's capacity to assimilate knowledge in its local environment?

New insights often come from new data and the development of new methods to use those data. In this study, I take advantage of a unique source of subsidiary-level innovation data derived from U.S. patent records. Briefly, for every patent issued to U.S.-

based subsidiaries of foreign multinationals between 1980 and 1990 – over 16,000 patents – I have assembled a variety of geographic, organizational, and technological indicators. Most importantly, this patent database contains detailed information on the references or "citations" to prior patents listed on every subsidiary patent record. These citations represent the technological antecedents of the patented invention. In the empirical analysis, I use the *geographic* information contained in these citations to draw inferences about the extent and conditions under which innovating subsidiaries are drawing upon home or host country sources of science and technology, and the extent to which this knowledge is eventually diffused to other parts of the multinational network. The patent citation methodology is modeled on the pioneering work of Jaffe, Tratjenberg and Henderson (1993).

This study is explicitly inter-disciplinary in its theoretical orientation. In addition to the multinational literature, I draw upon concepts and ideas originating in the literatures on innovation and economic geography. The argument has two main steps. First, drawing on March (1991), I argue that the innovative activities of foreign subsidiaries can be categorized into two broad "logics": a logic of exploitation and a logic of exploration. Exploitation – "the refinement and extension of existing competencies, technologies and paradigms" (March, 1991: 85) – is hypothesized to be associated with sources of knowledge in the home base of the firm, most fundamentally from within the parent firm itself. Exploration -- "experimentation with new alternatives" (1991: 85) – is hypothesized to be associated with knowledge sources originating in the subsidiary's host country locale. Second, drawing on what I term the "embeddedness" perspective on external innovation networks, I argue that the ability of subsidiaries to participate effectively in local knowledge sharing networks will be conditioned on a set of subsidiary- and parent-level factors influencing the credibility and legitimacy of the subsidiary within those networks. In short, the argument is that agency – the logic or strategy of subsidiary innovation – will be moderated by structure, the social and institutional obstacles to the subsidiary's effective participation in external innovation networks.

Important findings emerging from this study include:

- A substantial amount of evidence that U.S. subsidiaries assimilate localized spillovers of technical knowledge during the process of technological innovation. The results are especially strong at micro geographic levels – host state and region.

- This finding is quite robust over the 1980 to 1990 time period and is not driven by the presence of acquired U.S. firms in the subsidiary sample. Greenfield subsidiaries also show considerable evidence of being able to "tap into" localized sources of knowledge.

- U.S. subsidiaries also build importantly upon sources of knowledge originating in their home country, most fundamentally upon knowledge generated by the parent organization itself, a finding that is consistent with a more conventional view of the multinational firm than is implied by the above results.

- Some evidence is also found that other parts of the multinational firm derive a learning advantage from having a subsidiary that is geographically proximate to sources of knowledge in the host country.

- Supporting the hypotheses developed in the study, structural characteristics of subsidiaries as well as specific features of their innovations are found to be important predictors of the location of the knowledge sources that underpin subsidiaries' innovations. Some of these factors also influence the likelihood of local knowledge being diffused through the multinational network.

Findings from this research have important implications for theory and practice. Perhaps the study's most fundamental theoretical implication is the doubt it casts on the notion – frequently advanced in the multinational literature -- that there is a single "model" of innovation in the multinational firm, or even that firms are converging toward a particular model. The empirical results contained in this thesis show important and sustained variation across, and even within, particular subsidiaries in the geographic underpinnings of their technological innovations. For managers, the most far reaching implication of this study is the evidence it provides of the importance of location (and all that term implies) to the process by which firms generate new and valuable technical knowledge.

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Although the methodology adopted in this study draws upon secondary source data, I owe a considerable debt to the many managers, public servants, and fellow academics that helped me make sense of these data through the opinions they expressed during my interviews with them. To all of them, thank you.

That MIT is a special place is well known to virtually everyone. To have experienced MIT as an insider is truly an experience that I will carry with me as long as I live. I would like to thank all of the many people at the university who contributed to my development, often in fundamental ways. Richard Locke was instrumental in encouraging me to apply to the doctoral program at the Sloan School, and, even though our research interests never in the end overlapped much, was always a source of support and encouragement. Richard is a product of MIT's excellent political science department, and, to an important degree, I feel I am too. My thinking was changed importantly through the many courses and seminars I took in the department with the likes of Suzanne Berger, Charles Sabel, Ken Oye, Ronald Dore and Michael Piore. The MIT-Harvard dissertation seminar run by Suzanne Berger and Peter Hall was especially important to my development. Although, in the end, I decided to pursue a thesis topic that was less directly connected to key issues in political economy than I had originally intended, the training I received in the political science department was invaluable. Through my teaching activities, in particular, I continue to draw upon that training to a degree that would be hard to overstate.

It would also be difficult to overstate the patience and encouragement of my thesis committee, Rebecca Henderson, Don Lessard, Eleanor Westney, and Nick Ziegler. Like any good thesis committee, they pushed me hard to produce the best product I could. Looking back at the course of this project, it is remarkable to me how much the final outcome diverged from the vision of it that I held at the outset. There were times when I never thought I would get to the end, but, here I am, and I owe each of them a special debt of gratitude. Each member played, in their own way, a vital role. Don was, and continues to be, a fountain of new and fascinating ideas, and I have benefited a great deal from the localized spillovers (!) he generates. Nick was extraordinarily supportive throughout the project, even when the ideas and methods I adopted diverged from his core interests. His encouraging phone calls to me in London, Ontario were much appreciated. Rebecca was central to the development of this project. She pushed me hard, but was always there with an encouraging word when I veered close to the breaking point. Thank you. I would especially like to thank my thesis chair, Eleanor Westney, who has been a tremendous mentor throughout my MIT years, especially so during the job market and thesis stages of the process. I hope one day I can repay the debt.

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Finally, it is entirely appropriate that this thesis sits collecting dust on a shelf right next to another thesis -- written by my wife, Ann Frost. These two projects, hers and mine, are inextricably linked. We came to graduate school together, we left together. Ann gave me constant support throughout the long process of completing the thesis. She read my work, she suggested new ideas, she offered approaches for analyzing and presenting the data. She kicked me in the butt when that was what was called for. Simply put, I could not have done it without her. I look forward to many new adventures in the future.

Speaking of adventures, certainly the greatest one that I have ever embarked upon – contemporaneous with the dissertation – has been the adventure of having children. Our first daughter, Zoë, was born in 1993 when Ann and I were at the early stages of our theses. When she learned to talk two years later, she would from time to time sit down with a pen and claim to be "working on her thesis", just like mom and dad. Eden was born nearly three years later, when I was still in the middle of analysis and writeup. There are many people who have said we were crazy to try to complete two theses, start demanding new jobs, and have children at the same time...but those people will never know. My "girls" – all three of them – are my constant joy. This thesis is dedicated to them.

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Chapter 1 Introduction and Overview

1. Background and Motivation for the Study

This dissertation is about multinational firms and the geography of technological innovation. It addresses a series of questions about knowledge creation in multinational firms, especially technical knowledge created by foreign subsidiaries. The specific focus of the research is on a variable I refer to as the geographic sources of innovation, defined as "the territorial origin of the scientific, technical, and commercial ideas the underpin and inform a particular organization's technological innovations". In short, the primary goal of this study is to understand where, geographically, foreign subsidiaries draw their ideas from during the process of creating new and commercially useful technical knowledge.

Where, geographically, innovating subsidiaries draw their ideas from is a question that has not received explicit research attention in the academic literature. However, the answer to this question is, I argue, of critical importance to current debates about the nature and evolution of foreign direct investment (FDI) and the multinational enterprise. Conventionally, the multinational has been viewed as a contractually efficient institution through which innovations developed by the parent firm are exploited in foreign markets (Buckley and Casson 1976; Caves 1982; Vernon 1966). At its core, this view rests on two inter-related claims about the nature and locus of innovation in multinational firms. First, that innovations are generated through activities performed by the headquarters organization, i.e., by units of the firm located in the home base of the firm. And second, that the ideas underlying multinationals' innovations – the impetus for the innovation, the key characteristics, and the technical knowledge and approaches to technical problem solving underpinning these innovations – derive from characteristics of the firm's home country's commercial and technological environment.

However, over the last decade and a half, scholars have begun to treat seriously a rather different perspective, namely that the multinational firm is – or is evolving toward -- an organization able to assimilate, generate, and transfer knowledge on a worldwide scale (Bartlett and Ghoshal 1989; Hedlund 1986; Hedlund and Ridderstrale 1992; Kogut 1992; Kogut and Zander 1993; Porter 1990; Storper 1993;Vernon 1979). A cornerstone of this knowledge-based perspective of the multinational firm is the idea that, increasingly, foreign subsidiaries are no longer responsible simply for exploiting the existing knowledge base of the firm. Rather, they may also play an important role as contributors to the development of that base through the introduction of new technologies, new products, even new ideas – in a word, of new knowledge.

A key conjecture in this alternative perspective is that what makes the multinational unique as a learning organization is its structural position spanning heterogeneous institutional environments. Certainly the quantity, quality, and diversity of innovation resources available to firms with boundary spanning operations is vast. The opening of new markets, the expansion of international commerce, and the emergence in many industries of new competitors with an often diverse set of origins and capabilities has created an ever-expanding pool of commercial, technical, and scientific knowledge. This trend has been further reinforced over the last two decades by the gradual "catch-up" of the world's advanced industrial nations to the U.S. technological lead. As a result, important centers of science and technology have appeared or been rediscovered in various locations around the globe, further increasing the scope and diversity of the knowledge pool available to boundary-spanning organizations. To the extent that multinational firms have the capabilities to build and manage a network of subsidiaries able to "tap into" and leverage these diverse sources of knowledge, the view of the multinational firm as a "multi-point learning organization" is theoretically plausible (Lessard and Amsden 1996; Porter 1990; Soivel and Zander 1991). To date, however, there exists little in the way of systematic evidence that foreign subsidiaries actually assimilate knowledge originating in the host countries in which they are located - much less that this knowledge is actually utilized, either locally by the subsidiary, or elsewhere within the firm.

In large part, the shortcomings in the existing multinational literature are due to the paucity of detailed, large sample data on these firms' technical activities. Obtaining subsidiary-level innovation data, in particular, has been virtually impossible for any reasonable sample of firms (Kogut and Chang 1991). As Hedlund and Ridderstrale (1993: 8) have noted "empirical grounding is sparse and impressionistic and perhaps colored mainly by the pioneers among the MNCs rather than a more representative sample".

The most fundamental objective of this study, then, is to break the logjam in the current debate by focusing empirical attention on the subsidiary-environment interface in the context of technological innovation. New insights often come from new data and the development of new methods to use those data. In this study, I take advantage of a unique source of subsidiary-level innovation data derived from U.S. patent records. Briefly, for every patent issued to U.S.-based subsidiaries of foreign multinationals between 1975 and 1992 – over 20,000 patents – I have assembled a variety of geographic, organizational, and technological indicators. Most importantly, this patent database contains detailed information on the references or "citations" to prior patents listed on every subsidiary patent record. These citations represent the technological antecedents of the patented invention. In the empirical analysis that follows, I use the *geographic* information contained in these citations to draw inferences about the extent and conditions under which innovating subsidiaries are drawing upon home and/or host country sources of science and technology, and the extent to which this knowledge is eventually diffused to other parts of the multinational network. The patent citation methodology is modeled on the pioneering work of Jaffe, Tratjenberg and Henderson (1993), and is discussed in detail in Chapter 3.

The remainder of this introductory chapter provides an overview of the research project. Section 2 begins with a discussion of the research questions, placing them in the context of current debates about the nature and evolution of the multinational enterprise. Some points of departure from the existing literature are described in Section 3, along with the theoretical orientation of the study. Section 4 provides an overview of the empirical approach adopted in this study and explains the rationale for several important delimitations of its scope. Finally, the chapter concludes with an outline of the remaining chapters.

2. Research Questions

Three research questions are the main focus of this study:

1. Where, geographically, do foreign subsidiaries derive their scientific and technical ideas from during the process of technological innovation?

2. Under what conditions do innovations generated by foreign subsidiaries build upon sources of science and technology in the home and/or host country?

3. To what extent and under what conditions do other parts of the multinational firm derive a learning benefit from a foreign subsidiary's capacity to assimilate knowledge in its local environment?

The first question addresses the basic, but essential "mapping" issue that is the subject of much of the controversy and speculation in the multinational literature. Note that the question does *not* address the overall location of R&D or innovation in the multinational firm – a topic that has received a large amount of research attention dating back to the mid-1970s (e.g., Creamer et. al. 1976; Lall 1979; Patel and Pavitt 1991). Rather, the question focuses instead on the location of the *sources of knowledge* that underpin and inform the technical activities of particular units within the multinational firm.

The seemingly straightforward question of "where do subsidiaries draw their scientific and technical ideas from" turns out to contain numerous interesting dimensions, which I explore to some degree in the empirical chapters. First, I investigate the importance of both host *and* home country sources of knowledge on subsidiaries' technical activities – as is implied by the question. Surprisingly perhaps, this is an important point of differentiation from much of the existing research on this topic, which has tended to focus on the search for host country influences (Cantwell 1993; Herbert 1989). Second, I explore whether there are differences in the geography of the knowledge sources utilized by subsidiaries established through greenfield investment or through acquisition of local (i.e., host country) firms. There are many suggestions in the multinational literature that the acquisition of foreign firms may be motivated, in part, by the goal of gaining access to technology - and to technical networks - in the host country (Teece 1992; Hakanson and Nobel 1993). It would not be particularly surprising to discover that acquisitions are highly connected to the local technical environment; the more interesting question is whether *greenfield* subsidiaries - which can be expected to possess a quite different set of orientations, technical capabilities, and management systems - are also able to establish themselves in the local environment and participate effectively in the "invisible college" that often defines and regulates local knowledge sharing communities.

Finally, in the context of the "where" question, I also ask several more specific questions about the nature of the knowledge, and the knowledge sources, that foreign subsidiaries draw upon. For example, to what extent does knowledge originating in the subsidiary's home base actually come from the parent firm itself? Certainly the multinational literature suggests that headquarters organizations act as important sources of tangible and intangible assets to their overseas subsidiaries. Or, how geographically proximate are key sources of knowledge in the host country to innovating subsidiaries? As discussed later in the chapter, much of the existing literature on foreign innovation is cast at the national level, i.e., in terms of the market and/or technological influences of the host country on observed patterns of subsidiary innovation. An interesting and important question addressed in this study is whether sources of knowledge resident in sub-national locations (i.e., same region or even same city as the subsidiary) also act as important underpinnings of subsidiary innovations.

A related concern is the question of whether the knowledge that foreign subsidiaries assimilate in the host country is *localized*, i.e., whether it remains to a significant degree embedded in the local milieu in which it originated. As discussed in Chapter 2, this question is critical to the idea that multinationals are able to derive a learning advantage from having a network of subsidiaries near to diverse centers of knowledge and innovation. After all, if information about new scientific and technical developments travels seamlessly across spatial and institutional boundaries, then proximity to its point of origin should not provide firms with a particularly important learning advantage. Interestingly, the frequent observation that foreign firms' technical facilities are often located near to leading research universities and other centers of innovation in the host country suggests that the local assimilation of knowledge by multinational firms may indeed be an important empirical phenomenon (Herbert 1989; Florida and Kenney 1995; Dalton and Serapio 1993). This study seeks to test this proposition explicitly.

The second research question shifts the analysis to levels below the ecological level – i.e., below the level of the population of foreign subsidiaries – to the level of the subsidiary and the subsidiary innovation. That is, whereas the objective of the first question is to generate some generalizable conclusions about the importance of home and/or host country sources of knowledge to the population of foreign subsidiaries[1], the second question explores the possibility that there may be variation across subsidiaries, and perhaps even within them (e.g., over time, or across technical areas), in the extent to which home and/or host country sources of knowledge are utilized during the process of technological innovation.

In short, the reason for addressing this question in the thesis is to begin to build a more contextualized theory of the geographic sources of foreign subsidiaries' innovations: not simply *whether* they "tap into" host country sources, but *under what conditions* are home (including the parent firm) and/or host country sources utilized in the innovations developed by these units. Framed in this way, answers to this question will also help to reconnect the literature on foreign R&D to the core theory of the multinational firm, something it has often neglected to do.

The third and final question expands the scope of the study from a focus purely on subsidiary-level assimilation and learning, to one that also considers the firm-wide impact of local learning opportunities. The question of whether knowledge that subsidiaries assimilate from the local environment is ever diffused to other parts of the firm is integral to the emerging knowledge-based view of the multinational firm. Kogut and Zander (1993: 640) capture the essence of this perspective:

> The sequential expansion of a firm's activities after the first entry into a country is an expression of the evolutionary acquisition and recombination of knowledge. In its more advanced evolution, this process alters the global knowledge of the firm and may result in its transformation towards a network of subsidiaries characterized by the cross-border transfer of learning.

However, if there is still considerable skepticism in the literature about the capacity of foreign subsidiaries to assimilate local knowledge, there is even greater doubt about the extent to which firms have been able to develop an effective set of mechanisms for diffusing such knowledge back through the multinational network.

Although recent conceptual models of the MNE, buoyed by a growing body of case study evidence, suggest a possible evolution toward "network" forms of organization characterized by cross-border coordination, integration, and learning (Bartlett and Ghoshal 1989; Ghoshal and Nohria 1991; Hedlund 1986; Westney 1992a), the prevailing view among scholars is that most firms struggle with an apparent trade off between such integration and the local "embeddedness" of particular subsidiaries. To the extent that foreign subsidiaries are involved with and, indeed, reliant upon local "innovation networks", the argument goes, they can be expected to be systematically less likely to contribute knowledge to the rest of the firm. Ultimately, however, this is an empirical question, one that, because of its complexity and the lack of suitable data, has not, to date, been systematically investigated to any significant degree. An objective of this thesis, then, is to offer at least some preliminary empirical insight into the "network diffusion" hypothesis.

In summary, the questions addressed in this thesis are inspired by a core debate about the nature and evolution of the multinational firm. The role of host country sources of knowledge as underpinnings to subsidiary innovations, in particular, occupies a central position in the current academic discourse. Yet, despite their importance, these questions have for the most part escaped systematic empirical research, largely because of limitations in the available data. This thesis seeks to advance our understanding of the subsidiary-environment interface in the context of technological innovation by drawing on a novel source of data – and new methods to use these data. Before addressing data and methodological issues, I turn first to a discussion of the scope of the study, followed by an overview of the theoretical orientation of the thesis.

3. Scope of the Study

The wide coverage of the patent data used in this study afforded many choices about the scope and focus of the study. Major dimensions along which design choices were made include: host country, industry/technical field, and time period. Decisions were made based on the objectives of the research, the balance between generalizability and "grain", as well as on time/cost considerations.

3.1 Host Country Focus

For several reasons, I chose to restrict my inquiry to a single host country, the United States. Operationally, this means the sample of subsidiaries whose innovations I am looking at is limited to U.S.-based subsidiaries of foreign multinationals such as Siemens, Hitachi, and Northern Telecom. In addition to time and cost considerations, a single host country design was chosen because it allows a more finely grained investigation into the importance of regional (i.e., sub-national) sources of innovation within the host country environment, an interesting and potentially important aspect of the debate. This is also an important differentiating feature of this study. As mentioned earlier, much of the previous literature on subsidiary innovation, especially studies of "technology seeking" foreign investment have been anchored - at least empirically - at the national level. Notions of "country capabilities" and "national innovation systems" notwithstanding, a major theme in contemporary research on innovation is the importance of the sub-national level in defining the geographic boundaries of technological capabilities and knowledge spillovers. A major objective of the current study, then, is to investigate the micro-geographic origins of the intellectual sources of subsidiary innovations. A single host country design supported this objective.

The U.S. is in many ways a critical case for the questions addressed in this research. Many scholars have cited both the excellence and "permeability" of the U.S. national innovation system as major draws to foreign multinationals (Dunning and Narula 1995; Herbert 1989; Dalton and Serapio 1993). It follows, therefore, that if the results of this study indicate that innovating subsidiaries in the U.S. do not draw significantly upon sources of knowledge originating there, then such behavior is also unlikely to be observed in other host countries. In other words, a "null" finding - which would arguably be just as important as a positive finding - in the U.S. case can be regarded as a conservative result: generalizations of such a result to other host countries could be made with considerable confidence. On the other hand, a finding that U.S. subsidiaries do indeed assimilate and build upon local knowledge during the process of technological innovation could not be interpreted in the same way. That is, one would not want to infer the same behavior by, say, foreign subsidiaries in Japan or Germany, countries which posses quite different institutional structures for innovation. This, of course, would be an opportunitity for future research.

3.2 Industry / Technical Field

A more difficult design decision pertained to the choice of which industries or technical fields to focus the study around. The advantage of a single industry study, especially when using patents as a principle source of data, is that it controls for problems that arise from inter-industry differences in the meaning and importance of patents as indicators of technological innovation. However, as Griliches (1990) has pointed out, this problem can be dealt with statistically through the use of dummy variables or through the use of other, more direct indicators of relevant characteristics of particular technologies (e.g., maturity, pace of change, complexity, proximity to science, etc.). Moreover, it is apparent that an inter-industry approach is most problematic in studies that use patents as indicators of inventive *outputs* (e.g., in studies of research productivity or the propensity to patent), since such studies draw conclusions from differences across firms in the number of patents received. This is less likely to be a problem in this study, since patent data are used here as indicators of inventive *inputs*, i.e., as a source of information about the nature and characteristics of foreign subsidiaries' innovations. Comparisons across industries and technical fields as to the geographic sources of technological innovation are, in fact, both meaningful and interesting: Are the knowledge bases of some technical fields more localized than others? Do firms in some industries draw upon a broader range of technical fields than others? Answers to questions such as these are reliant upon a cross-industry study, and thus such an approach was not ruled out on methodological grounds.

Another reason for *not* focusing on a specific industry stems from the current state of knowledge in the field. Much of the research on distributed innovation in general, and local knowledge sourcing in particular, is plagued by sample bias. Studying the foreign operations of semiconductor firms - especially when those units are based in Silicon Valley - risks biasing the results in favor of a positive finding of local knowledge sourcing. Given the research questions addressed in this study, which focus on trying to understand the conditions under which foreign subsidiaries draw upon home and/or host country sources, a focus on a single industry, especially a high tech industry where the assimilation of current knowledge may be presumed to be especially important, risked not moving the debate beyond its current state, where questions of generalizability are paramount.

For these reasons, and because a broad set of patent data were available to me, I chose not to restrict the focus of the study to a particular industry or technical field, but rather to adopt the population of foreign subsidiaries in the U.S. as the sample frame. Another obvious advantage of this decision is sample size. Patent data are notoriously noisy, and the statistical procedures utilized in much of the empirical analysis (logistic regressions) are to an extent more than most procedures, quite dependent on large samples (xxx Sage cites xxx). Differences in industry/technical field are dealt with in the chapters that follow in one of two ways, either statistically as in much of the literature, or by comparing paired samples of patents that are matched along various important dimensions including technical field.

3.3 Time Period of the Study

The use of U.S. patents as the primary data source for the dissertation also delimits the time frame of the study. The data are available in electronic form for patents issued to firms between 1975 and 1992. These, however, are the dates on which the patents were *granted* by the U.S. Patent Office -- i.e. the date upon which a particular patent has passed through the technical review process by the patent examiner, as well as other legal and administrative hurdles. The more important date for the purposes of this study is the date when the patent application was initially filed with the patent office, since the filing date more accurately represents the time period when the technical activity leading to the invention occurred. Given an average lag between the filing date and the eventual granting of the patent of two to three years, the bulk of the patents in the dataset have filing dates from 1973 to 1990.

A further delimitation in the time frame of the study was necessitated because of the heavy reliance on the citation indicators listed on these patents. Citations, by definition, refer to pre-existing technology - "prior art" in the language of patents. Unfortunately, many citations listed on patents issued in the early part of the series are left-censored. For example, patents issued in 1975 cite mostly pre-1975 patents - too early to be in the database. Thus, in the chapters that use the methodology of patent citation analysis, I further delimited the same of subsidiary patents to those with application dates between 1980 and 1990. Although the 1980 patents will still contain many references to pre-1975 patents, there are enough post-1975 citations on these patents to at least allow a workable dataset. I discuss the methodological implications of this problem in more detail in the methods chapter, Chapter 3, and the subsequent empirical chapters.

4. Theoretical Orientation

This study fits broadly into the stream of literature concerned with innovation in multinational firms. Research by Hedlund (1986), Bartlett and Ghoshal (1989), Kogut and Zander (1993), Porter (1990) and Vernon (1979) are important foundations and in many ways anchor the debates to which this research is addressed. However, the studies of most immediate relevance to this thesis are those that take the technical subsidiary, i.e., a subsidiary engaged in some form of R&D, as the focal unit of analysis.

Broadly speaking, it is possible to identify at least three distinct lines of inquiry in this area, although with considerable overlap in the issues and findings across the three streams. The three streams, which are reviewed in detail in Chapter 2, are: (1) research concerning the location of technical activity within the multinational firm, and changes in its geographic concentration/dispersion over time; (2) research concerning the strategy, organizational practices, and evolution of individual R&D units; and (3) research concerning the subsidiary-host country environment in the context of technological innovation. Of the three streams, the third is of most concern to the objectives and questions dealt with in this study.

For the most part, research on the subsidiary-environment interface in this stream has drawn on theories and concepts originating from within the field of international management itself. For example, theories of foreign direct investment such as Dunning's OLI framework (e.g., Dunning and Narula 1995; Cantwell 1993) and Hymer-Kindelberger oligopoly theory (e.g., Kogut and Chang 1991) have been used in a general way to explain the phenomenon of "technology-seeking" foreign investment. Other studies in this stream have adopted more of a practitioner orientation (e.g., Herbert 1989; Perrino and Tipping 1989), focusing on a fairly general set of issues relating to how multinationals structure their international R&D operations to take advantage of the technological resources and capabilities resident in the local environment. Neither approach has yet led to the development of a clear set of hypotheses or predictions about subsidiary-environment interactions in the context of technological innovation. For the most part, prior work has not even considered explicitly the questions addressed in this study about the location of the knowledge sources underpinning subsidiary innovations.

This study is explicitly inter-disciplinary in its theoretical orientation. Although insights from several different perspectives are considered, I draw most heavily upon concepts and ideas originating in the literatures on innovation (e.g., Dosi 1988, Cohen and Levinthal 1990; Freeman 1982; Powell et. al. 1996; von Hippel 1988) and economic geography (Marshall 1920; Krugman 1990; Storper 1993). An existing body of research at the intersection of these two literatures is also utilized extensively (e.g., Acs et. al.; Feldman 1994; Jaffe 1989; Jaffe et. al. 1993). Both the innovation literature and the geography literature share a common perspective on the importance of the external environment as a source of stimulus and know-how for innovating organizations. Technological innovation, in this view, involves the combination of firm-specific proprietary knowledge and public knowledge; technical progress derives not only from activities performed within the boundaries of the innovating organization, but also outside it. Both literatures also point to the importance of spatially localized processes in the generation and the diffusion of technical knowledge. I build on both of these fundamental insights into the innovation process in the course of developing the theoretical argument.

The conceptual underpinnings of this this study are derived, then, from three main foundations: the multinational literature, the innovation literature, and the economic geography literature. The argument, which is based on a synthesis of these literatures, has two main steps. First, drawing on March (1991), I argue that the innovative activities of foreign subsidiaries can be categorized into two broad "logics": a logic of exploitation and a logic of exploration. Exploitation – "the refinement and extension of existing competencies, technologies and paradigms" (March, 1991: 85) – is hypothesized to be associated with sources of knowledge originating in the home base of the firm, most importantly from within the parent firm itself. On the other hand, exploration -- "experimentation with new alternatives" (1991: 85) – is hypothesized to be associated with knowledge sources originating in the subsidiary's host country locale. Thus, for example, I am hypothesizing that subsidiaries performing activities in technical fields that are outside of the main technical focus of the parent firm are likely to be drawing upon local resources and capabilities – much like local firms. Second, drawing on what I term the "embeddedness" perspective on external sources of innovation, I argue that the ability of subsidiaries to participate effectively in local knowledge sharing networks will be conditioned on a set of subsidiary- and parent-level factors influencing the credibility and legitimacy of the subsidiary within those networks. In short, the argument is that agency – the logic or strategy of subsidiary innovation – will be moderated by structure, the social and institutional obstacles to the subsidiary's effective participation in external innovation networks. The argument is developed more fully in the following chapter.

5. Empirical Approach

This study falls clearly into the positivist tradition of social science research. Notwithstanding the exploratory and descriptive aspects of a considerable proportion of the empirical analysis, wherever possible specific hypotheses are formulated and tested. The choice of this approach was driven by several considerations, but most importantly by the current state of the research stream to which this study contributes most directly. The last decade has witnessed the development of a considerable body of research around the topics addressed in this thesis, most of it based on inductive approaches -- focusing on the development of concepts and models from direct observation. Indeed, many of the most important insights generated by this stream of research has been grounded in clinical observation of leading multinational firms (e.g, Hedlund 1986; Bartlett and Ghoshal 1989; Prahalad and Doz 1989).

However, one negative consequence of this development has been that our conceptual models have often outstripped out capacity to test them, or even specific aspects of them. As suggested earlier, what is largely missing from this stream of research are empirical studies that seek to test specific hypotheses about the phenomenon being examined. Thus, in terms of contributing to the development of this trajectory, a research approach based on the formulation and testing of hypotheses appeared to offer the greatest possibility for advancement.

6. Data and Methods

Data used in this study were gathered from many different sources, including interviews with R&D managers and patent examiners, and archival sources such as company records, newspaper articles, and various print and electronic sources. However, the empirical analysis in this study draws primarily on U.S. patent data -- that is patents issued by the United States Patent and Trademark Office (USPTO).

U.S. patents have been used for many years in the innovation literature and a well established body of knowledge now exists on their use, limitations, and interpretation (Basberg 1987; Griliches 1990; Pavitt 1984; Scherer 1965; Schmookler 1950; 1966). The main advantages of U.S. patent data can be succinctly stated: they are one of the few sources of detailed, disaggregated data on the technical activities of a large population of firms that have been systematically collected for a long period of time.

For the purposes of this study, U.S. patents have three key characteristics. First, the data are disaggregated to the level of the inventing unit. In other words, particular patents can be associated with particular locations within a firm (e.g., Hoechst's laboratory in Summit, New Jersey) – a critical requirement for this study, which takes the subsidiary as the focal organizational unit of analysis. Second, the data are longitudinal. This facilitates the testing of hypotheses relating to changes over time in the technical activities of foreign subsidiaries, one of the important contributions of this study. Finally, U.S. patents have the advantage of providing excellent coverage of foreign (i.e., non-U.S.) firms (Basberg 1987; Griliches 1990). In fact, in many industries major foreign firms are frequently granted more U.S. patents each year than their main U.S. peers (Narin 1991).

From the database of all U.S. patents issued between 1975 and 1992, over one million patents, I identified a total of 23,315 patents that were issued to U.S.-based subsidiaries. Using the detailed information contained on each patent record, I constructed a variety of technological, temporal, organizational, and geographic indicators for each of these patents, including a detailed set of indicators on the prior patents cited as references. To the best of my knowledge, this is the most comprehensive set of indicators on the technical activities of foreign subsidiaries assembled to date. During the 1980 to 1990 time period for which the citation data could be assembled, 70,342 citations referenced by 16,209 subsidiary patents were included in the database.

In addition to the main subsidiary patent dataset, I also assembled a file containing a matching set of technological, temporal, and organizational indicators for each citation listed on the subsidiary patents. As described in detail in Chapter 3, these citations represent the technological antecedents of the current work; they "reveal the state of the technology to which the invention is directed" (Office of Technology Assessment and Forecast, 1976: 167). The basic assumption underlying the use of patent citations in this study is that by tracing the technological lineage of a particular patent, it is possible to shed light on the sources of knowledge upon which foreign subsidiaries are drawing during the process of technological innovation. The particular focus of this study is on the *geography* of these knowledge sources, i.e., their national and sub-national place of origin. Methodologically, the analysis of patent citations contained in this thesis builds upon and extends the pioneering work of Jaffe et. al. (1993), which I discuss at length in Chapter 3.

7. Outline of the Remainder of the Thesis

The remainder of the thesis is divided into seven chapters.

Chapter 2 reviews the relevant literatures on distributed innovation in the multinational firm and lays out the basic theoretical model underpinning the dissertation. A synthesis of three literatures - the multinational literature, the innovation literature, and the economic geography literature - leads to a set of hypotheses that are subsequently tested in the empirical chapters.

Chapter 3 sets the stage for the empirical chapters that follow by discussing important methodological issues, including the design of the research, the sources, limitations and key features of the data. Particular emphasis is placed on the process by which patents belonging to U.S. subsidiaries were identified and categorized geographically. An extended discussion of the methodology of patent citation analysis is also provided.

Chapter 4 presents background and descriptive statistics on the patenting activities of foreign subsidiaries in the United States.

Chapter 5 addresses the first research question, which focuses on the geographic sources of foreign subsidiaries' innovations. The research design used in that chapter is discussed followed by the analysis and results. Evidence is provided to substantiate the argument that foreign subsidiaries are systematically capturing localized spillovers during the process of technological innovation.

Chapter 6 address the second research question through a test of the hypotheses developed in Chapter 2. Measures used to operationalize the various constructs are discussed followed by the analysis and presentation of results. An extended series of checks of the robustness of the results is then conducted.

Chapter 7 turns to the final research question on the diffusion of local knowledge through the multinational network. The design of the analysis is first discussed followed by a presentation of the results. Factors associated with greater levels of knowledge diffusion in the multinational firm are identified and discussed.

Chapter 8 summarizes the findings from the research, discusses the limitations of the study, and outlines opportunities for future research.

Endnotes

[1] More accurately, to the population of U.S. subsidiaries, since I restrict the scope of the study to a single host country, the U.S. I discuss the rationale for this decision and other delimitations to the study later in the chapter.

Chapter 2 Literature and Hypotheses

1. Overview and Objectives

This study contributes to a longstanding and still core debate about the nature and evolution of the multinational enterprise. Whether, to what extent, and under what conditions multinationals utilize their network of foreign subsidiaries to generate knowledge are questions that have received a considerable amount of attention in the multinational literature. The purpose of this chapter is to review the existing research on distributed knowledge creation in multinational firms and to formulate a set of hypotheses about the geographic sources of foreign subsidiaries' innovations, the particular aspect of the debate that I focus on in this study. To recap, by "geographic sources of innovation" I mean the territorial origin of the scientific, technical, and commercial ideas the underpin and inform a particular organization's technological innovations.

For theoretical guidance, this chapter draws upon insights originating in fields outside of the international management literature, in fields concerned more directly with innovation and economic geography. The anchoring point for much of this work is economics, although the innovation literature is itself inherently inter-disciplinary. The argument developed here is based, then, on a synthesis of three literatures: the multinational literature, the innovation literature, and the economic geography literature. I argue that various currents within these often diverse literatures converge around the idea that *external* sources of knowledge play a pivotal role in shaping the pace and direction of technological change within innovating organizations. In the economic geography literature, this idea is expressed most clearly in the rapidly developing stream of research on technological spillovers – inter-organizational flows of knowledge not governed by license or other formal agreements (Glaeser et. al. 1991; Jaffe 1989; Jaffe, Tratjenberg and Henderson 1993; Krugman 1990; Romer 1986; 1990). The innovation literature has also produced an important body of knowledge on the nature and importance of external sources of knowledge – buyers, suppliers, competitors, universities -- to the process and outcomes of technological change (Dosi 1988; Dosi et. al. 1989; Freeman 1982, 1991; Schrader 1991; von Hippel 1986, 1988). Where knowledge travels, how quickly, and through what mechanisms are, I argue, questions that can also be usefully applied to the multinational debate. As discussed in Chapter 1, a key conjecture in this debate is that actors, institutions, and resources in the *host* country environment may act as important sources of innovation to foreign subsidiaries engaged in technological activities.

I do not attempt comprehensive reviews of either the innovation or geography literatures in this chapter. They are both vast and not everywhere related to the main concerns of this study. Moreover, many good reviews exist already (c.f., Feldman 1994; Scott 1988; Storper 1990; Dosi 1988; Dosi et. al. 1989; Van de Ven 1990). Rather, I use these literatures selectively as a way of formulating theory-driven, empirically testable hypotheses about the geographic sources of foreign subsidiaries' innovations – the specific focus of this study.

The remainder of this chapter is structured as follows. The next section reviews several distinct lines of inquiry on distributed knowledge creation in multinational firms. Section 3 builds on this existing body of research to generate a set of hypotheses about the conditions under which foreign subsidiaries are likely to draw upon home or host country sources of knowledge during the process of technological innovation. It is in this section that I draw upon concepts and ideas from the innovation and geography literatures. Section 4 summarizes and concludes.

2. Distributed Innovation in the Multinational Enterprise

Innovation has long played a central role in theories of the multinational enterprise. Beginning with Vernon's (1966) product life cycle model, scholars have viewed the multinational principally as an organizational mechanism for exploiting proprietary advantages (especially technological innovations) in international markets (Buckley and Casson 1976; Caves 1981; Kogut and Zander 1993; Porter 1990). For the most part, however, research on the multinational firm has taken the existence of some form of rent-producing innovation as a given and focused on where, when, and how it is exploited internationally. Comparatively little research has looked at where and how innovations within multinational firms are generated, although in recent years a growing number of scholars have identified these issues as critical to the development of a more robust and generalizable theory of the multinational enterprise (Bartlett and Ghoshal 1989, 1990; Cantwell 1994b; Dunning 1994; Hedlund and Ridderstrale 1992).

Conventionally, innovation has been understood as the domain of the parent organization located in the home base of the firm. This was Vernon's (1966) view, at least as the product life cycle model was initially formulated[1]. According to Vernon

(1966: 193), the rationale for anchoring product development in the home base was due:

> not to some obscure sociological drive for innovation but to more effective communication between the potential market and the potential supplier of the market.

Porter's most recent work (1990) similarly provides a strong argument in support of the notion that firms' innovation-generating activities should be concentrated geographically[2]. Successful firms, Porter claims, should maintain core technical activities in the home base not only to draw upon critical resources and capabilities in the local milieu, but also to sustain and help nurture an institutional setting conducive to continuous innovation and competitive upgrading.

Beginning as early as the late-1970s, however, an apparent evolution in the innovation strategies and structures of major multinational firms led researchers to begin to treat more seriously the possibility that foreign subsidiaries could act in an important knowledge creating capacity (Bartlett and Ghoshal 1989; Doz 1992; Hedlund 1986; Nohria and Ghoshal 1991; Vernon 1979; Westney 1990). Numerous examples were uncovered of foreign subsidiaries that had contributed importantly to the development of key products and processes (Bartlett and Ghoshal 1989). At the same time, many instances of investments by multinational firms in overseas facilities for basic and applied research, product design, new product development, and pilot manufacturing were documented in the academic and public presses (Dalton and Serapio 1993; Hakanson and Nobel 1993; Herbert 1989; Perrino and Tipping, 1989; Westney, 1992; Wortmann, 1990). Industry-level R&D statistics also hinted at a shift toward more geographically decentralized innovation structures (Brainard 1992; Hakanson and Nobel 1993).

The growing empirical salience of this phenomenon motivated the development of several ideal-type models of multinational strategy and organization, which, in contrast to the Vernon-Porter "home-based" model, shared a common belief in the knowledge creating potential of firms with the capacity to build and manage a global network of innovating sub-units. Although different in many important respects, concepts such as "heterarchy" (Hedlund 1986, 1991), "transnational" (Bartlett 1986, Bartlett and Ghoshal 1989) and "multi-focal MNC" (Doz 1986, Prahalad and Doz 1987) illuminated a similar set of systemic attributes of firms with distributed innovation capabilities. Several scholars even advanced the claim that such capabilities might constitute one of the key sources of sustainable advantage for the multinational firm (Bartlett and Ghoshal 1989; Hedlund and Ridderstrale 1992; Kogut 1989). In Bartlett and Ghoshal's (1989: 12) words:

> "the ability to link and leverage knowledge is increasingly the factor that differentiates the winners from the losers and survivors"

The idea of the multinational as a "distributed innovation network" has, in many respects, emerged as a touchstone for debates about the nature and evolution of foreign direct investment and the multinational enterprise. The interest in this issue has also given rise to the development of a considerable body of empirical research. Although there is notable diversity in the questions, as well as the answers, generated by this work, it is possible to identify at least three streams of direct relevance to the questions addressed in this study: (1) a "mapping" stream, focusing on the changing location of R&D and innovation in the multinational firm; (2) an R&D unit stream, looking at the strategy, organization, and evolution of technical facilities within multinational firms; and (4) a subsidiary-host country stream, focusing on the role of local stimuli and resources in shaping the direction of technical activity in foreign subsidiaries. In the remainder of this section, I briefly review each of these streams, focusing in more detail on existing empirical work on the subsidiary-host country interface in the context of technological innovation - the major focus of this study.

2.1 The Location of R&D in the Multinational Firm

Perhaps the largest volume of research on innovation in the multinational firm has been directed at what might be termed "mapping" questions: where do multinationals conduct various kinds of technical activities, how has the location changed over time, and why?

Research on these questions actually goes back to the 1970s when a series of early studies by Mansfield (1974), Creamer et. al. (1976), Dunning (1977), Mansfield, Teece and Romeo (1979) and Lall (1979) established initial evidence for what have turned out to be four of the most robust findings in the empirical literature on foreign innovation and R&D: (1) firms' technical activities are heavily concentrated in the home base; (2) there is considerable variation across firms in the propensity to locate technical activities abroad, due in large part to sectoral and home country effects; (3) the proportion of innovative activities carried out by foreign subsidiaries has risen over time, due in large part to the acquisition of foreign firms in R&D intensive industries;

and (4) overseas technical activities are overwhelmingly concentrated in the developed countries.

More recent studies that have contributed to this line of inquiry include those by Behrman and Fischer (1980), Dunning and Pearce (1985), Frost (1994), and Pearce (1992). Patel and Pavitt's (1991) analysis of patenting activities in 686 of the world's largest multinationals is perhaps the definitive study in this line of inquiry. Through 1986, the end point of their study, the authors found that multinationals still performed the overwhelming majority of their technical activities in the home country - a case, they argue, of "non-globalization".

2.2 Studies of Foreign R&D Units

A second stream of research on foreign innovation has taken the overseas R&D facility as the main unit of analysis. The focus of these studies is typically on understanding the strategy or "mandate" of the subsidiary, including the initial motivation for its establishment; the technical resources and capabilities of the unit, as well as key organizational systems relating to hiring and mobility of technical staff; and the nature and extent of linkages with other parts of the multinational firm, especially the headquarters organization. Representative studies in this line of inquiry include those by Florida and Kenney (1995), Rondstadt (1977), Hakanson and Nobel (1993a, 1993b), Westney (1992a), and Wortmann (1990).

A consistent finding in this stream of research is that most foreign R&D is geared toward the adaptation of existing products and technologies (i.e., products developed by the parent organization) to local market conditions. An early and important study by Ronstadt (1977) identified transfer of technology from the U.S. parent to foreign subsidiaries as the most frequent motivation for U.S. firms to locate technical facilities in international locations. The predominance of technology transfer and local adaptation as a motivation for foreign R&D is also indicated in survey and case research by Hakanson and Nobel (1993) on Swedish multinationals, by Florida and Kenney (1995) on Japanese multinationals, and by Wortmann (1990) on German multinationals. A survey by Pearce (1992) on a broader section of firms finds a similar result.

On the other hand, many of these same studies, as well as several others, have uncovered foreign R&D facilities with a more autonomous set of technical capacities and, in many cases, with corresponding mandates to create distinctly new products and technologies. Although many of the cases identified appear to be instances of subsidiary innovations taking on a "local-for-local" (Bartlett and Ghoshal 1989) character - i.e., new products and processes developed for local markets - several studies have identified foreign technical units with regional and even global product development mandates supported by a set of distinctive technical competencies (Birkinshaw 1996; Hakanson and Nobel 1993; Herbert 1989; Westney 1992a; and Ridderstrale 1997)[3]. The phenomenon is not necessarily new: 9 of the 42 foreign R&D units studied by Rondstadt (1977) were initially established to develop products and technologies for use outside of the host country[4]. What appears to be new is the growth in this phenomenon and its corresponding impact on the technical and competitive capabilities of multinational firms (Dalton and Scerapio 1993; Perrino and Tipping 1989; Westney 1990; 1992).

2.3 The Subsidiary-Host Country Interface

Of most interest to the current study is the literature that looks at the role played by the external environment in shaping the process and outcomes of subsidiaries' technical activities. The idea that sources of knowledge in the host country might inform the activities of foreign subsidiaries is central to the argument that the structural attributes of the multinational firm may provide a source of competitive advantage in terms of learning and innovation (Kogut 1989). The plausibility of this argument has increased over time as a result of major changes in the international economy, notably the growing parity of the advanced industrial nations in terms of their income levels and their capabilities in science and technology. For the first twenty plus years following World War II, there was little disagreement with Vernon's (1966) claim that "the United States market consists of consumers with an average income which is higher...than in any other national market - twice as high as that of Western Europe, for instance" (1966: 192), by the mid-1970s the world had changed. In fact, Vernon himself (1979) argued that, increasingly, important new market segments were appearing first in countries other than the U.S. - a development that, he reasoned, could induce firms to develop "a powerful capacity for global scanning" in which "markets, wherever located, have an equal opportunity to stimulate the firm to innovation and production".

In addition, changes in the global distribution of scientific and technological resources have been hypothesized by several authors to be driving greater amounts of "technology-seeking" foreign direct investment (Kogut and Chang 1991; Herbert 1989; Perinno and Tipping 1989). Not only are the advanced nations becoming more equal in terms of their capabilities in science and technology, they are also apparently becoming more specialized and differentiated, leading to the emergence of various centers of expertise in "technology districts" (Storper 1993) around the world (Archibugi and Pianta 1992; Lee and Procter 1991; Westney 1990). Even Porter (1990) has acknowledged the significant impact these changes have on firms, especially the growing need to:

> be aware of, and ideally have some access to, *all* the important scientific work going on in the world that is related to its industry....Today, a firm seeking competitive advantage should question its strategy if it does not have at least one foreign technology monitoring or research site. (1990: 609-610)

Unfortunately, empirical evidence that foreign subsidiaries actually draw upon host country sources of innovation to any important degree is sparse, and based mainly on anecdotal evidence. The few large sample studies that touch on this issue suffer badly from problems relating to aggregation bias, measurement error, and construct validity. Indeed, most of our current understanding of this phenomenon is derived from a few small sample studies of particular subsidiaries and technical facilities -- with the attendant problems of generalizability and sample selection bias. Representative studies in this line of work include those by Herbert (1989), Florida and Kenney (1995) and Wortmann (1990).

Herbert (1989) documents numerous examples of Japanese firms that have situated R&D facilities in US science valleys and established relationships with nearby universities and other centers of science and technology. This finding is echoed by Florida and Kenney (1995: 344) who find that an important subset of Japanese R&D facilities in the U.S. are located near major U.S. research centers to secure access to new sources of scientific and technical talent.

Dalton and Serapio (1993) report that "proximity to universities" and "availability of scientists and engineers" were rated as the most important reasons given by Japanese electronics firms for choosing particular R&D site locations – suggesting a technology-seeking motive for these investments. Westney's (1992) analysis of the U.S. R&D facilities of Japanese electronics multinationals similarly highlighted the strategic location (from a technology asssimilation perspective) of these investments: Silicon Valley (Canon); Princeton, New Jersey (NEC); and Cambridge, Massachusetts (Mitsubishi).

These findings with respect to Japanese firms are supported by additional studies of multinationals from other home countries. For example, Hakanson and Nobel (1993) identified several Swedish multinationals that have established foreign research units with a motive to monitor foreign technological developments and "tap into" host country technological infrastructures, a motive they argue has increased in importance over time:

> The need to monitor technological developments and competitors abroad – a negligible factor in pre-1970 establishments – has clearly become a significant consideration in the 1980s. (1993:7)

Similarly, Wortmann (1990) documents examples of German multinationals such as Bayer, Henkel, and Hoechst, which have established major R&D facilities in the U.S., in part because of a concern of being "isolated from important developments within the U.S. scientific community" (1980: 181).

Acquisitions by multinationals of foreign high tech firms provide another suggestion of the power of host country technological resources to "pull" foreign investment abroad. Acquisitions of U.S. high tech firms by foreign multinationals have been especially pronounced in the last half of the 1980s. Teece (1992), for example, lists numerous such acquisitions in the U.S. semiconductor, electronics, and pharmaceutical industries. Roche's 1990 acquisition of Genentech was widely interpreted as a way for the Swiss firm to gain access to U.S. biotechnology networks and to replenish its new product pipeline. To date, however, only one study has looked explicitly at the "technology seeking" motive for foreign acquisitions (Shan and Song 1995). The authors find a positive relationship between the level of patenting activity of target firms in the U.S. biotechnology industry and the likelihood of takeover.

Larger sample studies of the importance of host country knowledge sources to innovating subsidiaries are found in the work of Cantwell (1993), Kogut and Chang (1991), Anand and Kogut (1995), and Zander (1994). Cantwell (1993) links patenting activites of foreign multinationals to *host* country technological specializations, a finding he uses to argue that these firms are building on local technological trajectories and resources. However, he does not control for the possibility that these same technical areas might also be fields of *home* country technological specialization -- much more consistent with the Vernon-Porter "technology push" view of FDI and the multinational firm. Using a similar methodology, Zander (1994) explores nearly 100 years of patenting activites by Swedish multinationals, finding fluctuating support over time for the hypothesis that foreign subsidiaries are innovating in fields of host country expertise. In contrast, Dunning and Narula's (1995) analysis of R&D expenditures by foreign multinationals in the U.S. showed no support for the hypothesis that foreign R&D is concentrated in sectors and technologies of host country comparative advantage.

Studies of foreign investment by Kogut and Chang (1991) and Anand and Kogut (1995) are equally inconclusive in terms of the "technology seeking" hypothesis. Looking at factors that influence the rate of entry by Japanese firms into the U.S. market, Kogut and Chang (1991) find that industry level entry counts are positively associated with *host* country R&D intensity, suggesting that Japanese multinationals are "pulled" toward sectors in the U.S. that may provide important learning opportunities. However, a later study by Anand and Kogut (1996) using the same basic methodology but data from British, German and Japanese multinationals finds little evidence that these firms' investment decisions are motivated by the desire to access host country technical resources. In fact, the results indicate that host country R&D intensity is negatively related to industry entry by foreign firms, i.e., that it acts as a barrier rather than an encouragement to entry.

2.4 Summary and Points of Departure

Although research on the subsidiary-host country interface offers many clues and suggestions about the importance of host country knowledge sources, many, indeed most, of the key questions in this area remain subjects of controversy and speculation. For example, little is still understood about the extent to which actors and institutions in the host country act as important sources of stimulus and know-how for innovating subsidiaries, whether there are importance differences across subsidiaries in this regard, whether foreign firms are just as able as domestic firms to draw upon these sources, and whether and how this phenomenon may have changed over time.

In large part, the shortcomings in the empirical literature are due to the paucity of available data: simply put, there exist few sources of data that can be used to trace systematically the sources of knowledge upon which firms draw during the process of technological innovation. Much of the existing large sample research on this topic uses data aggregated to the industry level to draw inferences about inherently more micro level processes. Moreover, studies linking foreign direct investment to host country capabilities do not distinguish between different kinds of investment activities - e.g., distribution versus manufacturing versus R&D. In other words, in most of this work there is only a very tangential link between subsidiary innovation and local sources of stimulus and know-how.

The more finely grained studies of particular R&D units are generally more informative. However, this work also suffers badly from methodological problems, mostly relating to sample selection bias: studying investments by semiconductor firms in Silicon Valley or pharmaceutical firms in New Jersey, while likely to turn up a positive result with respect to the "tapping" hypothesis, cannot really tell us about the ubiquity and importance of the phenomenon. To date, obtaining the detailed, micro level (and preferably longitudinal) data needed to effectively address the major outstanding questions in this debate has been virtually impossible from a representative sample of multinational firms.

In addition to shortcomings stemming from data limitations, the subsidiary-environment literature has also been hampered by underlying conceptual problems. For example, in the rush to find evidence that foreign subsidiaries are drawing on *host* country sources of innovation, researchers have not yet considered how such behavior fits into a more general explanation of where innovating subsidiaries draw their scientific and technical ideas from. After all, a large thrust of the existing literature on the multinational firm suggests that the headquarters organization (and less so perhaps other subsidiaries in the multinational network) acts as a primary source of both tangible (people, technology) and intangible (e.g. knowledge) resources utilized by innovating subsidiaries. In short, whereas the question is typically framed in terms of *whether* foreign subsidiaries draw upon host country knowledge, the argument here is that the question should be reframed in terms of *under what conditions* do they, or, even broader, under what conditions do foreign subsidiaries draw upon home and/or host country knowledge sources, including the headquarters organization itself.

A further conceptual difficulty in much of the existing literature arises from the set of assumptions about the nature of knowledge and the firm-environment interface that often underpin this research, albeit usually implicitly. Certainly in the empirical literature little consideration is typically given to why firms might need to be physically present in a particular location to draw upon knowledge originating there. A related problem stems from casting much of the discussion of about "locational capabilities" and knowledge sourcing at the country level -- certainly that is where the empirical analysis is typically conducted. Notwithstanding the current fascination with different *national* systems of innovation, a large literature dating back at least to Marshall (1920) suggests that nations may *not* be the main geographic locus of knowledge generation and diffusion. Rather sub-national regions and even cities may be more likely to define the relevant boundaries of technological capabilities and inter-organizational flows of knowledge.

In the following section, I build on the accumulated findings of the literature reviewed to develop a set of hypotheses about the conditions under which innovations developed by foreign subsidiaries are likely to draw upon home and/or host country sources of knowledge. For theoretical guidance, I turn to recent developments in the economic geography and innovation literatures, focusing in particular on a body of research dealing with external sources of innovation. I argue that these literatures share a common concern with the geography of technological spillovers -- where technical knowledge travels, how quickly, and through what mechanisms. Findings from research on these questions are reviewed with reference to their implications for the multinational debate. This synthesis is then used to develop the hypotheses which are eventually tested in Chapter 6.

3. The Geographic Sources of Foreign Subsidiaries' Innovations: A Synthesis

Technological innovation involves the combination of proprietary and public sources of knowledge (Dosi 1988; Freeman 1982, 1991; Nelson and Winter 1982; Nelson 1993). The locus of technological innovation resides not only within the boundaries of the innovating organization, but also outside it, in the "interstices between firms, universities, research laboratories, suppliers, and customers" (Powell, Koput and Smith-Doerr, 1996: p.118). Many studies have established the importance of external sources of knowledge to the progress and commercial success of technological innovation (Allen 1984; Czepiel 1974; Freeman 1982, 1991; DeBresson and Amesse 1991; von Hippel 1986, 1988). As Cohen and Levinthal (1990) argue, this basic fact of the innovation process holds at "whatever the organizational level at which the innovating unit is defined", from the nation-state (through cross-border knowledge flows) down to the individual lab (where learning may occur between units of the same firm).

A recurrent theme in research on external sources of innovation is the spatial dimension -- the geography of knowledge production and diffusion. Where knowledge originates, and where and how it travels are also issues of considerable importance to the debate about distributed innovation in multinational firms. After all, if knowledge travels seamlessly across geographic and institutional boundaries then firms should derive little learning advantage from having technical units close to its source. On the other hand, if knowledge remains to some extent localized or travels only slowly across these boundaries, then multinationals with strategically placed subsidiaries should be uniquely positioned to monitor, assimilate, and combine the diverse set of technical inputs originating in various centers of scientific and technological expertise (Doz 1992; Hedlund and Ridderstrale 1992). It is this vision that in many ways lies at the center of academic discussions about the multinational as a distributed innovation network.

The question of how localized or location specific knowledge is has also emerged as a centerpiece in the recent renaissance of academic interest in spatial aspects of economic activity (Acs, et. al.1994; Glaeser et. al. 1991; Grossman and Helpman 1991; Jaffe 1989; Jaffe et. al. 1993; Krugman 1990; Romer 1990). A major thrust of the "new" economic geography has been to formalize and test ideas about geographic concentration first advanced over a hundred years ago by Alfred Marshall (1890/1920). Indeed, one of Marshall's great insights, derived from first hand observation, was that firms in the same industry tend to cluster together, at least in part because of the learning or spillover benefits derived from geographic proximity:

> The mysteries of the trade become no mystery; but are as it were in the air...good work is rightly appreciated, inventions and improvements in machinery, in processes and the general organization of the business have their merits promptly discussed; if one man starts a new idea it is taken up by other and combined with suggestions of their own; and thus it becomes the source of further new ideas.

As Audretsch and Feldman (1996) have argued, spillovers may be especially important for processes of innovation and technological change, which, more so than other economic activities, are highly dependent upon the ability to assimilate and utilize new sources of knowledge.

Although empirical research on spillovers suffers intrinsically from the problem "that they leave no trail" (Krugman 1990), several recent studies have sought to demonstrate empirically their existence and importance (see Griliches 1991 for a review). Jaffe (1986) and Henderson and Cockburn (1992) find a positive effect of third-party spillovers on R&D productivity, both at the level of the firm (Jaffe 1986) and the innovating unit (Henderson and Cockburn 1992). These studies support earlier work showing that knowledge spillovers contribute positively to total factor productivity at the firm level (Acs et. al. 1992; Bernstein and Nadiri 1988, 1989). Researchers have also sought to demonstrate the impact of spillovers on patterns of economic development and growth. Glaeser et. al. (1991), for example, find that spillovers across industries (more than within industries) contribute to the growth of industries within cities.

How localized are technological spillovers? Empirical research on this question is still in its infancy. Much of the existing research has simply *inferred* the presence of localized spillovers from patterns of geographic concentration across industries -- thereby ignoring the other two factors in the "Marshallian trinity". The fallacy of this inference, as Krugman (1990) argues, is that the spatial concentration of economic activity within and across countries is ubiquitous, and bears no obvious relationship to "high tech" industries where knowledge spillovers are thought to be particularly important. However, a recent study by Audretsch and Feldman (1996, p: 631) does find evidence that "innovative activity tends to cluster more in industries where knowledge spillovers play a decisive role". In a related study, Jaffe (1989) shows that corporate patenting and R&D expenditures are positively associated with the R&D expenditures of nearby universities, suggesting the presence of geographically mediated knowledge flows. Acs, Audretsch, and Feldman (1992) find a similar result using a product-based measure of innovation.

In a pioneering study using patent citations, Jaffe, Tratjenberg, and Henderson (1993) find considerable evidence that technical knowledge remains to a measurable degree localized to its place of origin. The effects are particularly significant at disaggregated geographic units of analysis -- state and city (SMSA) in their analysis -- consistent with theories of regional (i.e. sub-national) agglomeration. In addition, the authors find that localization of knowledge fades over time, implying some advantage to being proximate to *new* scientific and technological developments. A similar study of knowledge diffusion in the semiconductor industry by Almeida and Kogut (1994) also found evidence of localization, although with significant variation across regions and kinds of technical knowledge. The authors highlighted the mobility of technical personnel as a key mechanism by which knowledge diffuses across firms. Zucker and Darby (1994) report a similar space-time diffusion path of knowledge relating to important biotech innovations, a finding that also has many referents in the marketing and innovation literatures on the diffusion of innovations. Their study also identified the mobility of personnel, especially of personnel that have collaborated with "star" researchers in the field, as an important mechanism for knowledge diffusion.

Whether different kinds of organizations benefit more than others from technological spillovers (an issue with important implications for this study, which is about a particular kind of organization - a foreign subsidiary), has also received some attention in the literature. Acs et. al. (1994), for example, found that small firms benefit from knowledge spillovers more than large firms, and thus new firms were most likely to locate in "high spillover" regions. Powell et. al. (1996) argue that firms in emerging or rapidly developing fields are highly dependent upon access to new technological developments, many of which will occur outside the boundaries of the firm. In such cases, learning and technical progress is facilitated by active participation in the "technological community" that defines the individual and organizational structure of the field (Powell et. al 1996). Bierly and Chakrabarti (1996) argue that organizations make conscious strategic choices about the role of external knowledge sources to these organizations. They find evidence of systematic differences across groups of firms in the U.S. pharmaceutical industry in the extent and importance of external learning – a key component, they argue, of a firm's generic knowledge strategy.

The balance between internal and external sources of innovation varies not only across innovating organizations, but within them – over time and across areas or projects. Factors such as the type of knowledge utilized by different kinds of technical activity (e.g., the distinction between "R" and "D"), the stage of the technology development cycle (design - prototype - manufacturing), and the firm's capabilities and experience in a particular technological trajectory may all influence the overall internal/external orientation of its technical function as well as the nature and location of its external innovation network (DeBressen and Amesse 1991; Dosi 1988; Freeman 1982).

March's (1991) distinction between exploration and exploitation offers a useful encapsulation of this view. Exploitation, he argues, is characterized by "the refinement and extension of existing competencies, technologies and paradigms" (March, 1991: 85). The scope of innovative search may be reduced, and is more likely to reside internally, in the routines and problem solving heuristics that constitute the organization's knowledge base. Emphasis is placed on the appropriation of profits from current knowledge. Exploration, on the other hand, is characterized by "experimentation with new alternatives" (1991: 85), the returns from which are "systematically less certain, more remote in time, and organizationally more distant from the locus of action and adaptation" (1991: 73). The scope of innovative search may thus be broadened since the range of scientific and technical skills required will often exceed the existing capabilities of the organization.

Processes of exploitation and exploration also have many referents in the multinational literature. Recall, for example, that the most common motivation for overseas technical activity cited in the literature is the adaptation of existing products and technologies to local market needs. Although host country signals (e.g., from customers, regulatory agencies, or competitors) may in such cases provide the subsidiary's initial stimulus to innovate, the underlying ideas and principles embodied in the technology are likely to have originated elsewhere, most immediately from the parent organization itself, but also from within the parent's own external innovation network[5]. This suggests the first two hypotheses:

Hypothesis 1 Subsidiary innovations that build directly upon prior headquarter's innovations indicate a logic of exploitation, and will be (a) positively associated with external sources of knowledge located in the home country; and (b) negatively associated with external sources of knowledge located in the host country.

Hypothesis 2 Subsidiary innovations in technical fields that represent specializations of the home country indicate a logic of exploitation, and will be positively associated with external sources of knowledge located in the home country.

The multinational literature further suggests that exploration - the search for and development of new technical ideas, products and processes - is also an important aspect of at least some overseas technical activity. In this case, the stimulus to innovate and the location of innovative search are more likely to center on actors and institutions in the host country and its regions. Florida and Kenney's (1995) analysis of Japanese R&D investment in the U.S. offers perhaps the clearest statement of these "two logics" of subsidiary innovation and their geographic implications.

> On the one hand, Japanese R&D investment reflects an underlying strategy of "global localization" and the development of integrated innovation-production

complexes. In these cases, R&D is located in close proximity to existing factory sites. On the other hand Japanese R&D investment aims to harness the new sources of knowledge and ideas embedded in regionally based centers of innovation. In these cases, R&D facilities locate in regional innovation complexes, such as Silicon Valley in electronics or the Detroit area in automotive technology.

March's (1991) distinction between exploitation and exploration suggests, then, a basic association between the kinds of innovative activities performed by foreign subsidiaries and the location of the knowledge sources that underpin those activities. Yet the complexity of practice pushes against such a simple dichotomy. It is well established, for example, that many innovating subsidiaries have "multiple mandates", that is, they are simultaneously engaged in the refinement of existing technologies and the development of new ones, in exploitation *and* exploration. This suggests the need to cast the analysis at the level of the innovation, not just the level of the innovating unit.

The multinational literature further suggests that the linkage between exploitation / exploration and the geographic sources of subsidiaries' innovations needs to be formulated in dynamic terms. That is, the logic of subsidiary innovation may, under some conditions, evolve from exploitation to exploration, or at least to some balance between them -- with an attendant shift in the relevant external sources of knowledge (Ronstadt 1977; Hakanson and Nobel 1993). Hakanson and Nobel (1993: p.13), for example, note that "market oriented R&D units often evolve from simple adaptive development into more original R&D". Ronstadt's (1977) study similarly highlights an evolutionary pattern of growth, capability development, and strategic reorientation. Of the 31 "technology transfer units" in his sample, 14 eventually developed a more autonomous set of technical capacities built around local and sometimes global product requirements. A similar evolutionary pattern of internal capability development and greater contribution over time has been observed in many studies of foreign subsidiaries, not just those engaged explicitly in technical activities (e.g., Birkinshaw 1996; Malnight 1995; White and Poynter 1990; Prahalad and Doz 1981).

Interestingly, many of these studies also indicate that such an evolutionary process is not a deterministic function of the subsidiary's tenure in the host country. Over half of the technology transfer units identified by Ronstadt (1977) did not alter their basic orientation and capabilities, some after more than thirty years in the host country. Birkinshaw (1996) finds evidence that new product or process development initiatives developed by foreign subsidiaries are frequently terminated or transfered to the parent company. These and other studies (e.g., Bartlett and Ghoshal 1989; Hakanson and Nobel 1993, Ridderstrale 1997, and Fratocchi and Holm 1996) suggest there are many factors that govern the evolution of subsidiary activities away from a purely exploitation-oriented focus. Particularly important appears to be the ability of the subsidiary to develop a set of technical competencies that are (1) valuable -- commercially or technologically - to the firm; (2) non-redundant (i.e., differentiated from the parent), often because they are based on local market and technological opportunities; and (3) difficult for the parent firm to transfer back to the parent organization because of the specialized, cumulative and tacit nature of these competencies, and/or because they draw importantly upon location-specific resources (including knowledge) in the host country locale. The above arguments suggest, then, the following three hypotheses:

Hypothesis 3 — Subsidiary innovations in technical fields that represent specializations of the host country (or region) indicate a logic of exploration, and will be positively associated with external sources of knowledge located in the host country.

Hypothesis 4 — Subsidiary innovations that are technologically or commercially important indicate a logic of exploration, and will be positively associated with external sources of knowledge located in the host country. Less important subsidiary innovations will be positively associated with external sources of knowledge located in the home country.

Hypothesis 5 — Subsidiary innovations in technical fields in which the subsidiary has established a distinctive technical specialization within the firm will be (a) positively associated with external sources of knowledge located in the host country; and (b) negatively associated with external sources of knowledge located in the home country.

This linkage between exploitation/exploration on the one hand, and the location of the subsidiary's external knowledge sources on the other, fits into what may be described as the strategic perspective on external sources of innovation (Powell et. al. 1996). The basic assumption of this perspective is that participation in external networks (whether and in which networks to participate) is a strategic choice that organizations make (Bierly and Chakrabarti 1996).

A second, rather different strand of thinking emphasizes the emergent properties of such networks and their "embeddedness" (Granovetter 1985) in the social relations of technological innovation. Allen (1984) and Saxenian (1994), for example, note that school, career,and friendship ties are important mechanisms through which external technical knowledge is located, accessed and assimilated. Bianchi and Bellini (1991) argue that innovation networks are underpinned importantly by "social solidarity...best sustained through constant interaction and geographic proximity". Camagni (1991) claims that these networks are of a "mainly informal and tacit nature".

Interestingly, research by Schrader (1991) and von Hippel (1988) suggests that the two perspectives -- the strategic perspective and the embeddedness persepective -- may not be competing explanations. These authors find, for example, that the norm of reciprocity is a fundamental feature of knowledge sharing between actors in technological communities. Although the emergence and maintenance of these networks my be underpinned by notions of professional obligation, friendship, or social solidarity, this research also reveals a large measure of interest and strategy on the part of the participants.

Applied to the questions at hand, the embeddedness perspective points to several factors that may facilitate or impede a subsidiary's ability to participate in local innovation networks. The governing norm of reciprocity implies that the subsidiary's reputation as a reliable and trustworthy partner will affect its ability to participate in these networks. Since diffuse reciprocity (i.e., exchange based on trust rather than direct and immediate payback) tends to be established through repeat experience and the observation of cooperative behavior -- through simultaneous learning and monitoring in Sabel's (1993) terminology -- it is likely that would-be entrants into these communities may experience a "liability of newness" (Stinchcombe 1965) that manifests itself through restricted access to information channels. Schrader's (1991) research on knowledge sharing in the steel industry supports this point. Employees interviewed suggested that a factor they consider when deciding whether to provide technical assistance to individuals in other firms in the industry is "the length of the time they have known the inquirer" (1991:159). This imples:

Hypothesis 6 Innovations developed by older subsidiaries will be (a) positively associated with external sources of knowledge located in the host country; and (b) negatively associated with external sources of knowledge located in the home country.

Reciprocity also implies that innovating organizations have the capacity to provide potentially valuable knowledge as well as to receive it. Schrader (1991), for example, finds that "the probability of information exchange increases significantly if the inquiring party is known to control considerable technical knowledge". Pake (1986) reports a vice president of R&D at Xerox explaining that only with one's own R&D results to use as a medium of exchange may one participate with others in a meaningful knowledge exchange. Resource limitations, on the other hand, may prevent an organization from credibly offering to provide knowledge about important technical developments. This implies:

Hypothesis 7 Innovations developed by subsidiaries with greater technological resources will be (a) positively associated with external sources of knowledge located in the host country; and (b) negatively associated with external sources of knowledge located in the home country, including the parent firm.

It is also clear that an innovating unit's reputation for cooperation and its access to leading edge technical developments do not operate in isolation from the larger organization of which it is part. Many multinational firms have several technical facilities in a particular host country, some with long experience and considerable technical resources. Small or newly established subsidiaries that are part of such an organization in the host country may therefore be able to offset liabilities of newness and limited resources more readily than subsidiaries lacking this kind of "reputation by association". This implies:

Hypothesis 8 Innovations developed by subsidiaries that are part of a large host country organization will be (a) positively associated with external sources of knowledge located in the host country; and (b) negatively associated with external sources of knowledge located in the home country, including the parent firm.

The eight hypotheses and the basic conceptual model underpinning them are depicted in Figure 2.1. To recap, the argument is that the orientation of the subsidiary's technical activities toward the exploitation of existing advantages or the exploration for new ones is the primary driver of the geography of its external sources of innovation. Factors indicating a logic of exploitation are hypothesized to be positively associated with sources of innovation originating in the home country, and especially with sources originating in the parent organization itself. On the other hand, factors indicating a logic of exploration are hypothesized to be associated with the assimilation and utilization of knowledge sources resident in the host country. The exploitation/exploration dichotomy therefore governs the subsidiary's orientation toward sources of knowledge in the home or host country - i.e., its external innovation strategy. Its ultimate capacity to assimilate knowledge resident in the host country is, however, governed by additional factors relating to its "embeddedness" in the host country environment and the social relations of technological innovation in the local mileu. In Figure 1, then, local embeddedness moderates the relationship between the subsidiary's strategic orientation and the likelihood that it will draw upon host country sources of innovation.

[Insert Figure 2.1 Here]

4. Conclusion

This chapter presented a synthesis of three bodies of knowledge that contribute most directly to the research questions addressed in this thesis. Key aspects of the literature on distributed innovation in multinational firms were reviewed, focusing in particular on empirical work dealing with the subsidiary-environment interface in the context of technological innovation. Despite the centrality of the questions addressed in this thesis to core debates in the field of international management, relatively little is understood about whether, to what extent, and under what conditions foreign subsidiaries draw upon sources of knowledge resident in the host country during the process of technological innovation. To develop a set of hypotheses about the geographic sources of foreign subsidiaries' innovations, this chapter drew upon a synthesis of the multinational literature and related literatures on innovation and economic geography.

Endnotes

[1]In his later work on the PLC model of the multination firm, Vernon (1979) acknowledged the potentially important role of foreign subsidiaries in generating new ideas and technologies, a point I return to below.

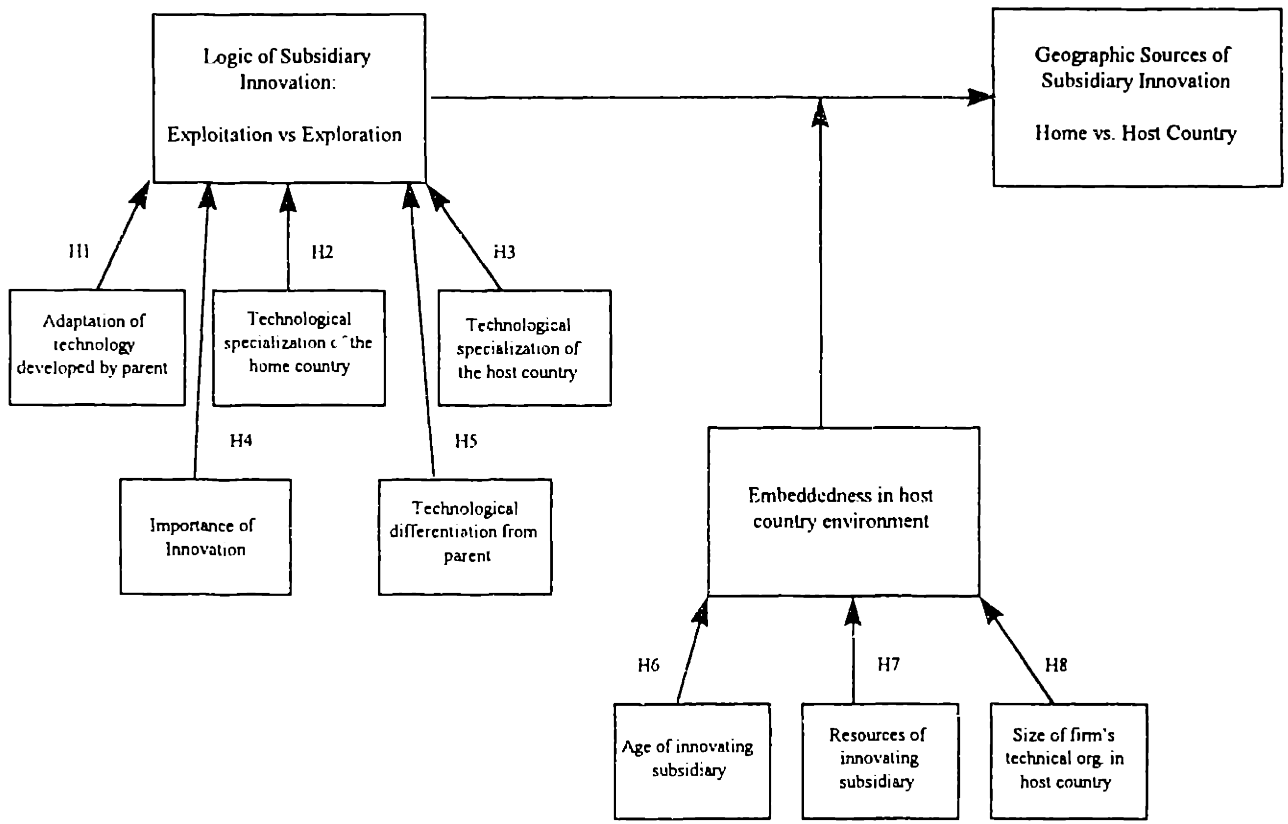
[2] Porter does offer a number of caveats and exceptions to this basic claim. He also holds open the possibility that firms might even change home bases – and presumably the locus of technological innovation – if the conditions conducive to advancement deteriorate to the point where the organization's survival is jeopardized.

[3] This line of research has also been bolstered by a considerable body of anecdotal evidence about specific subsidiary innovations that have proven particularly important to the technical and commercial stature of the firm: Burroughs Wellcome PLC's AZT (developed in the US), Alfa Laval's milking machine (also developed in the U.S.), and IBM's electron microscope (Switzerland) have been frequently cited in the literature.

[4] Five of these units were classified by Ronstadt as "global product units", i.e., units that were developing products for global markets; four were classified as "corporate technology units", i.e., units that were oriented toward basic or exploratory research for use by the entire corporation. An additional two units were classified as "indigenous technology units", which were developing new products but for local markets. The remaining 31 units were "technology transfer units". Ronstadt also examines the evolution of foreign R&D units from one type to another, a point I return to later in the chapter..

[5]Dating back to Vernon (1966), scholars have assumed that the external innovation network of the headquarters organization resides in the home base. Porter's (1990) study is the most recent statement. However, to my knowledge this proposition has never been systematically tested. I present evidence of this phenomenon in Chapter 5.

Figure 2.1 Conceptual Model and



Chapter 3 Data and Research Methods

1. Overview and Objectives

The purpose of this chapter is to provide a detailed overview of the data and methods used in this study. As discussed in the introductory chapter, the overall research approach adopted in this study is deductive. Notwithstanding the exploratory and descriptive aspects of a considerable proportion of the empirical analysis, wherever possible specific hypotheses are formulated and tested. Although data used in this study were gathered from many different sources, including interviews with patent examiners, interviews with R&D managers, company records, newspaper articles, and various print and electronic sources, the bulk of the empirical analysis in this study draws on U.S. patent data, and more specifically, on the citation indicators listed on U.S. patent documents. This chapter focuses mainly on methodological issues relating to the use of these data in the thesis. Chapter-specific issues such as the construction of particular variables, the specification of comparison groups for hypothesis testing, and the use of particular statistical procedures are discussed in the relevant chapters.

The remainder of this chapter is structured as follows. The following section, Section 2, provides an overview of U.S. patent data, including a discussion of their main advantages in the context of this study, and the nature of the information contained in each patent document. Section 3 briefly reviews the literature on patents as technological indicators, with specific reference to issues affecting the use of these data in this study. Section 4 discusses the construction of the datasets used in the thesis, focusing in particular on how patents issued to U.S. subsidiaries were identified and extracted from the main patent database. Section 5 provides an overview of the methodology of patent citation analysis, both as it was originally developed by Jaffe, Tratjenberg and Henderson (1993), and as it was adapted by me for the purposes of this project. Section 6 discusses issues relating to units and levels of analysis. Section 7 summarizes and concludes.

2. Data

2.1 Overview of U.S. Patent Data

This study uses U.S. patent data to draw inferences about the extent and conditions under which U.S.-based subsidiaries (1) assimilate and (2) generate localized knowledge during the process of technological innovation. A key point to bear in mind is that the patent data used in the study are derived from patent documents published by the United States Patent and Trademark Office (USPTO). It is in this sense that I describe the data as based on "U.S. patents". No comparisons are made across national patenting systems in this study; the institution granting the patent is a constant - it is the USPTO. For example, a patent identified as originating in a Basel, Switzerland unit of the Swiss multinational Ciba-Geigy is a U.S. patent in that it was issued by the USPTO. In the terminology adopted throughout this study, the patent in question will be said to have *originated* in Basel, Switzerland because that is where the particular organization that conducted the R&D that led to the patented invention was located. As discussed in Section 2.2.2, the location of the inventing unit is based on the address of the first inventor listed on the patent document. Note that the inventor (or more accurately, the company) may also have filed a patent application for the same invention in one or more other countries. I have no information on such applications. I observe only U.S. patents, i.e., those patents applied for and eventually issued by the USPTO.

A U.S. patent is a property right granted by the U.S. Government to the inventor. Its purpose is "to exclude others from making, using or selling the invention" (U.S. Department of Commerce 1993: p1). For a patent to be granted by the USPTO it must meet three basic criteria: (1) it must be novel; (2) it must be neither trivial nor obvious to an informed practitioner in the relevant technical field; and (3) it must have commercial potential. Patentable inventions may take the form of a "process, machine, manufacture, or compositions of matter, or any new and useful improvements thereof" (U.S. Department of Commerce 1993: 4). Ideas cannot be patented. With some exceptions (e.g., for certain pharmaceutical patents) the property right associated with the granting of a patent lasts 17 years, after which time the patentee loses rights to the invention.

U.S. patents have been used for many years in the innovation literature and a well established body of knowledge now exists on their use, limitations, and interpretation (Basberg 1987; Griliches 1990; Pavitt 1984; Scherer 1965; Schmookler 1950; 1966). The main advantages of U.S. patent data are straightforward: they are one of the few sources of detailed, disaggregated data on the technical activities of a large population of firms that have been systematically collected for a long period of time. As Griliches (1990: 1661) has stated, the richness of the data "loom up as a mirage of wonderful plentitude" in a topic area otherwise characterized as a "desert of data".

For the purposes of this study, U.S. patents have three key characteristics. First, the data are disaggregated to the level of the inventing unit. In other words, particular patents can be associated with particular locations within a firm. Obviously, this is a critical requirement in a study that seeks to draw inferences about the sources of innovation utilized by subsidiaries of multinational firms. To date, obtaining detailed unit-level R&D data has been virtually impossible on a large scale, a major reason why the literature on foreign innovation has proceeded mostly by the accumulation of anecdotes rather than through the systematic generation and testing of hypotheses. Second, the data are longitudinal. Although U.S. patents have been issued since the 19th century, the data are now available in electronic form dating back through 1975. This facilitates the development and testing of hypotheses relating to changes over time in the technical activities of foreign subsidiaries, one of the major contributions of this study.

Finally, U.S. patents have the advantage of providing excellent coverage of the inventive activities of both U.S. and non-U.S. firms (Basberg 1987; Griliches 1990). In fact, recent years major foreign firms have been granted more U.S. patents than their main U.S. competitors in some sectors such as computers and electronics (Business Week 1990). According to Griliches (1990), foreign *inventors* now account for about 50% of all U.S. patents issued, and, of these, over 80% are assigned to non-U.S. corporations (Griliches 1990; Narin 1991)[1]. The reason foreign multinationals file large numbers of U.S. patent applications is directly related to the size and importance of the U.S. market and to the high degree of legal protection afforded by U.S. patents (Basberg 1987; Pavitt 1982; Bertin and Wyatt 1988).

There are, of course, disadvantages associated with U.S. patent data, many of which constitute generic disadvantages of secondary source data. The two main concerns in this study relate to (1) the kinds of technical activity U.S. patents capture; and (2) the indirect measure of knowledge sources provided by patent citations. These issues are fundamental enough to the goals of this study that they warrant separate discussion, which I defer to Sections 3 and 5, respectively.

2.2 Data contained in U.S. Patent Documents

Figure 3.1 provides an example of the "front page" of a U.S. patent document. This section discusses the key elements listed on each patent document with reference to their use in the current study.

[Insert Figure 3.1 Here]

2.2.1 Dates

U.S. patents contain two temporal indicators: the date on which the patent was eventually issued (the grant date), in this case Dec. 3,1996; and the date on which the patent application was initially filed with the USPTO (the filed date), in this case June 1,1995. For the purposes of this study, the most relevant date is the filed date, since this represents most closely the time period in which the technical activity leading up to the invention occurred. The year and a half separating the two dates in this case is a function of the time it takes for the patent examiner to approve the patent application. The average "lag" between filed and grant dates was approximately 3 years during the 1980s. There is evidence of variation in this lag across technical areas due to factors relating to the nature of the technical field (i.e., its complexity and/or maturity) and the structure and resources of the USPTO (e.g., the number of patent examiners working in different technical fields) (Griliches 1990). For these reasons as well, this study uses the filed date as the key temporal indicator.

2.2.2 Inventor(s)

Every patent document lists the name, city, and state (if a U.S. inventor) or country (if a non-U.S. inventor) of residence of each inventor. Where more than one inventor was involved in the work leading to the invention, the patent document lists the complete name-address information for each inventor. This information is obtained from the patent application, which contains a signed oath by each inventor attesting to the accuracy of the information provided. Of particular importance is that the application must be certified "as the invention of the true inventor.... and not as the invention of the person who has purchased the invention from the inventor" (U.S. Department of Commerce 1993: 4).

For time and cost reasons, I use only the geographic information for the first inventor listed on the patent document. This corresponds to the first inventor listed on the patent application (i.e., they are not alphabetized by the USPTO). The use of first inventor information to identify the location of the inventing unit follows the vast majority of prior research using patent data (Acs et. al. 1994; Archibugi and Pianta. 1992a; Cantwell 1989; Jaffe 1989; Patel and Pavitt 1991; Zander 1994). Moreover, based on evidence in the one published study that used multiple inventor information (Jaffe et. al. 1993), the magnitude of any error associated with using only first inventor information appears to be small. Jaffe et. al. (1993) found that 98% of the patents in their sample had either only one inventor or had multiple inventors with the same country address. In other words, 98% of the sampled patents could be assigned unambiguously to a particular country. For patents issued to U.S. inventors, 90% could be assigned unambiguously to a particular state. At the city level, the figure drops to 86%, although an additional 6% involved situations where a majority of the inventors listed on the document were from the same state.

It is not clear whether the first inventor listed on the patent document is in any sense the "lead" inventor, as is often the case with academic journal articles. Interviews with patent examiners did not produce a clear picture of organizational practice in this regard, which can be expected to vary across sectors and institutions. However, it is well known that inventors increase their human capital (i.e., their value in the external labor market) through the issuance of a patent in their name, and it therefore follows that "first authorship" may provide at least some indication of a hierarchy in terms of involvement with, and contribution to, the development of the patented invention. This assertion is further supported by the fact that the names of the inventors listed on the patent documents are not systematically alphabetized. It follows that this study's use of first inventor information is probably the most justifiable approach - given a time- and cost-motivated limitation of using information on a single inventor.

2.2.3 Assignee

The assignee is the name of the individual or organization to whom the patent rights have been "assigned" by the inventor. Although individual inventors accounted for the majority of U.S. patents in the early part of the 20^{th} century, over three-quarters of all U.S. patents are now assigned to an organizational entity such as a firm, a hospital, or an educational institution (Griliches 1990; Scherer and Ross 1990). Quite obviously, this reflects the institutional structure of technological innovation in modem capitalist economies: today, the vast majority of R&D activity is performed in professional laboratories operated by firms, universities and other private and public institutions[2]. Technical personnel typically sign employment agreements stipulating that the hiring organization automatically owns the rights to all patents issued to the inventor while he or she works for that organization (Basberg 1987; Griliches 1990). Hence, the assignee listed on a patent document is in the vast majority of cases the inventor's employer. Following past research, I use the assignee name to associate particular patents with particular companies. In Section 4.3, I discuss how assignee names listed on patent documents were linked to particular parent companies.

2.2.4 Technical Field(s) of the Invention

Both the inventor and the patent examiner play a role in determining the technical field of the invention. The inventor is required to include a statement of the "field of endeavor to which the invention pertains" (U.S. Department of Commerce 1993: 2). Ultimately, however, it is the patent examiner who makes the final decision as to which field(s) a particular patent will be assigned. The mechanism through which the relevant technical fields are identified and applied is the patent classification system. Currently, the patent classification system contains over 100,000 9-digit technical classes. This number decreases to about 400 when aggregated to the 3-digit level. Examples of 3-digit patent classes include Refrigeration (Class 62); Ammunition and Explosive Charge Making (Class 86); Drug, Bio-Affecting and Body Treating Compositions (Class 514); and Robots (Class 901). Every patent is assigned to a primary patent class and an unlimited number of secondary classes.

Patent classes do not correspond directly to SIC codes, a long standing problem in the use of these data (Pavitt 1984; Scherer 1965). This lack of correspondence is indicative of the fact that patent classes are based on functional and technological principles, many of which can be applied to more than one industrial sector (e.g., inorganic chemicals) (Basberg 1987; Griliches 1990; Pavitt 1984; Scherer 1965; Schmookler 1966). For the purposes of this study, the classification of patents around technical fields rather than industrial characteristics is probably an advantage. For example, using the patent classification system instead of SIC codes means that it is possible to assess the extent to which foreign subsidiaries are innovating in technical fields that are subtly distinct from those of the parent organization, even if they are operating in the same basic industrial sector. Measures of technological differentiation between parent and subsidiary can then be calculated and used as variables to explain why parent and subsidiary may be drawing on technical ideas originating in different geographic locations.

Another reason for preferring patent classes to SIC codes stems from this study's focus on knowledge spillovers. Prior research has shown that inter-industry knowledge spillovers may be even more important than spillovers within industries (Glaeser, Kallal, Scheinkman, and Shleifer 1991). This result is partly explicable by the fact that industries and technologies do not correspond perfectly to each other. Firms in different industries often rely on developments in the same technical fields. IBM, for example, generates many patents each year in technical fields relating to chemistry. Using patent classes allows a more finely grained analysis of the technological "proximity" between the inventive activities of a particular subsidiary and its sources of innovation than would SIC codes.

In most of the empirical analysis contained in this study, I attempt to control for unobserved differences across technical fields in the nature and mechanisms of inter-organizational knowledge flows by introducing technical field dummy variables.

However, rather than using the 400 3 -digit patent classes, I utilize a concordance listed in Zander (1994) that aggregates the 3-digit patent classes of the US patent system to 33 broad technical fields[3]. These fields are, however, still based on characteristics of technology rather than industries (although the correspondence between the two systems is closer at this higher level of aggregation). Examples include agricultural chemicals, pharmaceuticals, image and sound equipment, and photographic instruments.

2.2.5 Related and prior art

For the purposes of this study, the key source of information contained in each patent document is the list of "References Cited", and specifically the prior U.S. patent documents listed as references on the focal patent. This information derives from the requirement that each patent application "contain a description of information known to the applicant, including references to specific documents, which are related to the applicant's invention... including related problems involved in the prior art which are solved by the applicant's invention" (U.S. Department of Commerce 1993: 2).

In principle, the listing of a reference on a patent document indicates a technological building relationship between the originating and cited patent. In Jaffe et. al.'s (1993: 580) words "a citation of Patent X by Patent Y means that X represents a piece of previously existing knowledge upon which Y builds." There is no limit to the number of prior patents that may be listed on a patent document, although patent examiners interviewed expressed a preference for including "a few key patents" rather than listing all possibly relevant patents. The process by which references are added to patent documents is important enough to this study that I discussed it in more detail in Section 5.

3. Patents as Technological Indicators

What patents actually measure is a question that has been widely addressed in the literature (Basberg 1987; Chakrabarti 1989; Griliches, Pakes and Hall 1987; Pavitt 1988; Griliches 1990; Schmookler 1953; 1966). Research using patent data tends to fall into one of two broad categories: studies that use patents as indicators of R&D inputs, and studies that use patents as indicators of R&D outputs. Studies using patents as output indicators have looked at such issues as R&D productivity (Griliches et. al. 1984; Henderson and Cockburn 1992), technological opportunity (Jaffe 1986), and corporate technological strength (Narin, Noma and Perry 1987). In contrast, the current study takes an input perspective. I view patents as a rich source of data about the nature of multinationals' inventive activities, including, especially, the location of the inventing unit, and the nature of the prior technology upon which the current invention builds. Schmookler (1966), one of the earliest and most careful users of patent data, adopted a similar perspective on the use of patent data (Griliches 1990). In addition, prior research on the internationalization of R&D in multinational firms using patent data (e.g., Cantwell 1989; Patel and Pavitt 1991; Zander 1994) has taken much the same perspective on their usage as I do here.

Figure 3.2, adapted from Basberg (1987) and Griliches (1990), shows the relationship between inventive activity and outputs from this activity, and also underscores two longstanding problems in the use of patent data. First, not all inventions are patented, or even patentable, a problem that manifests itself most clearly in sectoral variability in the propensity to patent. Second, not all patented inventions end up as innovations, i.e., reach commercialization. The purpose of this section is not to review the literature on these problems *per se*, since many excellent reviews already exist (c.f., Basberg 1987; Griliches 1990; Pavitt 1984) but rather to focus on the question of how these problems are likely to affect the geographic results that are the main focus of this study.

[Insert Figure 3.2 Here]

3.1 Patents and inventive activity

What kinds of inventive activity are captured in U.S. patent documents? Schmookler (1966) argued that patents were unlikely to capture either basic research (the search for new knowledge and/or essential properties of objects) or development (the refinement of existing products and processes) - the two ends of the conventional R&D continuum (Griliches 1990). Jaffe et. al. (1993) claim that patents are probably most representative of "applied research" since the results of basic research tend to be communicated via outlets such as journals and academic conferences. However, in sectors such as pharmaceuticals, metallurgy, and microelectronics, where technological advances depend upon and even contribute to fundamental advances in underlying scientific disciplines, the distinction between basic and applied research is, at best, blurred (Chesnais 1988; Dosi 1988; Nelson 1987). In these sectors, it appears likely that patent data will also capture a good deal of activity relating to basic research. This assertion is supported by the observation that patents in some technical fields frequently contain references to articles in scientific journals.

The question of whether patents are rather poor indicators of *development* activities has a particularly important bearing on the current study. One of the hypotheses I seek to test is whether subsidiary innovations that build incrementally upon technologies that already exist within the firm (and exist specifically within the headquarters organization) have a differential propensity to cite home versus host country knowledge sources. Clearly, if such advancements are excluded from patent data, a test of this hypothesis will be impossible. Notwithstanding the claims noted above, I shall argue that there are several reasons for believing that patents are likely to be a reasonable indicator of inventive activities oriented toward the refinement of existing products and processes.

First, the standards of novelty adopted by the USPTO as a criterion for the granting of a patent are not very high (Griliches 1990). Incremental advances are certainly not excluded from being patented. Second, it is apparent that, at least in some sectors, patent applications occur over the entire cycle of development and commercialization of an innovation (Basberg 1984; Pavitt 1984; Walsh 1982). Third, patent data are highly skewed toward inventions that generate little monetary value (Schankerman and Pakes 1983), suggesting that patents may not exclude minor technological developments - in fact, such developments may account for a large proportion of patenting activity. This finding is also supported by studies of citation rates to patents, which have shown that nearly 70% of all patents receive no citations from subsequent patents - an indication that the invention in question offers only a minor advance in the relevant technical area (Narin and Olivastro 1988)[4].

The above discussion suggests that U.S. patents do not systematically exclude inventive activity directed at incremental advances of existing products and processes. However, it is important to note that this does not imply that most inventions are useless or unlikely to end up in commercialized products or processes. In fact, data on patent renewal rates suggest that firms perceive at least some utility for the large majority of their patents: in the U.S., nearly 85% of 1981-1984 patents were renewed by the assignee after three and a half years, at a cost of $450 (Griliches 1990)[5]. The only extensive survey of patent holders, conducted in the 1950s, further corroborates this notion: survey respondents indicated that between 60 and 70 per cent of all patents were eventually used commercially (Schmookler 1966).

In summary, the argument advanced here is that patents are likely to embody inventions that span the range from basic and applied research to minor enhancements of existing products and processes, i.e., to both "R" and "D". The above discussion should also make clear that the nature of the inventive activities captured by patent documents will also vary considerably across industrial sector and technical field. Throughout this study, such variation - and other sources of variation that may be associated with field and/or sectoral differences - is accounted for by introducing a set of technology control variables. These are discussed in the relevant chapters.

Of considerable concern to this study is the fact that patents, by definition, represent codified knowledge. The innovation literature suggests an important distinction between knowledge that can be captured in documents such as blueprints, flow charts, and patents, and knowledge that cannot be so captured, or captured only at a great cost (Dosi 1988; Nelson and Winter 1982; Polanyi 1962). The importance of this distinction arises because of the connection between codifiability and processes of knowledge diffusion. Simplifying, the innovation literature suggests that codifiable knowledge will tend to diffuse rapidly across spatial and institutional boundaries, both because there are many effective mechanisms for its dissemination (e.g., journals) and because such knowledge is not characterized by the kinds of tacit and specific attributes that lead to stickiness and localization. Interactions between producers and users exemplify this kind of relationship between non-codifiable knowledge and local innovation processes. For example, von Hippel (1990) has shown how the locus of technical problem solving between producers and users depends importantly on the nature of the information generated by the particular task. This result has found strong support in several other studies on the producer-user interface in the context of technological innovation (Lundvall 1988; von Hippel 1988).

The implication of this fundamental aspect of patent documents is that studies that use patent data to assess the geography of knowledge spillovers will tend to be biased against finding significant localization. That is, across the spectrum of information generated by the innovation process, the kind of information captured by patent documents can be expected to exhibit less spatial boundedness than other kinds of information. Paradoxically, this feature is actually an advantage in terms of the objectives of the current study. Precisely because patent data will tend to understate the degree of localization that occurs during the innovation process, a finding that foreign subsidiaries are capturing and generating localized knowledge can be argued to be a conservative result. The risk, of course, is that the high hurdle established by the use of these data will prevent such a finding.

4. Data Collection and Assembly of the Patent Database

4.1 Overview

The data used in this study were collected and assembled through a process that encompassed five distinct phases, which are listed in Table 3.1. Each of these phases is discussed in the remainder of this section.

[Insert Table 3.1 Here]

4.2 Phase I: Extraction of patent data from CD-ROM to relational database

As a starting point for assembling the patent database used in this study, the raw patent data contained in CD-ROM format were extracted and transferred to a relational database. The entire database, which was available for grant dates from 1975-1992, encompassed a total of 1.3 million patents. It was essential to have the entire patent database in this format in order to be able to obtain the citation data that is essential to this study. For example, a patent issued in 1992 - the last year of the database - could theoretically cite *any* prior patent ever issued by the U.S. patent office (and patents on average cite about five prior patents as references). This means the population of prior patents "at risk" of being cited would encompass somewhere around five million patents, of which the above 1.3 million were contained in the 1975-1992 database. Finding an individual citation would clearly be a time consuming process if it had to be accomplished manually. Finding all of the citations listed on the population of U.S. subsidiary patents would, quite simply, be impossible without having the complete database on-line, in a relational database format, and on a powerful computer.

4.3 Phase II: Tracing of Corporate Histories of Major Non-U-S- MNCs

Having created the main database from which the datasets used in this study would be constructed, the next step in the data gathering phase involved identifying the relevant population of non-U.S. firms, i.e., those firms that were likely candidates to have patenting subsidiaries in the U.S. Several lists of major multinational firms were consulted, including lists contained in general business press sources such as *Business Week* and *Fortune,* as well as more specialized sources such as *World Investment Report*, *Global Company Handbook*, and *The Directory of Multinationals*. From these various publications, I assembled a master list of over 400 non-U.S. industrial firms.

Prior research on multinational firms using patent data has generally taken the ownership and affiliate structure of a firm as constituted in a single year and simply assigned patents to parent companies assuming no changes in this structure over time

(Cantwell 1993; Patel and Pavitt 1992). Such an approach ignores changes arising from mergers, acquisitions, and dispositions. This is likely to lead to serious problems in the assignment of patents to parent companies, especially in the late 1980s when many large cross-border acquisitions took place. To ensure that affiliate patents were allocated properly to the parent company, I traced the timing of mergers, acquisitions, and dispositions from the mid-1960s to 1992 for each of the major non-U.S. firms identified in Phase 1. Sources used in this tracing process included both electronic and print media such as *Moody's Industrial Manual* (various years); *Who Owns Whom* (various years); *The Directory of International Affiliates* (various years). Acquired firms were classified as part of a parent company when the parent had obtained a controlling interest (i.e., a >50% equity stake). Based on this information, affiliate patents were then assigned to the parent company, whenever possible using the exact date of any acquisition/disposition as the cutoff point for assignment. For example, Hoechst's acquisition of Celanese Corporation occurred on October 21, 1987. Thus all patents issued to Celanese that were applied for after this date were assigned to the new parent company, Hoechst. Using this same information, I was also able to indicate for every patent whether the affiliate that was issued the patent was initially established through an acquisition, a joint venture, or as a greenfield facility.

An additional problem associated with linking patents to parent firms arises because of name changes (e.g., ABB, which was formerly Asea Brown Boveri), spelling mistakes on patent documents, and country-specific affiliate names (i.e., American Barmag Corporation, the U.S. subsidiary of the German firm Barmag). Dealing with these issues required an extensive, and largely manual process of search and verification.

The example of Hoechst AG, the German chemicals multinational, illustrates the difficulties associated with this process. Table 3.2 lists the various assignee names under which patents belonging to Hoechst and its affiliates have appeared during the 1975-1992 time period. Some of these names appear because of spelling mistakes (e.g., Hoecht Aktiengesellschaft); some appear because of acquisitions (e.g., Roussel UCLAF [acquired in 1979]); and some appear because of foreign investments by the parent firm (e.g., American Hoechst, Hoechst U.K. Limited, Laboratoires Hoechst, S.A.) and its affiliates (Hoechst-Roussel Pharmaceuticals).

[Insert Table 3.2 Here]

4.4 Phase III: Identification and verification of U.S. subsidiaries' patents

The result of the second phase was a list of *all* patents belonging to the firms identified in Phase I. The next step in the process was to identify patents originating in these firms' U.S.-based subsidiaries. As discussed earlier, the mechanism for determining the originating location of the patent is the address of the first inventor listed on the patent document. As a first cut, then, I extracted from the database all patents assigned to these firms that were issued to a first inventor with a U.S. address. The resulting list of patents formed by initial "candidate" list of U.S. subsidiaries' patents.

Two main kinds of error could arise from the above procedure, which I term false inclusions and false omissions. False inclusions arise from patents that were classified using the above procedure as originating in a U.S. subsidiary, but which actually originated somewhere else, such as in the headquarters organization or in a subsidiary in a different host country. Reasons for this kind of error include: (1) the address of the first inventor not being representative of where the technical activity actually occurred (e.g., in cases where there is more than one inventor-location involved); or (2) the first inventor incorrectly or falsely listing a U.S. address on the patent document. Similarly, there are two main sources of false omissions: (1) again, from a lack of correspondence between the first inventor's address and the true location of the innovating unit; and (2) by not having a complete list of multinational firms with patenting subsidiaries in the U.S.

4.4.1 False Inclusions

Inventors seeking a U.S. patent must indicate on the patent application their address of *residence* and they must take an oath that this and other information contained in the patent document is correct. The main problem that arises here is due to expatriate inventors, i.e., inventors working abroad for a multinational firm. For example, imagine the case of a scientist whose principle residence is in the U.S. and who gets transferred by the British firm ICI to company headquarters in the U.K. Imagine now that our hypothetical scientist works on a project while in the UK that leads to a discovery for which the firm decides to file a U.S. patent application. What address does the scientist give? Her address in the U.S. (probably)? Or her address in the U.K.? If she gives a U.S. address, this would show up in my data as a U.S. originating patent belonging to a non-U.S. firm - i.e., the kind of patent I am classifying as originating within a U.S. subsidiary. In this case, this would be a false inclusion since the geographic location of the inventing unit is really the U.K.[6]

The source of error described above cannot be eliminated with 100% certainty. However, I attempted to minimize the impact of this problem by performing a verification procedure on each patent identified as a candidate for categorization as a U.S. subsidiary patent. Using publications such as *The Directory of Foreign Firms Operating in the United States: 7th Edition, The Directory of Foreign Manufacturers Operating in the United States: 5th Edition,* and *Directory of American Research and Technology* (various years), company reports, as well as electronic searches of ten years of U.S. newspaper publications, I sought to verify the existence of a U.S. subsidiary in the location identified on the patent document. This process was manageable because I did not, in the end, need to check every patent. Rather, I checked every unique company-location appearing on the list of candidates. For example, it was easy to verify that the Canadian firm Northern Telecom has a subsidiary in North Carolina. Thus all Nortel's patents issued to a North Carolina inventor (there were sixteen during the 1975-1992 period) were validated in one pass. Patents that could not be verified were eliminated from the sample. More than ninety-eight percent of the original candidate patents were eventually verified.

Another possible source of error is the falsification of an inventor's address, perhaps for tax reasons. That is, a multinational firm might derive a tax advantage by claiming that a patent originated in a low tax location, and, therefore, that royalties and other revenues from that patent should be taxed in, and therefore at the rate of, the originating location. Whether and to what extent this is a source of bias in the patent record has not been previously discussed in the patent literature. In this sense, I am following past practice by simply ignoring this problem. There are, however, several factors that push toward a minimalist view of the scope of the problem.

First, such a falsification requires deceit at many different levels: inventor, inventing unit, and corporate. Over and above the ethical issues raised by this possibility, such a strategy would leave the company exposed to information leaks that could lead to adverse publicity, costly and embarrassing law suits, and even extortion. Moreover, inventors can be expected to be very reluctant to lie under oath for something that does not directly benefit them. In addition, since inventors derive personal value from the issuance of a patent in their name (their reputation and thus human capital increases), they are unlikely to be inclined to either lie about their address for the sake of the company, or to leave their name off the patent record (substituting a different inventor's name-location would also be one way to generate the hypothetical tax advantage). In short, it appears unlikely that the geographic information contained on U.S. patent documents would be subject to any significant amount of bias due to corporate gain-seeking through patent document falsification.

4.4.2 False Omissions

A second kind of error arises from the possibility of false omissions, i.e., patents belonging to U.S. subsidiaries of foreign firms that were not identified through the initial search procedure. Expatriate inventors working in the U.S. but listing their home address on a patent document are one such source of error. Unfortunately, there is no way to check for this kind of error over a large sample of patents. Another scenario that offers at least some scope for correction, is that of a relatively small multinational firm (too small to make the lists of major multinational firms initially consulted) that establishes a U.S. subsidiary that eventually generates a U.S. patent. The multinational literature suggests that the number of such subsidiaries and associated patents is likely to be small. It is well known, for example, that even major multinational firms tend to concentrate their R&D operations heavily in the home country due to scale and learning economies as well as the cost and complexity of managing dispersed R&D facilities. For these same reasons, small firms can be expected to experience strong centralization pulls on their R&D function. However, given the objective of obtaining the entire population of U.S. subsidiaries' patents, and because small firms that do have patenting subsidiaries in the U.S. might, for several reasons, be unusual and interesting, I designed an additional search procedure intended to minimize these errors of omission.

The search procedure takes advantage of the fact that almost every firm in the world performs more R&D in the home base than at any other single location in the world. Thus, for each assignee listed in the U.S. patent database, I developed an indicator of its "revealed home base" - the country location in which the largest number of that assignee's patents originated during the 1975-1992 time period. Candidates for categorization as U.S. subsidiaries were identified when (1) the revealed home base of the assignee was outside the U.S.; and (2) the patent was issued to a U.S. inventor. For each candidate patent, I performed the same verification procedure described earlier to ensure that each patent did indeed belong to a U.S. subsidiary. Although most of the patents identified through this approach could not be verified as belonging to a U.S. subsidiary and were subsequently eliminated, the process did turn up several U.S. subsidiaries that had generated multiple patents. Interestingly, the verification process also turned up information to suggest that these at least some of these subsidiaries had generated technical advances that were important to the firm's competitive position in the U.S. and other markets[7].

The combined search procedures described above eventually produced a total of 23,315 patents that were issued to U.S. subsidiaries of foreign multinationals between 1975 and 1992. To the best of my knowledge this is the most complete database of patenting activity by U.S. subsidiaries assembled to date.

4.5 Phase IV: Construction of indicators for each subsidiary patent

Having identified the population of patents issued to U.S.-based subsidiaries of foreign multinationals between 1975 and 1992, I then used the information contained on each patent record to develop a detailed set of indicators that could be used to answer the main research questions posed in the introductory chapter. Appendix 1 lists these indicators and describes how each was constructed. Descriptive statistics including time trends, spatial patterns, and sectoral concentrations relating to these data are presented in Chapter 4.. Two important and inter-related methodological issues arose during this process: (1) defining the relevant geographic units of analysis at sub-national levels; and (2) assigning particular patents to particular subsidiaries. I discuss both of these issues together in the remainder of this section.

4.5.1 Geographic Units of Analysis and Geographic Assignment of Subsidiary Patents

As discussed earlier, each patent issued to a U.S. inventor lists the inventor's city and state address. Note that the geographic information pertains to the inventor, not the subsidiary *per se*. So, for example, a patent holder who lists her address as Ann Arbor, Michigan may actually work for a subsidiary based in Auburn Hills, Michigan (a suburb of Detroit, half an hour away). Since this study seeks, in part, to relate characteristics of subsidiary innovations (as well as characteristics of the subsidiary itself) to spatial flows of knowledge at micro-geographic levels, it is important to be able to associate a particular patent with a particular subsidiary. I considered several alternative approaches to this issue before deciding upon a particular strategy.

The first strategy I considered was simply to use the state-level data contained on the patent record. This approach would lead to the following rule: all patents issued to a particular firm that originate in a particular state are classified as belonging to a single subsidiary. So, using the example above, if the company in question is the Canadian autoparts manufacturer Magna, such a rule would mean classifying all of

Magna's Michigan patents as originating in a single subsidiary. This approach runs into several potentially serious problems. First, in large states such as California, a particular firm may have several subsidiaries in different locations. In such a scenario the state-level approach would introduce error into the data pertaining to the subsidiary characteristics, such as its age, size, and technical foci -- characteristics that I use to predict geographic patterns in the sources of knowledge these units are drawing on during the process of technological innovation. Second, many technologically active regions of the U.S. span state boundaries. Again, this approach would lead to biased indicators of subsidiary characteristics.

Another approach I considered was the city level, which would entail categorizing each city address into a Standard Metropolitan Statistical Area (SMSA). The problem with this approach is that the SMSA-level is *too* finely grained, as illustrated by the Magna example. Ann Arbor and Detroit are actually distinct SMSAs. Thus the patent issued to the Ann Arbor resident would be classified as originating in an Ann Arbor subsidiary, when in fact the subsidiary is in Detroit. This approach also runs into the problem that technologically active regions often span state boundaries while SMSAs do not.

The solution to these problems adopted here was to use geographic classifications developed by the Bureau of Economic Analysis (BEA). BEA regions have the advantage that they are based on actual surveys of economic activity within and across states. The basic unit of aggregation used by the BEA is the U.S. county.

Counties are aggregated into economic regions based primarily on commuting patterns, "so each economic area includes, as far as possible, the place of work and the place of residence of its labor force" (Johnson 1995). For the purposes of this study, commuting patterns probably represent the ideal aggregation system since the city address listed on a patent document represents the address of the inventor (who presumably commutes to the subsidiary from home). The BEA system also solves the two main problems noted above. First, BEA regions may span more than one state as in the Philadelphia, PA-Wilmington, DE -Atlantic City, NJ region. Second, many states also have more than one BEA. San Diego for example, is a BEA region separate from the Los Angeles-Riverside-Orange County region.

Using BEA classifications reduces, but does not completely eliminate, the problem of erroneous assignments of patents to particular subsidiaries. For example, in the Magna example, the patent would be classified as originating in the Detroit-Ann Arbor-Flint BEA region. However, if Magna has a subsidiary in both Ann Arbor and Detroit, any and all patents issued to inventors in the Detroit-Ann Arbor-Flint BEA would simply be lumped under the aegis of a single subsidiary. Thus to the extent that multinational firms have established more than one patenting subsidiary in the same BEA, this will introduce a source of error into the data.

Since none of the above approaches will eliminate entirely sources of error in assigning patents to particular subsidiaries, I also conducted robustness checks in the empirical analyses by changing the definition of a subsidiary from the BEA-level definition chosen to the state-level definition outlined above and examining the impact on my results[8]. Additionally, throughout the study I search for spillover localization at several different geographic levels, including state and SMSA. Overall, the main results of the study proved to be highly robust to these alternative specifications. Details are contained in the relevant chapters.

4.5.1.1 Assignment of patents to BEA regions

Since BEA regions are constructed from U.S. counties, it was essential to classify each U.S. subsidiary patent into a county. Unfortunately, U.S. patent data contain only city-state information, not county information. To overcome this problem, I obtained from the BEA a city-county concordance, which I used to assignee each city listed on a patent document to a U.S. county. With the county information for each patent I was then able to assign each patent to a particular BEA region.

4.6 Phase V: Identification and assembly of patents citations

Once the main subsidiary patent database had been constructed, the final phase in the data collection process was to identify and assemble files containing (1) all prior patents cited as references by each subsidiary patent; and (2) all patents that subsequently cited each subsidiary patent. The first file is used to trace the geography of the technical ideas flowing into innovating subsidiaries; the second file is used to trace the geography of the technical ideas flowing out of innovating subsidiaries. The process was conceptually straightforward, but computationally intensive. The subsidiary patents cited a total of 91,694 prior patents issued between 1975 and 1992.

The subsidiary patents were, themselves, cited a total of 62,583 times through 1992.

Each citation (prior and subsequent) is cross-referenced in the database to the subsidiary patent it is associated with. Since each citation is also a patent, the database of citations contains the same set of indicators listed in Appendix 1. I reserve a discussion of how these data are used to draw inferences about the geography of knowledge flows until the next section.

5. Patent Citation Analysis

5.1 Overview

Citation analysis is a generic term for a set of well-known techniques with a long history in bibliometric studies of scholarly communication and scientific progress (Borgman 1990; Narin 1976). Similar to its bibliometric analogue, patent citation analysis takes advantage of the fact that U.S. patents contain disclosures of prior technology in the form of citations to earlier patents. Essentially, a citation defines a technological building relationship between two inventions (Stuart and Podolny 1996). In other words, the citations listed on a patent represent the technological antecedents of the current invention (Trajtenberg 1990). In recent years several studies have analyzed patent citations to investigate the geography of technological spillovers (Almeida and Kogut 1994; Jaffe et. al. 1993), the extent to which technological learning occurs between alliance partners (Mowery, Oxley, and Silverman 1996), and to characterize firms' technological "positions" relative to those of other firms in the same sector (Stuart and Podolny 1996).

The basic assumption underlying the use of patent citations in this study is that by tracing the technological lineage of a particular patent, it is possible to shed light on the sources of knowledge upon which foreign subsidiaries are drawing during the process of technological innovation. Of particular interest in this study is where, geographically, those knowledge sources are located, e.g., in the home or host country, in the host state, etc. This approach is modelled on the pioneering work of Jaffe et. al. (1993). In that study, the authors examined the geography of the citations received by a sample of "originating" patents issued to (1) U.S. universities, (2) major U.S. firms; and (3) other U.S. firms in order to draw inferences about the extent to which knowledge spillovers generated by these organizations were localized geographically.

The methodological approach adopted in this study is subtly different than the Jaffe, et. al. (1993) approach. Rather than looking at the geography of *subsequent* citations received by a sample of originating patents as did the Jaffe et. al. study, this study looks at the geography of *prior* citations listed on a sample of citing patents issued to U.S.-based subsidiaries of foreign multinationals. In essence, this approach is the mirror image of the Jaffe et. al. approach. The reason for this approach relates, of course, to the research questions I am addressing. In Chapter 5, the question addressed is whether there is evidence that U.S.-based subsidiaries are building upon localized (to the host country) sources of knowledge during the process of technological innovation. In Chapter 6, I extend the analysis to test specific hypotheses about the conditions under which innovating subsidiaries are likely to draw upon home versus host country sources of technical knowledge. The questions addressed in both chapters imply the need to examine the geography of the prior inventions upon which innovating subsidiaries are building. In the remainder of this section I discuss patent citation analysis in the context of the modified Jaffe et. al. (1993) approach developed in this study.

Figure 3.3 illustrates how this approach works in practice. An hypothetical U.S. subsidiary patent is shown on the right hand side of the page. The patent is assigned to Ciba-Geigy, the Swiss chemicals multinational. The patent originated in Chatham, New Jersey (BEA region 12), i.e., that is the resident address indicated by the first inventor on the patent application. The subsidiary patent cites three prior patents, shown on the left hand side of the page. The first citation is to a patent assigned to the U.S. firm, American Cyanamid. It originates in Sufferin, New York, also in BEA region 12. In constructing the set of relationship indicators for this patent-citation combination, this citation would be classified as originating in the same location as the subsidiary patent at both the national and regional levels, but not at the state and SMSA levels. Note, too, that the two patents are in the same technical field (Patent Class 260), a fact that would be captured by a "primary technical field match" indicator. The second citation is an intra-firm citation, i.e., a citation to an earlier patent generated by the same firm. However, this is not a "pure" self-citation in the sense of the inventing unit citing its own prior work. Rather, this is an example of a subsidiary unit citing the headquarters organization in Switzerland - an intra-firm citation, but not an intra-unit citation. In the empirical chapters that follow, I use information on such intra-firm citations to draw inferences about the extent to which subsidiaries are drawing on technical ideas originating in the parent organization, and vice versa. The final citation is to a patent issued to a German firm, Zimmer AG, and a Germany-based inventor. Note that while this citation is the most temporally proximate to the subsidiary patent (the application for the Zimmer patent was filed only 13 months earlier than the citing subsidiary patent), there are no geographic matches (either to the subsidiary's home base, Switzerland, or to anywhere in the host country, the U.S.) between the two patents. The Zimmer citation is also the only one that does not have the same primary patent class as the subsidiary patent, suggesting that it may be technologically more distant from the subsidiary patent than the other two citations.

[Insert Figure 3.3 Here]

The above example should make clear how a stream of geographic, technological, temporal, and organizational indicators can be generated from each subsidiary-citation relationship. Although these indicators, like all indicators based on patent documents, will tend to contain large amounts of variability and noise due, in part, to the mechanics of the citation process, the promise of this approach is to be able to identify patterns in the data generated from a large sample of U.S. subsidiary patents, and, of course, to test specific hypotheses about the nature of those patterns. In the remainder of this section, I discuss the process by which citations are added to patent documents, and the possible sources of bias this process introduces into the geographic analysis that is the main focus of this study. Mechanisms for reducing the impact of these sources of bias are then discussed.

5.1.1 The Patent Citation Process

Citations are added to patent documents through a process involving the inventor, a patent attorney, and a patent examiner, with the patent examiner determining the final list of references. It is with the role of the patent examiner that the analogy between patent citations and journal citations breaks down, since the decision about which journal articles to cite is typically the prerogative of the author[9]. However, as I argue below, the rather large role afforded the patent examiner in the process may actually be an advantage in the context of the current study.

Although the inventor is legally required to disclose all knowledge of prior inventions, in practice there may be a bias toward under-reporting this knowledge since the listing of a citation delimits the scope of the inventor's claims to novelty[10]. In this respect, the inventor applying for a patent faces a fundamentally different set of incentives from those normally faced by authors of scientific journal articles. Adding citations to journal articles is essentially costless. Citations may be added for reasons having to with legitimacy, demonstration of knowledge of the literature, as well as a host of social and institutional reasons. Inventors filing patent applications, on the other hand, will tend to be reluctant to add references beyond the minimum necessary since each citation reduces the claim to novelty of the invention – with the attendant economic implications. The patent examiner, who is supposed to be an expert in the relevant technological area, pushes against this bias toward under-reporting by searching the patent database for relevant references that were missed or concealed by the inventor, and then adding them to the patent record[11].

Given the complexity of this process, and the intervention by actors other than the inventor, a key question for any study using patent citations is whether and how biases might be introduced into the results. Table 3.3 provides a simple framework for analysing the potential sources of geographic bias in this study.

[Insert Table 3.3 Here]

Ideally, all citations that appear on a patent document would fall into Cell I, where an actual knowledge source utilized by the inventor is included in the list of citations appearing on the patent document. Cell IV, correct omissions, also poses no problems. Realistically, Cells II and III will also contain entries. In fact, the innovation literature suggests that missing citations, Cell III, are likely to exist in large numbers since the exchange of knowledge within a technological community occurs mostly through *informal* channels and mechanisms. Although knowledge spillovers may be ubiquitous in the real world, as discussed earlier most will go unreported on formal documents such as patent records. Fortunately, it appears likely that the omission of actual knowledge sources will tend to make the effects of the independent variables more difficult to distinguish, i.e., to produce a conservative test of the hypothesized relationships. After all, if the hypothesized relationships are correct, then the pattern of unobserved knowledge flows should correspond to the hypothesized pattern: including the missing citations would therefore tend to strengthen the results, while omitting them will tend to weaken the results.

A potentially more serious source of bias arises with Cell II, where a citation is included that does not represent an actual source of knowledge contributing to the development of the current invention. The most likely scenario for this occurrence is the patent examiner's intervention. Although the number of such citations is impossible to estimate, interviews with patent examiners suggest that it is likely to be large. Patent examiners do not confirm citations with the inventor. That is, there is no effort made by the examiner to ensure that a citation is proxying for an actual knowledge source utilized by the inventor. Patent examiners interviewed indicated that their search process is based entirely upon technical considerations, i.e., on the functional and technological principles embodied in the invention.

The key issue raised by the patent examiner's intervention is how "false inclusions" are likely to influence the geographic results that are the core focus of this study. As a first cut, these citations can be expected simply to add random noise to the data and, as with false omissions, to bias downward the likelihood of discerning systematic patterns in the data. This is supported by the interview data: none of the patent examiners interviewed indicated that they use the geographic information on patent applications as a basis for searching for prior art. This is critical. After all, if patent examiners search for citations based on the address of the inventor listed on the patent application, this would produce an overestimation of the localization of knowledge flows occurring during the innovation process. If true, this would lead once again to a conservative test of the hypothesized relationships.

However, as discussed by Jaffe et. al. (1993), citations added by patent examiners may in fact contain a systematic geographic bias, namely *they will tend to reinforce the pre-existing geographic patterns in the U.S. patent database.* A citation added by a patent examiner to a drug patent, for example, has a high probability of having originated in the New York-New Jersey area simply because a disproportionate share of the world's drug patents happen to originate there. Of course, this is partly the underlying argument of the thesis, which is that firms may be drawn to such hotbeds of innovation in order to "tap into" the sources of knowledge and other agglomeration benefits resident there. However, support for such an argument would be much stronger if, in fact, the results demonstrate a pattern of local citing that is significantly more localized than would be expected from the underlying geography contained in the U.S. patent database. Formally, we would like to establish a test that allows us to reject the null hypothesis of no localization in favor of the alternative hypothesis that significant localization is observed. In other words, it is important to establish that any meaningful patterns exhibited in the citation data are not simply explicable through a "random citation model", i.e., a pattern that could be predicted from drawing citations randomly from the population of technically and temporally similar patents contained in the patent database. This is the hurdle Jaffe et. al. (1993)

establish in their study before concluding that the empirical results support the claim that knowledge spillovers exhibit a significant degree of geographic localization. In the remainder of this section, I first provide a somewhat different example of how this problem could manifest itself in the current study, and then provide a description of the approach taken to minimize this problem.

The following example illustrates how a set of seemingly random citations added to a group of subsidiary patents could lead to a set of spurious conclusions about the geographic sources of foreign subsidiaries' innovations. In 1989, inventors in Japan accounted for approximately 21% of all patents in the telecommunications field, a figure that has risen steadily since the early 1970s. In 1975, for example, the figure was 13%. Inventors in Sweden, on the other hand, accounted for only about 1% of all telecommunications patents in 1989, a proportion that has not changed significantly since the early 1970s. To the extent that citations added by patent examiners tend to mimic these underlying geographic patterns, this could lead to two spurious conclusions: (1) that U.S.-based subsidiaries of Japanese multinationals have a significantly higher propensity to cite home country sources than do subsidiaries of Swedish multinationals; and (2) the strength of this "Japan effect" has increased over time. Clearly, such a conclusion would require first establishing a "baseline expectation" against which to compare the propensity of the two kinds of subsidiaries to cite their respective home bases. After all, we should expect home-citation propensities to differ across Swedish and Japanese firms. We should also expect that the propensity of Japanese firms to cite their home base will have changed over time - specifically, it can be expected to have risen in line with the secular increase in telecommunications patents issued to Japanese inventors. For the purposes of this study, the key question is whether either subsidiary is citing their home base more or less than would be expected from the underlying geographic distribution of patenting in the relevant technical field and time period.

5.1.1.1 Controls for Geographic Distribution of Patenting

Following Jaffe et. al. (1993), I develop a set of geographic controls intended to capture the expected citation rate discussed above. The controls are constructed by pairing each citation with a "shadow" citation. This shadow citation is chosen based on three criteria: (1) it must have the same 3-digit primary patent class as the citation it is paired with; (2) it must have been issued in the same year as the citation it is paired with; and (3) it cannot itself have been cited by the citing subsidiary patent. In other words, the shadow citation replicates the technological and temporal characteristics of the citation it is paired with, while at the same time having no direct antecedent relationship with the citing patent. When the above criteria generated a list of more than one candidate, the patent that was closest in terms of its grant date to the citation was chosen.

Figure 3.4 illustrates how the shadow citations can be used to generate a set of geographic control variables. The citing subsidiary patent and its citations shown in Figure 3.4 are identical to those shown earlier in Figure 3.3. On the far left side are the set of shadow citations, each matched to an actual subsidiary citation based on the criteria described above. As before, a stream of indicators is generated from this information, this time by analyzing the geographic relationships across each subsidiary patent-shadow citation combination. In the regression analyses that follow in the empirical chapters, these geographic indicators enter the models as a set of dummy variables indicating whether the shadow citation originates in the focal location being modelled or not (e.g., home country, host country, host BEA region, host state, etc.). It turns out, for example, that the Merck & Co. shadow citation also originates in the same BEA region as both the subsidiary patent and the American Cyanamid citation. This would enter into the BEA level model as a match (i.e., a "1") on the geographic control variable associated with that observation. The same would be true in the host country model. On the other hand, the control variable would enter as a no-match (i.e., "0") in the host state, host SMSA, and home country models. The question, then, is whether after taking into account these geographic controls, there is any left over variation in the dependent variable that is explained by the indicators used to operationalize the hypothesized causal relationships. As Jaffe et. al. (1993) argue, this establishes a high hurdle, and thus a conservative test of the hypothesized relationships. That is, the geographic controls alone will tend to account for a large amount of the variation in the dependent variable, thus leaving little variation to be explained by the other independent variables.

[Insert Figure 3.4 Here]

5.2 Other Issues in the Use of Patent Citation Data: Truncation Bias

The main dataset used in this thesis consists of the population of U.S. subsidiary patents issued by the U.S. Patent and Trademark Office between 1975 and 1992. The citations listed on these patents obviously refer to earlier patents, i.e., patents that were issued prior to the citing patent. This raises a problem, namely that some of the citations listed on subsidiary patents will be "truncated" – not contained in the USPTO database -- because they were issued prior to 1975 when the electronic form of the database begins. Clearly, for subsidiary patents issued in the late 1980s to early 1990s the problem is less severe than for subsidiary patents issued earlier than this. For patents issued in, say, 1975 the problem is extreme: very few of the citations listed on these patents are present in the database.

The basic approach I adopted to overcome the truncation problem was to use only 1980-1990 citing patents in the empirical analysis of subsidiary patent citations. This is an unfortunate but inevitable solution to the problem. However, it is only a partial solution. Although enough data exist to analyze the 1980-1990 cohorts, a problem remains that each cohorts will possess a different citation lag structure, i.e., a different age distribution of cited patents. To the extent that the age of a citation influences its geography – and work by Jaffe et. al. (1993) suggests that it might – then comparisons across cohorts of citing patents may be biased due to their different proportions of left-censored citations. The exact nature of this bias is specific to the particular analysis being conducted and thus I defer a discuss to the appropriate chapter. The purpose of this section is to highlight the problem.

Figure 3.5 illustrates the variation in the lag structure of different cohorts of citing patents. It shows the proportion of total citations referenced by three cohorts of subsidiary patent as a function of the age of the citation. The latest cohort (those with an application year in 1990) contains references to prior art dating back over twenty years, although the vast majority of this group's citations are to patents that are between one and ten years old. Patents between two and four years old are especially highly cited. However, for the 1980 cohort, there is a severe drop off after about six years, which represents patents with an application year of 1974[12].

[Insert Figure 3.5 Here]

In the empirical chapters (5-7) of the thesis, I deal with this truncation problem, and the possible bias it introduces, in several different ways. Typically, I first run the main analysis ignoring the problem. Then, as a robustness check on these results I truncate *all* of the 1980-1990 cohorts' citations by an equal amount, and then compare the results to the main analysis. In addition, much of the regression analysis in the empirical chapters is conducted in cross-section using a late enough cohort (1988-1990) of citing patents to minimize the severity of the truncation problem. The various approaches are discussed in more detail in the appropriate chapters.

6. Units and Levels of Analysis

The disaggregated nature of U.S. patent data gives rise to important issues relating to units of measurement and analysis. Figure 3.6 illustrates how organization and technology are nested at different levels in this study. *The fundamental unit of* *measurement in this study is the cited patent, or citation.* In other words, citations constitute the rows of the data matrix; each citation provides an indicator of the location of the knowledge sources underpinning a particular innovation (patent). Of issue here is how the citation data should be aggregated, if at all, to test the various hypotheses developed in this thesis. In other words, what is the appropriate unit of analysis -- the unit to which the data are assigned for hypothesis testing and statistical analysis? This question is ubiquitous, if often implicit, in studies of organizational behavior (James 1982; Rousseau 1985), strategy (Rumelt 1991; Schmalensee 1985), and technological innovation (Katz and Allen 1982; Tushman 1979). As Glick (1985: 613) notes "most important problems in organizational science potentially involve multilevel problems".

[Insert Figure 3.6 Here]

Unfortunately, there is no simple, universal rule for dealing with issues of level such as "always aggregate" or "never aggregate". That aggregated data are often used in social science research is due mostly to their convenience and availability (Kidder and Judd 1986): "they are not generally the preferred type of data" (Rousseau 1985: 7). Given a source of micro-level data such as the patent data used here, the literature suggests that the decision to aggregate depends on several inter-related considerations (Glick 1985; James 1982). In terms of theory, a key (but often difficult) starting point is to define the appropriate unit of theory (Glick and Roberts 1984; Roberts et. al. 1978). The unit of theory is the unit to which generalizations are made. It is often *not* identical to the level of analysis or to the level of measurement (Rousseau 1985).

In the context of this study, the question is whether the main unit of theory is (1) the subsidiary or (2) the innovation developed by the subsidiary (measured by a patent). I shall argue that the main unit of theory in this study is actually the innovation. That is, declarative statements that emerge from this research are of the form "subsidiary innovations characterized by X are more likely to draw on sources of knowledge originating in location Y". This is not to say that subsidiary level effects are ignored. In fact, characteristics of an innovating subsidiary are hypothesized to play a key role in shaping the sources of knowledge that inform a particular innovation. But subsidiary characteristics take on the role of independent rather than dependent variables. In this sense, this research is an example of a cross-level design[13]. Inferences about subsidiaries that emerge from this study are thus framed in terms of innovations (e.g., "innovations developed by older subsidiaries are more likely to draw upon host country knowledge sources") rather than in terms of subsidiaries *per se* (e.g., "older subsidiaries are more likely to draw upon host country knowledge sources"). This is analogous to research on group behavior that uses organizational variables such as climate or culture as contextual factors: e.g., "groups working in hierarchical organizations are less likely to generate new product ideas".

The main reason for selecting the innovation rather than the subsidiary as the focal unit of theory stems from existing research on the internationalization of R&D. Recall from Chapter 2, that the literature suggests that foreign R&D units tend, over time, to develop a set of differentiated (from the parent) technical capabilities based around resources and opportunities in the host country context. However, this same literature also suggests that this evolutionary process is not deterministic; and that these differentiated capabilities, if developed, tend to be additive rather than substitutive. That is, subsidiaries that do develop distinctive technological specializations (and not all do) are also likely to retain capabilities in existing technical areas – areas that may represent more traditional foci of the parent organization. Thus generalizations about, say, the effect of subsidiary age on the geography of innovative search will be undermined by at least two sources of heterogeneity: (1) heterogeneity in the evolutionary path along which subsidiaries' technical capabilities and foci develop; and (2) heterogeneity within subsidiaries in the scope of their technical activities. In this study, this heterogeneity is not an explanandum *per se*. That is, I am not trying to explain which subsidiaries develop differentiated capabilities and which do not. Rather, I am seeking to test the hypothesis that differentiated technical capabilities (as measured by patents in technical areas not well represented in other parts of the firm) will tend to be underpinned by sources of knowledge resident in the host country context. Adopting the innovation as the focal unit of theory means that aggregation of the citation data to the subsidiary level is unwarranted. Indeed, aggregating to the subsidiary level would create a serious lack of correspondence between the unit of theory and the unit of analysis.

The remaining question, then, is whether the citation data should be aggregated to the level of the patent. In terms of theory, aggregation to the patent level is justifiable as it would lead to a direct correspondence between the unit of theory and the unit of analysis, a desirable characteristic in social science research (Kidder and Judd 1986). However, as Drexler (1977), James (1982), and Rousseau (1985; 1990) point out, the aggregation decision also depends on empirical considerations, especially on the underlying heterogeneity in the unit of measurement. Rousseau's (1985) discussion of this issue in the context of organizational behavior research captures the essence of the argument:

> When individual level data are aggregated to the unit level to measure characteristics or attributes of the unit, it is important to establish the extent to which unit members agree on their descriptions of the unit prior to aggregation. (Rousseau 1985: 31).

In the context of this study, Rousseau's statement implies the need to assess the degree of *within-patent* homogeneity in the geographic information contained in the citations. In short, is it meaningful to classify individual patents as, say, "home country" oriented or "host region" oriented based on the geographic location of their citations?

Table 3.4 provides some indication of the within-patent geographic variance. It shows the percentage of subsidiary patents issued between 1980 and 1990 that contain citations to (1) the home base of the firm; and (2) the same BEA region as the subsidiary. For example, 15.1% of all subsidiary patents contain at least one citation to the home base (excluding intra-firm citations). However, note that only 1.5% of subsidiary patents cite *just* home country citations; and only 2.8% cite a plurality of home base originating patents. The figures are similar at the BEA region level. It appears that classifying patents as home country or host region oriented using either of these two decision rules (unanimity or plurality) would be undermined by the geographic diversity in the citation data. Aggregation to the patent level thus risks throwing away a considerable amount of data, and, worse, producing a meaningless set of indicators at the patent level[14].

Another approach to the aggregation problem is to compare for each subsidiary patent the number of citations to the focal location with the "expected" number. Such a measure can be developed using the control or "shadow" citations discussed in Section 5. Subsidiary patents that have a greater than expected propensity to cite, say, the home base, could then be classified as "home oriented". The results of such an analysis are indicated by the number in the far right column of Table 3.4. So, for example, 11.1% of all subsidiary patents have a higher proportion of citations to the home base than do the control or "shadow" citations. The figure is 15.9% at the BEA Region level. These numbers correspond much more closely to the proportion of subsidiary patents that have at least one citation to the focal location – meaning less data would be lost using this aggregation technique. Moreover, it can be also argued that using this technique to aggregate to the patent level may have the added advantage of reducing some of the random noise in the citation-level measures.

[Insert Table 3.4 Here]

Despite the discovery of a potentially meaningful way to aggregate the citation-level geographic information to the patent level, there is a further argument for maintaining the data in their fundamental, disaggregated form. This stems from the loss of the *non-geographic* information contained in each citation that would result from aggregation. As discussed in Section 5, because each citation is also a patent, it is possible to establish a variety of relationship measures between citing and cited patents: organizational (is this an intra-firm cite?); technological (are the two patents in the same narrowly defined technical field?); temporal (are the application dates listed on citing and cited patents far apart or relatively close in time to each other?). Obviously, this information is lost if the data are aggregated to the patent level.

Of particular concern is the loss of the period or temporal information contained in each citation. A key finding in the Jaffe et. al. (1993) study is that citations to more recent patents have a higher likelihood of originating in nearby geographic locations, a finding that supports the hypothesis that knowledge spillovers travel along a space-time diffusion path. Although not an integral part of this study, such a finding would add an interesting and potentially important qualitative dimension to the observed results. For example, it would be interesting to know whether citations by subsidiary patents to the host country represent relatively current technical developments or not, and how this varies according to the nature of the subsidiary innovation and the subsidiary itself.

The discussion in this section suggests that, while a compelling argument can be made for maintaining the citation as the unit of analysis, aggregating to the patent level is both theoretically justified and potentially useful, particularly as a robustness check on the citation-level results. This is the approach I adopt in the empirical chapters. For the most part, the core of the analysis is conducted using the fundamental, disaggregated unit of measurement – the citation. As discussed above, this also allows me to explore the relationship between geographic and non-geographic measures contained in each patent-citation combination. However, I also explore the sensitivity of the citation-level results to changes in the unit of analysis by running a similar set of analyses using measures aggregated to the level of the patent.

7. Summary and Conclusion

The purpose of this chapter was to provide a detailed overview of the data and methods used in this study. The focus of the chapter was on the nature and use of U.S. patent data – the main source of data used to answer the research questions addressed in this study. The chapter began with an overview of U.S. patent data, the kinds of information contained on U.S. patent documents, and the main advantages of these data in the context of the current study. The question of what patent documents actually measure was then addressed along with a discussion of how a fundamental feature of the data – the fact that they capture codified knowledge – was likely to affect the geographic results that are the main focus of this study. It was argued that patents are likely to provide a conservative test of the "geography matters" hypothesis that underpins and indeed motivates the entire thesis. The innovation literature, in particular, suggests that codified knowledge such as that captured by patent documents is likely to travel quickly across spatial and institutional boundaries. Processes of localized knowledge diffusion should therefore be difficult to discern from the use of these kind of data. From a research design perspective, this characteristic of patent data was argued to be an advantage. Although the risk of a null finding with respect to localization is high, a positive finding can be interpreted with considerable confidence as representing a powerful empirical phenomenon.

The rest of the chapter described the extended process by which the raw U.S. patent data were assembled and used in this study, and the various steps that were taken to ensure the integrity of the sample. The methodology of patent citation analysis was then described. Building on the pioneering work of Jaffe et. al. (1993), the methods used in this study extend the boundaries of citation analysis beyond current practice in several ways. The key adaptation of the Jaffe et. al. (1993) methodology was discussed, specifically the use of prior rather than subsequent citations to measure the geographic sources of subsidiaries' innovations. Other minor adaptations are discussed in the individual chapters where they are most relevant. The final section of the chapter discussed issues relating to units and levels of analysis as they pertain to this study. It was argued that the main unit of observation, the citation, should also constitute the main unit of analysis. In this respect, this study follows past research using patent citation analysis (e.g., Almeida and Kogut 1994; Jaffe et. al. 1993). However, mostly as a robustness check of the citation-level results, the analysis contained in the empirical chapters will also be conducted using the patent as the unit of analysis (i.e., by aggregating the citation data to the patent level).

Endnotes

[1] Patents granted to foreign inventors are also assigned to U.S. corporations as a result of these firms' international R&D activities. Patents granted to foreign inventors may also not be assigned to a corporate entity, although, as in the U.S., the number of patents assigned to individuals continues to decrease.

[2] Schmookler (1966) shows that patenting activity attributable to individual inventors declined from over 80% in the early 1990s to slightly over 1/3 in the late 1950s. Scherer (1980) estimates the proportion of patents attributable to individuals not affiliated with a particular organization at 23% (a conservative figure) during the 1971-1975 time period. Scherer and Ross (1990) provide further evidence of this secular decrease: in their study covering patents issued in the early 1980s, the proportion of individual patenting had declined to 18.5% of all U.S. patents. Pavitt (1988) notes research indicating a similar trend in other advanced industrial countries.

[3] Using the 400 3-digit patent classes as dummy variables would create problems in terms of degrees of freedom since some patent classes are represented by only a few subsidiary patents. Another disadvantage is the length of time it takes to run statistical procedures with over 400 variables.

[4] Several studies have established a connection between the number of citations a patent receives and the patent's economic and technological significance (Tratjenberg 1990; Narin, Noma, and Perry 1987). For example, Trajtenberg (1990) showed that citation-weighted patent counts are highly correlated with independent measures of the social value of innovations in the field of Computed Tomography (CAT) scanners - more highly correlated than simple patent counts.

[5] Although the granting of a U.S. patent establishes a seventeen year property right, assignees are required to pay a renewal fee for patents that were applied for after 1980. For corporations, these fees are payable three and a half, seven and a half, and eleven and a half years after the granting date at a cost of $450, $890, and $1340 respectively (Griliches 1990).

[6] This problem can be seen most obviously in the case of an organization that does have any foreign subsidiaries. For example, during the 1975-1992 period MIT was issued several patents that listed inventor addresses outside the U.S. However, this work is not attributable to a "foreign subsidiary" of MIT. Rather the most likely explanation is due to the large number of foreign-resident scientists that visit MIT. A visiting scientist who generates a patentable invention during his stay at MIT may well list his home address on the patent application.

[7] For example, the Swiss packaging company Bobst has a U.S. subsidiary that is known worldwide for its rotogravure press and flat bed cutter-creasers used in the production of folding cartons. Bata, the Canadian shoe manufacturer, has a subsidiary in Maryland that has carved out a niche in the development and manufacturing of waterproof polyvinyl chloride boots for industrial workers.

[8] Another way to check the results is simply to look at how subsidiary characteristics such as age, size, and degree of technological differentiation from the parent organization correlate with each other using the alternative geographic classifications. Overall, the correlation between BEA and state-defined subsidiary characteristics is consistently over 0.9 indicating a high degree of correspondence between the two measures.

[9] The exaggerated role of the patent examiner is akin to having a journal editor decide which references should be included on a particular journal article.

[10] Such a delimitation has legal and, potentially, economic consequences.

[11] The patent examiners I interviewed typically had undergraduate degrees in technical fields that were relevant to their area of responsibility within the USPTO. However, it is not uncommon for examiners in complex and emerging fields such as biotechnology to hold graduate degrees, even to the Ph.D. level.

[12] Patents with application years of 1974 are in the database. The 1975 cutoff is based on date of issuance.

[13] Cross-level designs specify relationships between variables at different levels. For example, individual-level measures and units of analysis may be used to draw inferences about organizational phenomenon.

[14] Another possible aggregation scheme is to classify each patent in terms of the percentage of its citations that are to the focal location (home country, host country, host region, etc.). However, this approach runs into problems because of the small number of citations typically listed by a citing patent, and the variation in that number. The percentage approach is more appropriate for aggregate comparisons between, say, foreign subsidiaries and domestic firms. In fact, I use this approach for such a comparison in Chapter 5.

Table 3.1 Phases of Data Assembly and Construction

Phase I	Extraction of patent data from CD-ROM to relational database
Phase II	Identification of patents belonging to major non-U.S. MNCs
Phase III	Identification and geographic assignment of U.S. subsidiaries' patents
Phase IV	Assembly of indicators for each subsidiary patent
Phase V	Identification and assembly of citation data

Table 3.2 Assignee Names of Listed on Patents Belonging to Hoechst AG and its Affiliates

American Hoechst Corp.
American Hoechst Corporation
American Hoeschst Corporation
American Hoescht Corporation
Behringwerke A.G.
Behringwerke AG
Behringwerke Akitengesellschaft

Behringwerke Aktiengellschaft
Behringwerke Aktiengesellschaft
Behringwerke Antiengesellschart
Beiersdorf AG; Hoechst AG
Cassella AG
Cassella AG.
Cassella Aktiengesellschaft
Cassella Aktiengesellschaft; Dresser Industries, Inc.
Cassella Aktiengesellschaft; Theodor Hymmen KG
Cassella Aktiengesellschaft; Tokico Ltd.
Cassella Aktiengessellschaft
Cassella Farbewerke Mainkur Aktiengesellschaft
Cassella Farbwerke Mainkur AG
Cassella Farbwerke Mainkur AKT
Cassella Farbwerke Mainkur Akt.
Cassella Farbwerke Mainkur Aktiengesellschaft
Cassella Farbwerke Mainkur Atiengesellschaft
Celanese Corporation
Celanese Engineering Resins
Celanese Engineering Resins, Inc.
Celanese Fibers Inc.
Celanese Fibers, Inc.
Crall, Hugh C.; Hoechst Celanese Corp.
Eigenbrod, Volkmar; Hoechst Aktiengesellschaft
Farbwerke Hoechst Aktiengesellschaft
Farbwerke Hoechst Aktiengesellschaft vormals Meister Lucius & Bruning
Ficht GmbH; Hoechst CeramTec Aktiengesellschaft
Herberts G.m.b.H.
Herberts Gesellschaft
Herberts Gesellschaft mit beschraenkter Haftung
Herberts Gesellschaft mit beschrankter
Herberts Gesellschaft mit beschrankter Haftung
Herberts GmbH
Herberts Industrieglas GmbH & Co. KG
Herbertsgesellschaft GmbH
Hoechat-Roussel Pharmaceuticals, Inc.
Hoechest Celanese Corporation
Hoechst A.G.
Hoechst AG
Hoechst AG Werk Ruhrchemie
Hoechst AG.
Hoechst AG; Vereinigte-Aluminum Werke A.G.
Hoechst AG; Vereinigte-Aluminum Werke AG.
Hoechst AK
Hoechst Akteingesellschaft
Hoechst Aktiegesellschaft
Hoechst Aktiengellschaft
Hoechst Aktiengelselschaft
Hoechst Aktiengeselischaft
Hoechst Aktiengesell
Hoechst Aktiengesellachaft
Hoechst Aktiengesellchaft
Hoechst Aktiengesellcshaft
Hoechst Aktiengesselleschaft
Hoechst CeramTec Aktiengesellschaft
Hoechst Ceramtec Aktiengesellschaft; Pacific Wietz
Hoechst Fibers Incorporated
Hoechst Fibers Industries
Hoechst Fibers Industries, Div. of American Hoechst Corp.
Hoechst Fibers Industries, Div. of American Hoechst Corporation
Hoechst Fibers Industries, Division of American Hoechst Corporation
Hoechst France
Hoechst Gelanese Corp.
Hoechst Gosei Kabushiki Kaisha
Hoechst Italia S.p.A.
Hoechst Italia Sud SPA
Hoechst Japan Kabushiki Kaisha; Nisso Petrochemica
Hoechst Japan Limited
Hoechst Japan Limited; Nissho Corporation
Hoechst Roussel Pharmaceuticals Inc.
Hoechst Roussel Pharmaceuticals Incorporated
Hoechst Roussel Pharmaceuticals, Inc.
Hoechst Roussel Pharmaceuticals, Inc.; University
Hoechst U.K. Limited
Hoechst UK Limited
Hoechst-Perstorp AB
Hoechst-Rouseel Pharmaceuticals Inc.
Hoechst-Roussel Incorporated
Hoechst-Roussel Phamraceuticals Inc.
Hoechst-Roussel Pharmaceticals Incorporated
Hoechst-Roussel Pharmaceutical Inc.
Hoechst-Roussel Pharmaceutical Incorporated
Hoechst-Roussel Pharmaceuticals
Hoechst-Roussel Pharmaceuticals Inc.
Hoechst-Roussel Pharmaceuticals Incorporated
Hoechst-Roussel Pharmaceuticals, Inc.
Hoechst-Roussel Pharmaceuticals, Incorporated

Hoechst-Roussel Pharmacueticals Inc.
Hoechst-Roussell Pharmaceuticals Inc.
Hoechst-Roussell Pharmaceuticals, Inc.
Hoechstaktiengesellschaft
HOECHSTMASS Balzer GmbH & Co.
Hoecht Aktiengesellschaft
Hoecht Celanese Corp.
Hoecsht Aktiengesellschaft
Hoeschst Aktiengesellschaft
Hoeschst-Roussel Incorporated
Hoeschst-Roussel Pharmaceuticals Inc.
Hoeschst-Roussel Pharmaceuticals, Inc.
Hoescht Aktiengesellschaft
Hoescht Celanese Corporation
Hoffman & Engelmann AG
Kalle, Niederlassung der Hoechst AG
Laboratoires Hoechst S. A.; Behringwerke Aktienges
Laboratoires Hoechst S.A.
Laboratoires Hoechst, S.A.
Laboratories Hoechst S.A.
Marbert GmbH
Messer Greisheim
Messer Greisheim GmbH
Messer Griesheim
Messer Griesheim G.m.b.H.
Messer Griesheim GmbH
Messer Griesheim GmbH.
Messer Griesheim GmbH. Patentabteilung

Hoechst Aktiengesellschafat
Hoechst Aktiengesellschaft
Hoechst Aktiengesellschaft & Internationaler Dienst fur Betriebsberatung und Marktforschung GmbH
Hoechst Aktiengesellschaft Knapsack
Hoechst Aktiengesellschaft; AJAX International Mac
Hoechst Aktiengesellschaft; Alfred Teves GmbH
Hoechst Aktiengesellschaft; Chemiefaser Lenzing Aktiengesellschaft
Hoechst Aktiengesellschaft; Deutsche Gelatine-Fabr
Hoechst Aktiengesellschaft; Dudzik, Joachim; Dudzik, Winfried
Hoechst Aktiengesellschaft; ELTI Apparatebau und E
Hoechst Aktiengesellschaft; Hiechst Celanese Corpo
Hoechst Aktiengesellschaft; Hoechst Aktiengesellschaft
Hoechst Aktiengesellschaft; Licentia Patent-Verwaltungs-GmbH
Hoechst Aktiengesellschaft; Max-Planck-Gesellschaf
Hoechst Aktiengesellschaft; Messer Griesheim GmbH
Hoechst Aktiengesellschaft; Ruhrchemie Aktiengesellschaft
Hoechst Aktiengesellschaft; Teves, Alfred
Hoechst Aktiengesellschat
Hoechst Aktiengesellshaft
Hoechst Aktiengsellschaft
Hoechst Aktinegesellschaft
Hoechst Atiengesellschaft
Hoechst Atkiengesellschaft
Hoechst Calanese Corporation
Hoechst Celanese
Hoechst Celanese Chemical Co.
Hoechst Celanese Coproration
Hoechst Celanese Corp
Hoechst Celanese Corp.
Hoechst Celanese Corporation
Hoechst Celanese Corporation; Alkaril Chemicals, Inc.
Hoechst Celanese Corporation; Alpha Precision Plas
Hoechst Celanese Corporaton
Hoechst Celanse Corp.
Hoechst CeramTec Ag
Messer Griesheim GmbH; Krauss und Reichert
Messer Griesheim Industries, Inc.
Messer Grieshiem GmbH

MG Industries
MG Industries, Inc.
Novel Hoechst Chimie
Riedel de Haen Aktiengesellschaft
Riedel-de Haen AG
Riedel-de Haen Ag.
Riedel-de Haen Aktiengesellschaft
Roussel Bio Corporation
Roussel Rclaf
Roussel UCAF
Roussel Uclaf
Roussel Uclafi
Roussel Ulcaf
Roussel Vclaf
Roussel-Uclaf
Roussel-Ulcaf
Roussell Uclaf
RousselUclaf
Schloemann-Siemag Akt.; Hoechst Aktiengesellschaft
Sheen Kleen, Inc.; Hoechst Celanese Corporation
Societe Francaise Hoechst
Societe Francaise Hoechst of Tour Roussel-Hoechst
Spinnstoffabrik Zehlendorf Aktiengesellschaft
Uclaf, Roussel
Uhde GmbH
UHDE GmbH; Ekato Ruhr-und Mischtechnik GmbH
Uhde GmbH; Kali Chemie AG
Uhde GmbH; Ruhrkohle Ol und Gas GmbH; Hoechst AG;
Uhde GmbH; Siekmann, Helmut E.
Uhde GmhH
Uhde, GmbH

Table 3.3 Relationship Between Actual Knowledge Sources and Patent Citations

		Knowledge Source	
		Utilized by Inventor	Not Utilized by Inventor
Citation	Included on Patent	I Correct Inclusion	II False Inclusion
	Not Included on Patent	III False Omission	IV Correct Omission

Table 3.4 U.S. Subsidiary Patents and their Citations

	At Least One Citation to Focal Location	100% of Citations to Focal Location	Plurality of Citations to Focal Location	More Citations to Focal Location than Controls
Home Country	15.1%[a]	1.5%	2.8%	11.1%
BEA Region	18.9%	1.8%	3.1%	15.9%

[a] Numbers in cells represent percentage of U.S. subsidiary patents issued between 1980 and 1990

Figure 3.1 The front page of a U.S. patent document

United States Patent 5,580,873
Bianco, et. al. Dec. 3, 1996

Enatiomerically pure hydroxylated xanthine compounds to treat proliferative vascular diseases

Inventors: Bianco; James A. (Seattle, WA); Woodson; Paul (Bothell, WA); Porubek; David (Edmonds, WA); Singer; Jack (Seattle, WA).
Assignee: Cell Therapeutics, Inc. (Seattle, WA).
Appl. No.: 456,899
Filed: Jun. 1, 1995

Related U.S. Application Data

Division of Ser No. 343,810, Nov. 22, 1994, which is a division of Ser. No 307,554, Sept. 16, 1994, which is a continuation of Ser. No. 13,977, Feb. 4, 1993, abandoned, which is a continuation-in-part of Ser. No. 926,665, Aug. 7, 1992, abandoned, which is a continuation-in-part of Ser. No. 846,354, Mar. 4, 1992, abandoned.

Intl. Cl.: A61K 31/52
U.S. Cl.: 514/263
Field of Search: 514/263

References Cited | [Referenced By:]

U.S. Patent Documents

3,373,433	Mar., 1968	Mohler et al.	343/850
3,422,107	Jan., 1969	Mohler et al.	544/267
4,515,795	May, 1985	Hinze et al.	424/253
4,525,309	Jun., 1985	Matteson et al.	260/462
4,576,947	Mar., 1986	Hinze et al.	514/263
4,636,507	Jan., 1987	Kreutzer et al.	514/263
4,965,271	Oct., 1990	Mandell et al.	514/263
5,096,906	Mar., 1992	Mandell et al.	514/263
5,112,827	May, 1992	Saunders et al.	514/263
5,118,500	Jun., 1992	Hanel et al.	424/85.1
5,272,153	Dec., 1993	Mandell et al.	514/263
5,310,666	May, 1994	Aretz et al.	435/119
5,409,935	Apr., 1995	Schubert et al.	514/265

Foreign Patent Documents

435153	Jul., 1991	EP
435152	Jul., 1991	EP
3942872	Jun., 1991	DE
WO92/21344	Dec., 1992	WO

Other References

Bianco et al., Blood, vol. 78, No. 5, pp. 1205-1211, "Phase I-II Trial of Pentoxifylline for the Prevention of Transplant-Related toxicities Following Bone Marrow Transplantation", 1991.

Davis et al., Applied And Environmental Microbiology, vol. 48, No. 2, pp. 327-331, "Microbial Models of Mammalian Metabolism: Microbial Reduction and Oxidation of Pentoxifylline", 1984.

Davis et al., Xenobiotica, vol. 15, No. 12, pp. 1001-1010, "Microbial Models of Mammalian Metabolism: Stereospecificity of Ketone Reduction with Pentoxifylline", 1985.

Matteson et al., J. Am. Chem. Soc., vol. 108, pp. 810-819, "99% Chirally Selective Syntheses via Pinanediol Boronic Esters: Insect Pheromones, Diols, and an Amino Alcohol", 1986.

Soundarajan et al., J. Org. Chem., vol. 55, pp. 2274-2275, "Hydroboration with Boron Halides and Trialkylsilanes", 1990.

Primary Examiner: Criares; Theodore J.
Attorney, Agent or Firm: Oster; Jeffrey B.

Figure 3.2 The relationship between inventive activity, inventions, innovations, and patents

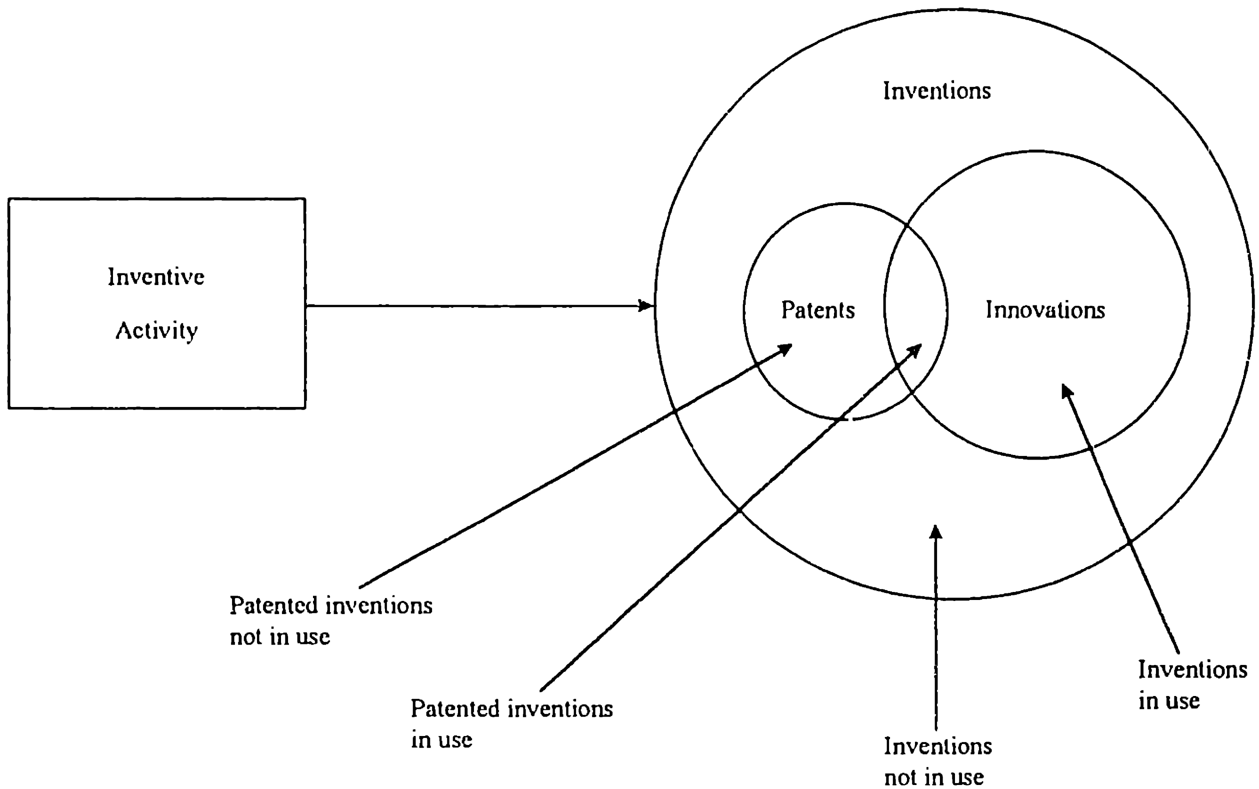


Figure 3.3 Hypothetical U.S. Subsidiary Patent and Prior Patents It Cites as References

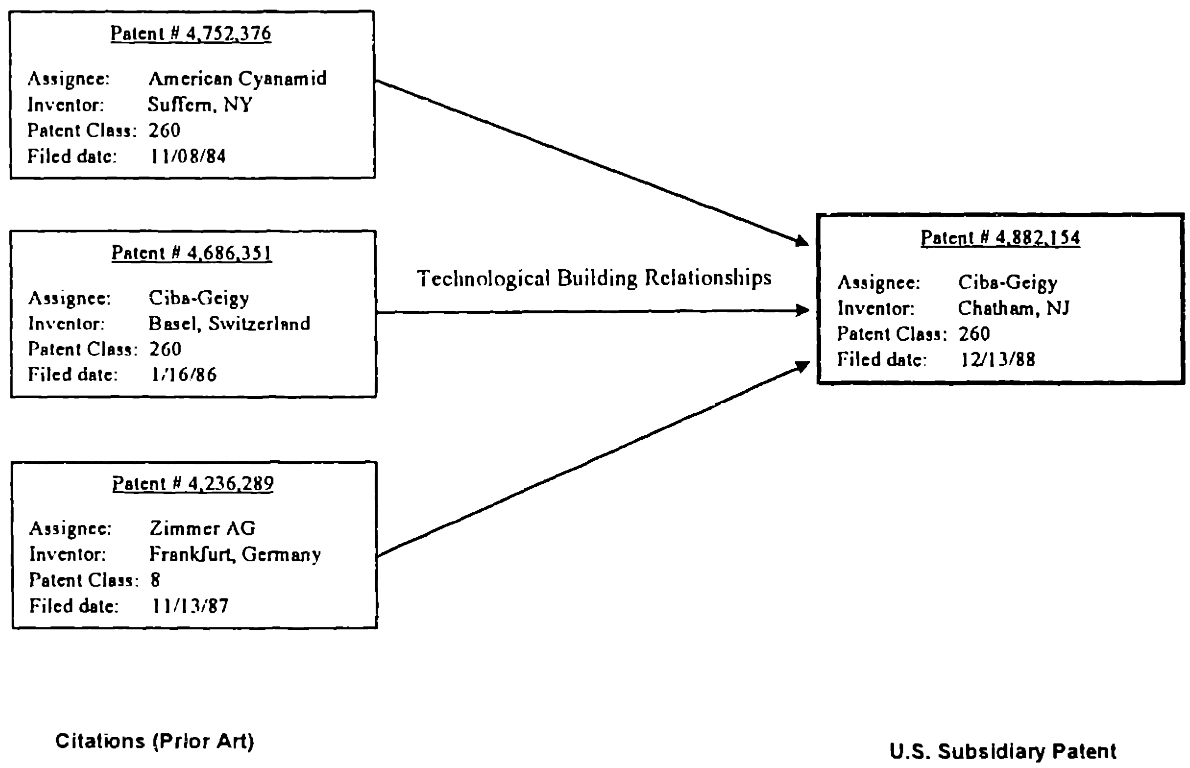


Figure 3.4 Hypothetical U.S. Subsidiary Patent, Prior Citations, and "Shadow

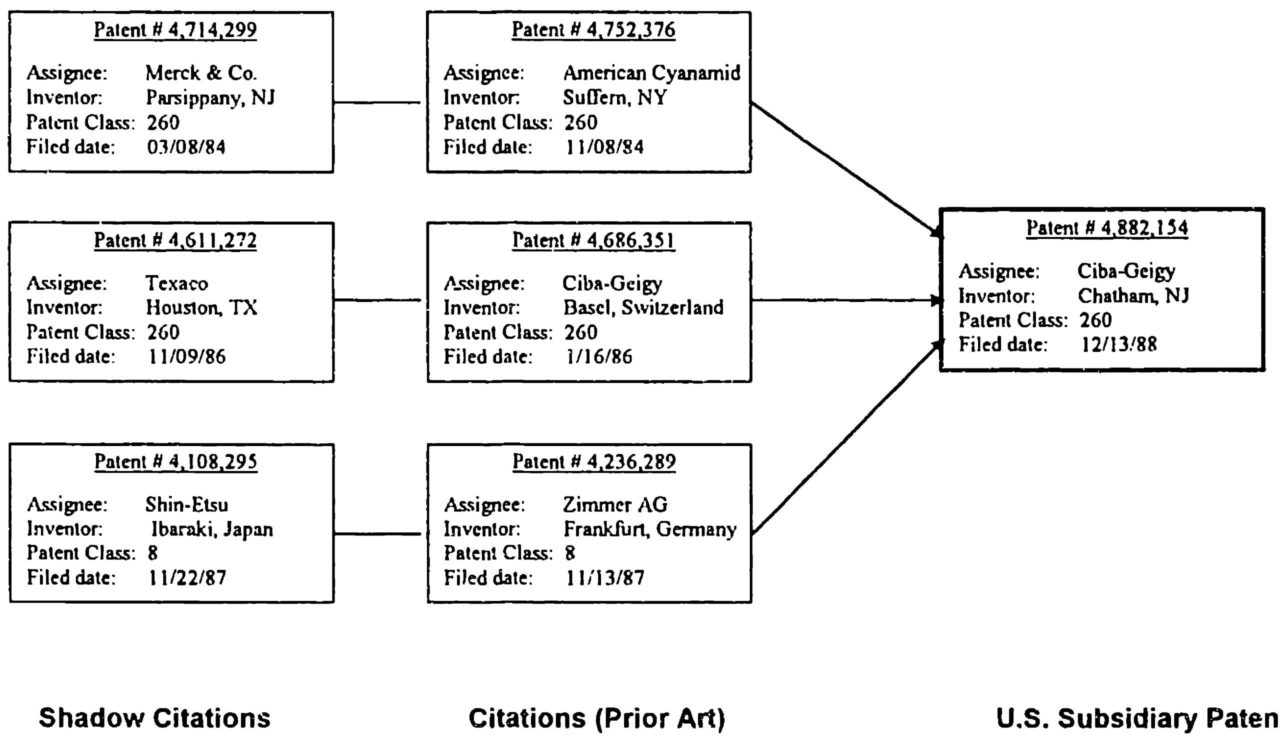


Figure 3.5 Patent Citations by Age of Cited Patent: 1980, 1985, and 1990 Citing Subsidiary Patents

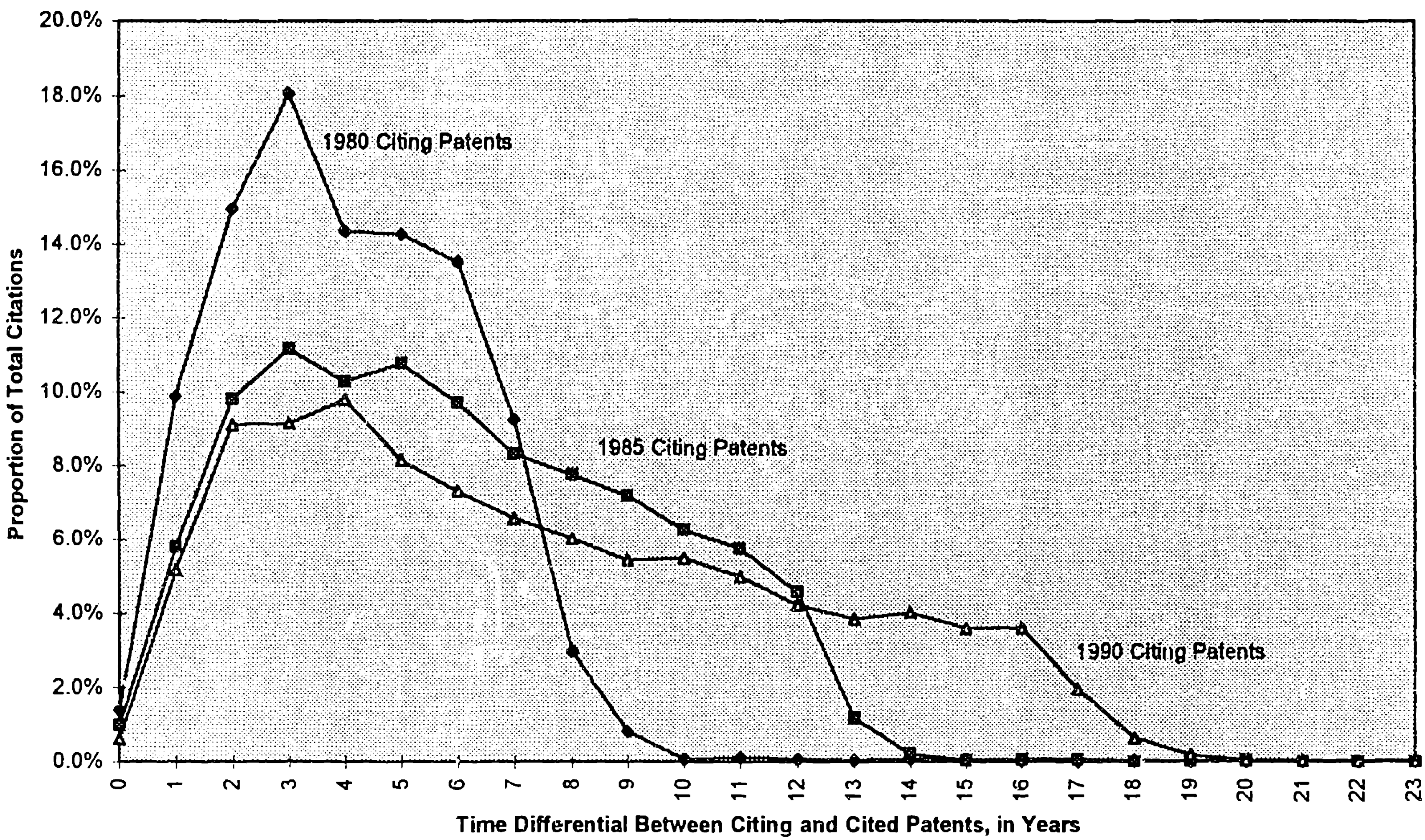
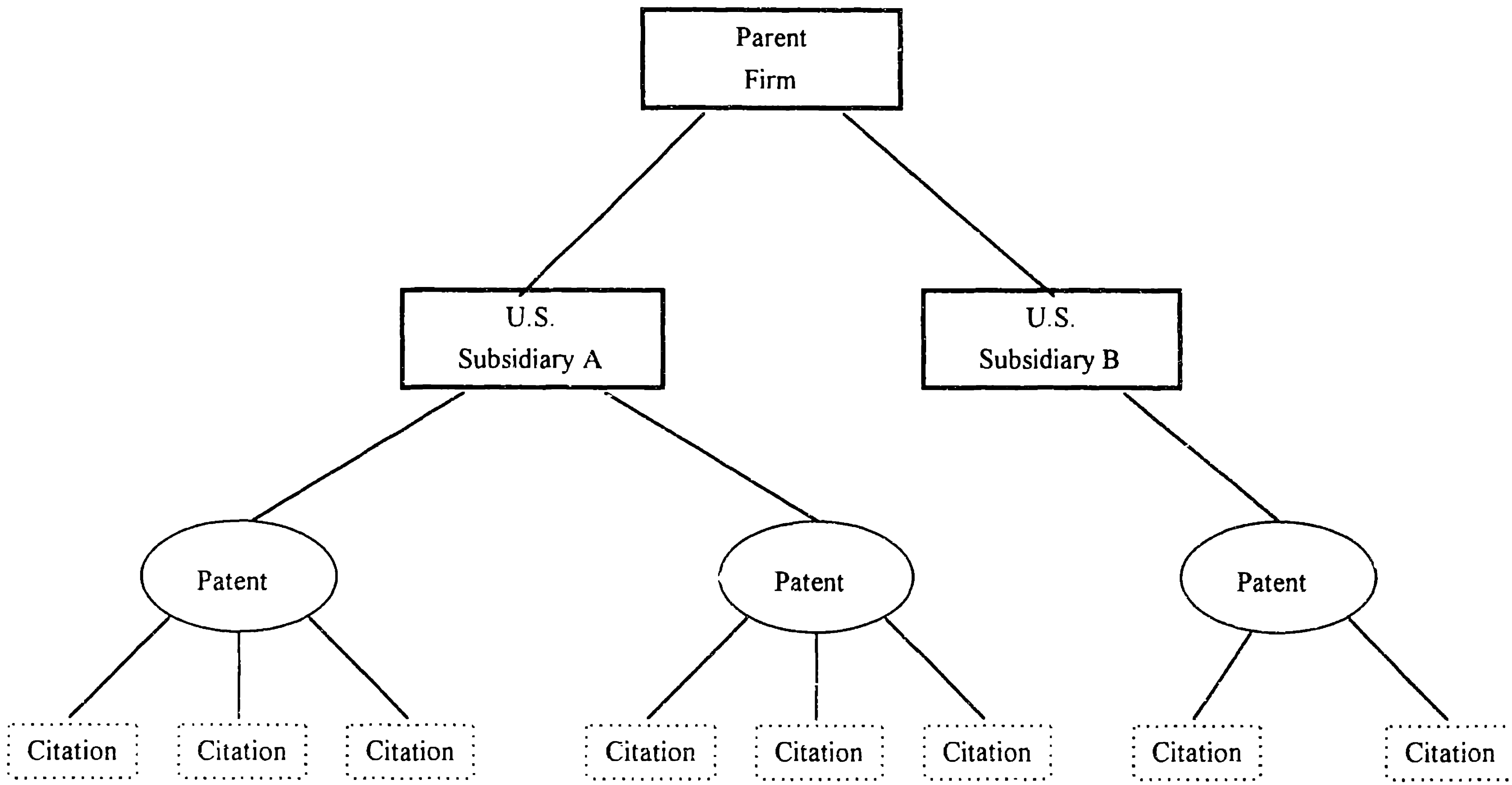


Figure 3.6 Units and Levels of Analysis in this Study



Chapter 4 Overview of Patenting by U.S. Subsidiaries

1. Overview and Objectives

This chapter presents background information on the patenting activities of U.S.-based subsidiaries of foreign multinationals. The purpose of the chapter is to provide an overview of the composition, geography, and evolution of U.S. subsidiary patenting during the full eighteen years covered by the database. The information presented in this chapter provides the context for the analysis and hypothesis testing that follow in Chapters 5-7. Additional descriptive statistics are presented in those chapters as well. The difference in the material presented here and the material presented in those chapters is primarily one of scope. In Chapters 5-7, the focus is on the analysis of the *citation* data contained in U.S. subsidiary patents. For reasons discussed in the previous chapter, this limits the analysis to the 1980 to 1990 time period. This chapter, in contrast, uses the extensive set of *non-citation* indicators contained in U.S. patent documents to explore various aspects of U.S. subsidiary technical activity over a longer period of time. In addition, in Chapters 5-7, descriptive statistics are typically presented for specific sub-samples of the overall population (e.g. greenfield subsidiaries or acquisitions), and most often in comparative context (e.g., comparisons between patents issued to U.S. subsidiaries and patents issued to U.S. firms or to the subsidiary's parent organization). The goal of the current chapter, then, is to provide a more complete picture of the nature and evolution of U.S. subsidiary patenting.

The remainder of this chapter is divided into two main sections. The next section (Section 2) presents a detailed set of population-level indicators on U.S. subsidiary patenting: time trends in the volume of subsidiary patenting, sectoral and home country composition, mode of entry, and geographic organization. Section 3 shifts the analysis from the population level to the corporate level, looking at the patenting activities of a subset of major patenting firms. Section 4 summarizes and concludes.

2. Profile of Patenting by U.S. Subsidiaries

2.1 The Growth of U.S. Subsidiary Patenting

Between 1975 and 1992, the United States Patent Office issued 23,315 patents to U.S.-based subsidiaries of foreign multinationals. Figure 4.1 shows the evolution of U.S. subsidiary patenting over time. The years shown, 1973-1990, represent the date of *application* of these patents, i.e., the year in which the patent application was filed by the assignee with the USPTO. As discussed in Chapter 3, filing dates provide a better indication than issuance dates of the actual time period of the technical activities leading to the invention. The solid line represents the number of patent applications by U.S. subsidiaries (left hand scale)[1]. As a benchmark, Figure 4.1 also shows the total number of patents issued to all U.S.-based inventors, regardless of whether they are working for U.S. companies or U.S. subsidiaries of foreign multinationals (dashed line, right hand scale)[2].

Figure 4.1 highlights the secular increase in U.S. subsidiary patenting during the period shown and its rapid increase after about 1986. The apparent dip after 1989 is almost certainly due to the fact that not all patents applied for in 1990 had been issued by the end of 1992, the latest point in the series. The growth rate in U.S. subsidiary patenting is clearly higher than the overall growth in patenting by U.S. inventors – especially after 1986. Note, however, that the number of U.S. subsidiary patents represents a small fraction of overall patenting by U.S. inventors: in 1973, the figure was 1.4 percent of the U.S. total; by 1990, it had risen to only 2.6 percent[3]. Still, U.S. subsidiary patenting is by no means trivial. As a comparison, between 1965 and 1992 U.S. universities were issued a total of 12,804 U.S. patents (Henderson, Jaffe and Trajtenberg 1994), about half the number issued to foreign subsidiaries in the U.S. In addition, although patenting by U.S. subsidiaries and U.S. universities both grew rapidly in the last half of the 1980s, the rate of growth of subsidiary patenting was actually higher (not shown).

[Insert Figure 4.1 Here]

The growth in U.S. subsidiary patenting is driven by at least three conceptually distinct phenomenon: (1) subsidiary evolution; (2) new subsidiary entry, including the acquisition of U.S. firms by foreign multinationals; and (3) new *parent* firm entry[4]. Subsidiary evolution refers to the growth in the number of patents issued to particular subsidiaries after initial "entry", which I define as the date of their first patent application[5]. Figure 4.2 provides some indication of the importance of this growth driver. It shows the average number of patents issued over time to four "entering cohorts": subsidiaries with initial patent application dates in 1973; 1977; 1981; and 1985[6]. For example, the results for the 1973 cohort show a relatively stable level of patenting through about 1984, followed by a rapid increase thereafter. In contrast, the average number of patents issued to the 1977 cohort has not increased significantly over time. The 1981 cohort, which averaged 1.9 patents per subsidiary in the initial year, shows a steady increase to an average of just under 14 patents per subsidiary in 1990.

[Insert Figure 4.2 Here]

Growth in U.S. subsidiary patenting is also driven by the entry of new patenting subsidiaries, some of which belong to firms with an existing network of U.S. technical units, and others that arise from the activities of "new" multinationals, i.e., those without a pre-existing U.S. network. Figure 4.3 provides an indication of the importance of both factors. The dashed line (left hand scale) shows the steady increase in the number of parent firms with patenting subsidiaries in the U.S. In 1973, 71 foreign multinationals had at least one patenting unit in the U.S. By 1989, the figure had risen to 242, before falling to 211 in 1990[7]. To put this figure in context, the 1990 *Directory of Foreign Firms Operating in the United States* (7th edition) lists over 1600 foreign firms with operations of some kind in the U.S., meaning that about 1/8th of all foreign multinationals in the U.S. had some kind of patenting operation in the host country that year. The solid line (right hand scale) shows a similar increase in the total number of patenting subsidiaries, from a low of 142 in 1973 to a high of 622 in 1989.

[Insert Figure 4.3 Here]

Figure 4.4 provides an indication of the importance of the various modes by which U.S. patenting units are established: greenfield investments; acquisitions of U.S. firms; and joint ventures. Greenfield investments are responsible for the lion's share of

U.S. subsidiary patents, although acquisitions account for an increasing share of total patenting over time. In 1973, acquisitions accounted for less than 12 percent of the total; in 1989, the figure had risen to just under one-third of the total. The relatively small share of patents accounted for by acquisitions is perhaps surprising given that much of the political controversy over foreign R&D investment in the U.S. has been over the acquisition of U.S. high tech firms by foreign multinationals. One possible explanation is that high tech acquisitions tend to be of relatively small firms (e.g., Genentech, Intellistor) that, by warrant of their size, have been issued a relatively small number of patents when viewed in comparative terms. Patents issued to joint ventures continue to account for a negligible proportion of the total. Whether this level reflects the actual volume of technical activity carried out by joint ventures, or whether joint ventures simply patent less (perhaps for legal reasons) is impossible to say.

[Insert Figure 4.4 Here]

2.2 U.S. Subsidiary Patenting by Home Base

The distribution of U.S. subsidiary patenting by the home country of the parent firm is presented in Table 4.1 for the ten largest home countries. Firms from these countries accounted for over 98 percent of all U.S. subsidiary patenting during the 1973-1990 time period. Table 4.1 also shows the average annual growth rate of patenting during this period, the proportion of subsidiary patents accounted for by acquired U.S. firms ("acquisitions"), the total number of U.S. subsidiaries from each home base, and the total number of parent companies with at least one patenting U.S.

subsidiary during this time period. The names of the top patenting firms from each country are listed in the far right column.

[Insert Table 4.1 Here]

German firms were responsible for the largest number of U.S. subsidiary patents, followed by firms from Great Britain, the Netherlands, and Switzerland. These four countries accounted for over 70 percent of all patenting by U.S subsidiaries over the eighteen years of the data. Dunning and Narula (1995) report a similar concentration and home country composition of R&D expenditures by U.S. subsidiaries of foreign multinationals. For example, the authors report that, in 1977, firms from Switzerland accounted for 25.8 percent of all U.S. subsidiary R&D expenditures, followed by firms from the Netherlands (20.8 percent), Great Britain (16.6 percent), and Germany (10.8 percent). The corresponding figures based on the patent data used in this study are: Switzerland (31.8 percent), the Netherlands (19.8 percent), Great Britain (18.9 percent), and Germany (14.8 percent).

The corporate composition underpinning Table 4.1 is discussed in more detail in Section 3. At this point, note that for the Netherlands, Switzerland and France a relatively small number of parent firms are responsible for the large majority of each country's U.S. technical activities. In the case of the Netherlands, for example, only 12 parent firms had a patenting subsidiary in the U.S. during the eighteen years from 1973 to 1990, and the largest firm, Royal Dutch Shell, accounted for over half the total number of U.S. subsidiary patents attributable to Dutch firms. Switzerland is another case in point: the Basel chemical multinationals Roche, Sandoz, and Ciba-Geigy accounted for 33.5 percent, 32.7 percent and 14.5 percent of the Swiss total, respectively – together over 80 percent of the Swiss firm total.

Growth rates in U.S. subsidiary patenting are fairly evenly distributed across home countries, although Switzerland and Canada are noteworthy for the relatively low levels of growth in U.S.-based patenting activity, 0.8 percent and 6.0 percent average annual growth, respectively. Japanese firms had the highest average annual growth rate (22.7 percent), followed by firms from Sweden (21.5 percent), Germany (18.8 percent) and France (18.7 percent). The growth in the U.S. technical activity of Japanese firms is particularly impressive. From only 6 patenting subsidiaries in the U.S. in 1973, the number rose to 94 in 1990. The number of patents issued to these units rose from 13 in 1973 to 171 in 1990. Florida and Kenney (1995) report similar rapid growth in Japanese R&D establishments in the U.S., from less than 40 R&D facilities in 1985 to over 100 in 1990. A 1992 JETRO survey of Japanese establishments in the U.S. found that 481 of 950 respondent establishments engaged in some kind of R&D activity, either internally in labs and production facilities or externally through joint ventures (Florida and Kenney 1995). Another distinguishing feature of Japanese firms is the relatively small number of patents per subsidiary, which averages about five for the entire time period. The comparable figure for U.S. subsidiaries of Dutch firms is about 28, for German firms about 13. Although this result could be due to a "field effect" (i.e., Japanese firms tend to patent in technical fields with lower patent propensities), it may also be picking up one of the distinguishing characteristics of the technical activities of Japanese multinationals in the U.S. Several authors have reported on the relatively small size of Japanese R&D labs in the U.S. (Dalton and Scerapio 1993; Herbert 1989; Westney 1992)

A point of greater divergence across home countries is the relative proportion of patents accounted for by acquisitions, which range from a high of 81.4 percent for Belgian firms to a low of 6.7 percent for Canadian firms. German, British, French, and Swedish firms also had relatively high levels of patenting activity accounted for by acquired U.S. affiliates. Joining Canadian multinationals at the low end of the distribution are firms from the Netherlands and Switzerland. In many cases, the high end figures are driven by a few major acquisitions. The Belgian figure, for example, is due almost completely to Petrofina's 1963 acquisition of the U.S. oil and gas firm Cosden. Other acquisitions that significantly increased the American technical presence of foreign firms include Bayer's 1977 acquisition of Miles Laboratories, Unilever's 1978 acquisition of National Starch and Chemical, Hoechst's 1987 acquisition of Celanese Corporation, and Roche's 1990 acquisition of Genentech.

Figures 4.5 and 4.6 provide a more complete picture of the evolution of U.S. subsidiary patenting by firms from different home countries between 1973 and 1990. Figure 4.5 shows the number of patents issued to greenfield subsidiaries over time, while Figure 4.6 provides the same set of data for acquisitions. In both figures, the countries are stacked from bottom to top by total patents, i.e., by the combined 1973 to 1990 total for firms from that country. So, for example, U.S. greenfield subsidiaries of Dutch multinationals were issued the most patents, followed by Swiss and German firms. For acquisitions, the ordering goes Germany, Great Britain, France. Together, the two figures highlight not only the differences in entry mode across home countries, but also changes in the composition of greenfield vs. acquisition over time. The example of firms from Switzerland is instructive. Figure 4.5 shows the that the number of patents issued to greenfield subsidiaries has actually declined over time, from a high of 296 patents in 1975 to a low of 91 patents in 1983. By 1989, the figure had risen again to 165. In contrast, Figure 4.6 shows that the number of patents issued to U.S. firms acquired by Swiss multinationals has risen considerably from a low of 6 in 1973 to a high of 91 in 1989.

[Insert Figure 4.5 Here]

[Insert Figure 4.6 Here]

2.3 U.S. Subsidiary Patenting by Technical Field

Figure 4.7 shows the distribution of U.S. subsidiary patenting across five broad technical fields over the 1973 to 1990 time period. The grouping of patent classes into technical fields was done based on a concordance developed by Jaffe (1986, 1989), which is reproduced in Appendix 2. To put those numbers in context, Figure 4.8 shows the sectoral breakdown of patents issued to *all* U.S. inventors during the same period. Across all eighteen years, chemical patents represent the largest area of U.S. subsidiary concentration, representing 37.6 percent of total subsidiary patents. In contrast, only 21.2 percent of all patents issued to U.S. inventors during this period were in chemicals-related patent classes (Figure 4.8). Drugs and Medical patents comprise between about 7 and 12 percent of the U.S. subsidiary total over this period, and are again over-represented relative to the U.S. total, which ranges between about 4 and 9 percent. The main area of *under*-representation in U.S. subsidiary patenting is

Mechanical Arts, which comprises about 15-20 percent of the U.S. subsidiary total versus about 25-30 percent of the U.S. total.

[Insert Figure 4.7 Here]

Although U.S. subsidiary patenting grew in absolute terms in all five technical areas, it grew faster in some areas than others. Electronic Arts, in particular, has grown rapidly over this period, from just over 10 percent of total U.S. subsidiary patenting in 1973 to nearly 30 percent in 1990. However, the most recent figure is approximately the same as the U.S. total in 1990. The difference is that U.S. inventors have always patented quite heavily in electronics - on average about 25-30 percent of their total. In other words, U.S. subsidiaries have historically been under-represented in terms of their emphasis on electronics relative to overall U.S. activity. As discussed below, part of the explanation for this pattern stems from the home country composition of U.S. subsidiary patenting - and changes in that composition over time. Within electronics, the areas of most rapid growth include Electrical Systems, Other Instruments, Office Equipment, and Telecommunications. Figure 4.9 shows the growth over time in subsidiary patenting in various sub-fields of electronics technology. Perhaps surprisingly, semiconductors remains relatively unimportant in the context of U.S. subsidiary activity in electronics since many of the better known examples of foreign firms targeting U.S. technology relate to semiconductors (e.g., Kim 1997)

Table 4.2 provides a more detailed picture of the sectoral composition of U.S. subsidiary patenting, its relationship to the overall pattern exhibited by U.S. inventors, and changes over time in these patterns. Patent classes are broken down into 33 fields of technology based on a concordance contained in Zander (1994) (See Appendix 3). The foreign-U.S. index (Column C) provides an indication of the intensity of subsidiary patenting in particular technical fields and how it has changed over three time periods: 1973-1978; 1979-1984; and 1985-1990. Scores over unity indicate that U.S. subsidiaries are more involved in these fields than other U.S. inventors; scores less than unity indicate the reverse. Thus U.S. subsidiaries show an especially high propensity to patent in Pharmaceuticals, Other Organic Chemicals, and Chemicals Processes relative to patenting by all U.S. inventors. Areas of relative de-emphasis include Aircraft, Textiles and Wood Products, and Nuclear Reactors.

[Insert Table 4.2 Here]

A question that emerges from the preceding analysis is whether the technical foci of U.S. subsidiaries tends to reflect areas of specialization of the home country, the host country, or both. The traditional innovation-based theory of the multinational firm dating back to Vernon (1966) suggests that foreign operations (not just R&D operations) will tend to reflect capabilities that derive from the institutional landscape of the home base. According to this view, patenting activity of U.S. subsidiaries can be expected to reflect traditional areas of technical strength of the parent firm's country of origin. However, as discussed in Chapter 2, a more recent conjecture in the multinational literature is that firms may be "pulled" to foreign centers of innovation in order to take advantage of the knowledge resident there, suggesting that U.S. subsidiary patenting might also reflect strengths of the host country (or region). Of course, as many scholars have noted, these conceptions are not mutually exclusive:

foreign investment clearly encompasses both "technology push" and "technology pull" modes.

Table 4.3 provides some initial evidence of how the technical activities of U.S. subsidiaries relate to the technological specializations of home and host countries. The measure used to capture the technological specialization of a particular location is the widely used index of "revealed technological advantage" or RTA (Cantwell 1989; 1993; Dunning and Narula 1995). RTA is analogous to measures of comparative advantage used in the trade literature and simply represents the extent to which a particular location accounts for a disproportionate share of patenting in a technical field relative to its share of patenting in all technical fields. RTA is calculated at the level of the patent class (3-digit level). In Table 4.3, I calculate separate RTAs for the U.S. as a whole and for each state. The state level figures, which will tend to capture regional effects such as the specialization of Silicon Valley in electronics fields, reflect the weighted average state RTA for all U.S. subsidiary patents. At the country level, the regional diversity will, of course, be lost due to the effects of aggregation. However, the country-level figures are still interesting in that this is typically the level that the debate about "technology seeking" FDI is cast. Formally, RTA is given by:

$$RTA_{ij} = (P_{ij} / \Sigma P_{ij}) / (\Sigma P_{ij} / \Sigma_i \Sigma_j P_i)$$

Where i = patent class i; and
j = location j

Table 4.3 shows the average home country RTA, host country (i.e., U.S.) RTA, and host state RTA for U.S. subsidiary patents issued to firms from the major home countries. Average scores above unity indicate that subsidiary patenting is concentrated in technical fields representing specializations of the focal location. Scores below unity indicate relative disadvantage, or lack of specialization in the particular technical area. The figures in brackets represent the proportion of subsidiary patents that have RTAs greater than one for the particular location. The data are divided into three time periods: 1973-1978, 1979-1984, and 1985-1990. Interestingly, Table 4.3 suggests that the patenting activities of U.S. subsidiaries are in technical fields that are well supported both at home and in the U.S. For every country and in each of the three time periods, the average home country RTA of U.S. subsidiary patents is greater than one. In addition, the proportion of U.S. subsidiary patents with home country RTAs greater than one is generally more than half, with Swiss, Japanese, Swedish and German firms showing consistently high propensities to patent in areas of home country specialization. Swiss firms have a particularly strong home country orientation. In the 1973-1978 period, over 80 percent of their U.S. subsidiaries' patents were in patent classes for which Switzerland was relatively advantaged (i.e., RTA > 1). This figure has dropped over time to 76.2 percent in 1979-1984 and 61.0 percent in 1985-1990. That Swiss firms are so focused on technical areas of home country specialization is not altogether surprising since one of the main motivations cited by these firms for locating R&D activities abroad is to offset shortages (and the high cost) of skilled technical personnel in Switzerland. In that sense, the overseas technical activities of Swiss firms appears to reflect less a strategy of seeking leading edge and/or heterogeneous sources of technical knowledge than it does a strategy of supplementing the existing technological resources of the firm.

[Insert Table 4.3 Here]

RTA scores for the host country (i.e., the U.S.) and host state are also interesting: state-level scores are particularly high, suggesting that multinationals tend to site their technical facilities in locations that specialize in fields of technology that the subsidiary is working on. It remains for the remainder of the thesis to demonstrate that foreign subsidiaries in these locations are actually drawing upon the technical knowledge that is resident there. The state-level RTA scores presented in Table 4.3 certainly support at least the face validity of the "tapping" hypothesis. In contrast, the U.S.-level scores do not provide a clear pattern. Across all three time periods, firms from about half the home countries have average US RTA scores greater than one and half below one. In the most recent period, 1985-1990, Japanese firms have the lowest average US RTA (.92); and only 39.1 percent of their U.S. subsidiaries' patents are in technical fields in which the U.S. is comparatively advantaged. The finding contradicts to some extent the popular wisdom that Japanese firms have been especially aggressive in seeking U.S. sources of high technology (Teece 1992; OTA 1994).

As a way of providing more context to the numbers presented in Table 4.3, Figures 4.10 - 4.13 show the evolution of subsidiary patenting by home base of the parent firm in four of the five broad technical areas used earlier (the residual category "Other" is not shown). As in the earlier area charts, the countries are stacked from bottom to top in terms of total patents for the combined 1973-1990 period. So, for example, in chemicals-related patent classes (Figure 4.10) U.S. affiliates of German firms had the highest number of patents followed by affiliates of firms from

Switzerland, the Netherlands, and Great Britain. This pattern is hardly surprising given the historical strength of these countries in chemical industries. The pattern in Drugs and Medical Technology (Figure 4.11) is also consistent with long-standing areas of country specialization: subsidiaries of Swiss firms had the largest number of patents in this area, followed by German and British firms. The major firms involved are some of the dominant players in the drug and medical industries: Roche, Ciba-Geigy, Bayer, Siemens, Glaxo, Wellcome. The traditional weakness of Japanese firms in chemical and pharmaceutical industries shows up in their negligible volume of U.S. subsidiary patenting in these technical areas (Figures 4.10 and 4.11), although in recent years Japanese pharmaceutical firms such as Fujisawa, Otsuka, and Yamanouchi have established technical facilities in the U.S. In contrast, subsidiaries of Japanese firms have a much greater presence - and a rapidly growing presence - in electronics and mechanical-related patent classes (Figures 4.11 and 4.12). The expansion of U.S. technical activity by Japanese firms in these two sectors reflects the growing stature and international presence of electronics firms such as NEC, Sony, Ricoh, Toshiba, and Hitachi over this period. In mechanical-related patent classes, Japanese firms such as Honda, Nissan, Aisin Seiki, Komatsu and Yamaha have significantly increased their U.S. technical presence in recent years. Surprisingly perhaps, U.S. subsidiaries of French firms were issued the largest number of electronics patents over the 1973-1990 period. However, the rapid expansion of U.S. electronics activity by French firms is explained in large part by major acquisitions, such as Schlumberger's 1979 acquisition of Fairchild and Group Bull's 1986 acquisition of Honeywell's computer operations, although direct investments by companies such as Alcatel and Thomson also played a role.

[Insert Figure 4.10 Here]

[Insert Figure 4.11 Here]

[Insert Figure 4.12 Here]

[Insert Figure 4.13 Here]

2.4 Geographic Patterns

Having discussed the volume and composition of U.S subsidiary patenting in some detail, I turn now to explicit consideration of its geography. Table 4.4 shows the state-level distribution of U.S. subsidiary patenting activity. The left side of Table 4.4 shows the total number of patents issued to U.S. subsidiaries by their state of origin; the right side shows the total number of patenting subsidiaries by state. Table 4.4 makes clear that, at the state level, the economic geography of U.S. subsidiary patenting is highly concentrated. Over 50 percent of all U.S. subsidiary patents originate in just four states: New Jersey, Texas, California and New York. Nine states are host to over 50 percent of all patenting subsidiaries.

[Insert Table 4.4 Here]

Looking at Table 4.4, it is possible to discern at least four major geographic centers of subsidiary patenting activity. California stands by itself as a major magnet for foreign technical activity, with nearly 10 percent of all patenting subsidiaries and 12 percent of all U.S. subsidiary patents over the combined 1973 to 1990 period. Within

California, virtually all patenting activity is located in either the San Francisco-Oakland-San Jose region, which includes Silicon Valley, or the Los Angeles basin (Los Angeles-Riverside-Orange County). A second major concentration, in fact the largest, is what might be termed "Metro Northeast", including the New York City-New Jersey-Philadelphia area and extending north through Connecticut to Boston, Massachusetts. Together, these five states are host to nearly 30 percent of all patenting subsidiaries and over one-third of all subsidiary patents. A third concentration is in the industrial states of Michigan, Ohio, and Illinois, with major centers in the Detroit-Ann Arbor and Chicago-Gary-Kenosha areas, and lesser concentrations in the "automotive corridor" from Detroit down through Akron, Ohio. Another area of concentration, although more dispersed, might be termed the "New South", with a corridor extending from Washington, D.C. in the north down through Boca Raton, Florida in the south. An increasingly important anchor to this region is the Research Triangle area of North Carolina (Raleigh-Durham-Chapel Hill). Over the 1973 to 1990 time period, North Carolina ranked seventh in terms of total subsidiary patents, and thirteenth in number of patenting subsidiaries. However, it also experienced the most rapid growth of any state in terms of the number of U.S. subsidiary patents it was home to during this period. From just seven subsidiary patents in 1973, North Carolina claimed 132 in 1989. Texas is also an important state for U.S. subsidiary patenting. Houston is home to Royal Dutch Shell, which has had a major technical presence in the Houston area for a long period of time. Another concentration is evident in the Dallas-Ft. Worth area, which has become an increasingly important center for electronics (especially telecommunications) activity: Northern Telecom, Siemens, Alcatel, Thomson, Fujitsu and Ericsson all have technical facilities there.

Table 4.5 provides a further breakdown of the economic geography of U.S. subsidiary patenting. Table 4.5 moves the geographic analysis from the state level to the level of the BEA region. It also provides a sectoral breakdown, by again dividing subsidiary patents into five broad technical areas (four are presented; "Other" is again not shown). For each technical area, the left hand side (Columns A-D) shows the total number of patents originating in the top 10 BEA regions over three time periods: 1973-1978; 1979-1984; 1985-1990. The right side (Columns E-H) shows the number of subsidiaries in each location that filed at least one patent in the particular technical area during these time periods.

[Insert Table 4.5 Here]

The juxtaposition of location and technology in Table 4.5 demonstrates even more clearly the concentrated geographic nature of U.S. subsidiary patenting. The New York-New Jersey-Long Island region emerges as a major U.S. location in all four technical areas. However, it is dominant in only two - Chemicals (Excluding Drugs), and Drugs and Medical Technology -- due in large part to the activities of the major Swiss and German chemical multinationals such as Roche, Ciba-Geigy and Hoechst, all of whom have had important technical facilities in this area for many years. Along with the "Metro Northeast" region stretching from Philadelphia to Boston, other important areas of foreign technology development in chemicals include Houston (largely attributable to the activities of Royal Dutch Shell), San Francisco and Detroit-

Ann Arbor. San Francisco-Oakland-San Jose experienced the most rapid growth over the three periods shown from only 28 subsidiary patents between 1973 and 1978 to 192 in the 1985-1990 period.

In electronics, along with the New York area, the two main economic regions in California anchored by the cities of San Francisco and Los Angeles are important hosts to U.S. technical units of foreign multinationals. The San Francisco-Oakland-San Jose region (which includes Silicon Valley) experienced particularly rapid growth during the 1973 to 1990 time period. The number of patenting subsidiaries in the region has risen by a factor of three from 16 to 53, and the number of patents issued to these subsidiaries has skyrocketed from only 66 in the 1973-1978 period to over four hundred in 1985-1990. The Boston area, including the Route 128 technology district, is another location that has experienced rapid growth in the amount of foreign electronics activity it is host to. U.S. subsidiary patenting in this area grew by more than a factor of five, from only 31 patents between 1973 and 1978 to 174 in the 1985-1990 period. Although this growth is attributable in part due to the acquisition of Honeywell's computer operations by the French firm Group Bull, the number of patenting subsidiaries in this region has also nearly tripled over the same period due to investments by, among others, major Japanese electronics firms such NEC, Canon, Hitachi, and Minolta.

In Mechanical Arts, the Detroit-Ann Arbor region has grown rapidly over the eighteen year period covered by the data, especially in the most recent six year period shown. Although it was home to fewer patenting subsidiaries than the New York-New Jersey area, there were more patents generated by U.S. subsidiaries in Detroit-Ann

Arbor. In fact, in the 1985-1990 period, Detroit-Ann Arbor was home to half again as many subsidiary patents as the New York area, 144 compared to 95, a 144 percent increase over its total in the 1979-1984 period. Not surprisingly, the growth in foreign technical activity in this area is focused around automotive technology, with suppliers such as Siemens, Magna, Lucas Industries, Automotive Products, GKN, Robert Bosch and Fanuc all having patenting units in this area along with at least two of the major Japanese automobile manufacturers, Mazda and Toyota.

Finally, Table 4.6 shows the geographic distribution of U.S. subsidiary patenting by home base of the parent firm[8]. The numbers shown represent the proportion of total patents accounted for by each BEA region over the 1973-1990 time period. With the exception of Swedish firms, the thirteen BEA regions that were named at least once in Table 4.5 are home to over half of all U.S. subsidiary patents issued to firms from the major home countries. Patenting by Swiss firms is especially concentrated with 60 percent of these firms' U.S. subsidiary patents originating in the New York area. As suggested earlier, the impact of Royal Dutch Shell's Houston-based technical facilities shows up clearly in these data: Houston-Galveston is home to 46 percent of Dutch firms' U.S. subsidiary patents. The patenting activities of Japanese multinationals are concentrated in the two main regions of California (San Francisco area: 17.4 percent; Los Angeles area 19.5 percent), a finding that is also highlighted by Florida and Kenney's (1995) analysis of Japanese R&D units in the U.S.

[Insert Table 4.6 Here]

3. Selected Corporate Level Indicators

Having discussed the evolution, composition, and economic geography of U.S. subsidiary patenting, this section shifts the level of analysis to the corporation, focusing in particular on the patenting activities of the relatively small number of parent firms that dominate foreign technology development in the U.S. Table 4.7 shows the top twenty patenting firms, ranked by the total number of patents generated by their U.S. subsidiaries during the combined 1973-1990 period. These twenty firms accounted for nearly three quarters of all U.S. subsidiary patents during this period. Table 4.7 also shows the average number of patents issued to each firm in each year, the total number of distinct patenting subsidiaries over the eighteen year period, and the average number of U.S. subsidiaries to apply for (and eventually receive) a patent in each of the eighteen years.

[Insert Table 4.7 Here]

The firms listed in Table 4.7 are noteworthy for being heavily oriented toward chemicals industries, and all from Europe: 5 German firms, 5 British firms, 4 Swiss firms, and 3 firms each from the Netherlands and France. Although over 100 Japanese firms had at least one patenting subsidiary in the U.S. during the 1973-1990 period, the heavy concentration of these firms' activities in electronics (where the propensity to patent is lower than in chemicals-related sectors) and their relatively recent entry into the U.S. prevented them from making the top 20 list. The Japanese firm with the largest number of U.S.-originating patents was Dainippon Ink and Chemicals (83 patents, rank 42nd), due entirely to its acquisition of two U.S. chemicals' firms, Polychrome Corporation, and Sun Chemical. Other Japanese firms with a major U.S. technical presence include Ricoh (82 patents, rank 43rd), Yamaha (75 patents, rank 45th) and Toshiba (71 patents, rank 49th).

Also noticeably absent from Table 4.7 are multinationals from Canada and Sweden. The largest Canadian firm, International Nickel, had 158 patents, all of them before 1985. In contrast, Northern Telecom, the next largest Canadian firm measured by number of U.S. subsidiary patents, had a total of 149 patents, most of them for technical activities conducted in the mid to late 1980s. It ranked 24th among all multinational firms. Moore, the Canadian business forms manufacturer, generated 139 patents in the U.S., ranking it 28th. Other Canadian firms with technical units in the U.S. include Massey-Ferguson (84 patents, rank 40th) and Alcan (60 patents, rank 56th). Among Swedish multinationals, Electrolux had the largest number of U.S. subsidiary patents (126, rank 30th), although many of these patents are attributable to its acquisition of White Consolidated Industries. Other important Swedish firms with patenting units in the U.S. include ABB (100 patents, rank 33rd); Kamyr (97 patents, rank 37th); and Alfa-Laval (72 patents, rank 47th).

Table 4.8 provides an indication of the time period in which major foreign firms established their technical facilities in the U.S. The three columns list the top 30 firms, ranked by number of U.S. subsidiary patents, for each of three entering cohorts: an early cohort, defined as firms with U.S. subsidiaries that filed their initial patent applications before 1979; a middle cohort (initial U.S. subsidiary patent application between 1979 and 1984); and a late cohort (initial U.S. subsidiary patent application after 1984). Not surprisingly, the top 20 patenting firms identified earlier are almost all early entrants. In fact, some of these firms, notably the Swiss multinationals, as well as Royal Dutch Shell and Unilever have had technical facilities in the U.S. since at least the Second World War. Group Bull, the only Top 20 firm not to appear in the early entrants lists is the exception that proves the rule: its large number of U.S. patents came completely as a result of its acquisition of Honeywell's computer business. Also interesting is how the home country composition of the early cohort differs from subsequent cohorts. Japanese firms are not represented in the top 30 firms of the early cohort. However, in the middle and late cohorts they have a total of 22 entries, more than one-third of the total. Firms from countries not heretofore mentioned also appear in the middle and late cohorts: Pacific Dunlop (Australia); Ahlstrom (Finland); Elscint (Israel); Elkem, Scandpower and Elopak (Norway); and Samsung (South Korea). Table 4.8 also highlights the obvious relationship between parent firm tenure in the U.S. and total number of patents generated there. The oldest cohort of firms have larger technical organizations in the U.S. as measured by total number of patents, total number of patenting subsidiaries (not shown) and average patents per unit (also not shown), suggesting an evolutionary expansion of foreign technical activity over time.

[Insert Table 4.8 Here]

Table 4.9 provides an indication of this evolutionary process for the Top 20 multinationals' identified earlier in Table 4.7. Although most of the firms on the list have increased their volume of U.S.-originating patents over the 1973-1990 time period, not all did so, and those that did, did so in different ways. For example, Table

4.9 highlights the significant *decrease* in patenting output generated by U.S. subsidiaries of the major Swiss chemical firms, Roche, Ciba-Geigy, and Sandoz. Roche, in particular, appears to have decreased its technical activity in the U.S. by a considerable margin, at least as measured by the number of patents issued to its U.S. organization, and by the number of patenting subsidiaries in the U.S. it controls. Total patents decreased from 667 in 1973-1978 to only 231 in 1985-90; the number of locations issued at least one patent declined from 12 to 9 over the same period; and the average output per patenting location declined by more than half, from 51.3 patents over the 1973-1978 period to 23.1 patents in 1985-1990. The only Swiss firm to expand its patenting activities in the U.S. during this period was Nestle, which increased its total patenting by a factor of four from 37 to 161 across the three periods shown. During this same period, the number of Nestle subsidiaries in the U.S. that filed patent applications nearly doubled, from 9 to 16, and output per unit more than doubled, from 4.2 to 10.1 patents.

[Insert Table 4.9 Here]

Multinationals that have substantially increased their U.S. technical activity over the eighteen year period covered by the data include Hoechst, Philips, Bayer and Siemens. Siemens had perhaps the most dramatic increase, from only 28 patents in 1973-1978 to 397 in the latest period. It also expanded its total number of U.S. patenting units from 12 to 34 over the same period, and patents per unit increased from only 2.3 patents to 11.7 patents. In the 1985-1990 period, Siemens had the second highest number of patenting subsidiaries. The firm with the most patenting subsidiaries, Philips, more than doubled its total to 40 from 18 in the earliest period. Note that for some firms, notably Wellcome and ICI, the expansion in U.S. technical activity was due to major increases in output (patents per location) from a relatively stable number of technical subsidiaries. Total patenting locations for Wellcome actually decreased from 7 to 5 across the three periods while the number of patents issued to these units more than doubled from 47 to 113. Virtually all of this increase came from the company's technical facility in Research Triangle, North Carolina, which, among other things, is noteworthy for its work on AZT, the company's blockbuster AIDS drug. Patents issued to this facility rose from 34 in 1973-1978 to 80 in 1979-1984 and again to 106 in the 1985-1990 period. ICI also doubled its patenting during this period, from 144 in 1973-1978 to 327 in 1985-1990, while maintaining relatively constant its total number of patenting subsidiaries. As a result, average patents per unit increased from 16.3 to 23.4 over this time.

Table 4.10 places the scope of these firms' U.S. technical operations in the context of the overall technical activity of the firm. For each firm, Table 4.10 shows the total number of patents issued to its worldwide operations during three time periods between 1973 and 1990, the proportion accounted for by U.S. subsidiaries, and the proportion accounted for by technical units in the firm's home base. The fourth column "Herf" provides an indication of the worldwide geographic dispersion of these firms' patenting activities using a Herfindahl-type measure of geographic concentration[9]. Herf ranges between 0 and 10,000: a score of 10,000 indicates complete concentration of the firm's patenting activities in one country; lower scores indicate greater dispersion.

[Insert Table 4.10 Here]

Table 4.10 highlights the substantial variation across major multinational firms in the importance of the U.S. as a technical center. Only two firms, Royal Dutch Shell and Schlumberger, generated more than 50 percent of their total patents in the U.S. in each of the three time periods shown. In contrast, nine firms had *home* country concentrations of greater than fifty percent in each period: all five German firms, Hoechst, Bayer, BASF, Siemens, and Henkel; the British firms ICI and GEC, as well as Ciba-Geigy and the French electronics firm Thomson. Looking at the Herfindahl scores, multinationals with relatively geographically dispersed technical operations (lower scores on "Herf") include Philips, Akzo, Nestle, and Unilever. Firms with geographically concentrated technical activities over all three time periods include Bayer, BASF, Siemens, GEC and Henkel. The strong home-country orientation of the major German multinationals shows up strongly in all of these measures.

Overall, the U.S. increased in relative importance for most of the firms listed in Table 4.10. Only four firms saw the proportion of total company patents accounted for by U.S. operations decrease over the earliest to latest time periods: Roche, BASF, Schlumberger, Sandoz and Akzo. Firms registering major increases in U.S. patents as a percentage of total company patents include Hoechst, Siemens, ICI, Bull, GEC, Thomson, and BOC. Three firms saw the U.S. overtake the home country as the firm's largest patenting location: BOC, Wellcome, and Bull. In the case of BOC and Bull, the increase was due to acquisitions: Airco, Murex, and Anaquest (BOC) and Honeywell Information Systems (Bull). A more complete list of important U.S.

acquisitions by foreign multinationals is presented in Table 4.11. Entries in italics indicate the Top 20 firms, which account for 20 of the 45 entries.

[Insert Table 4.11 Here]

3.1 Technological Evolution of U.S. Subsidiaries

The previous section highlighted the corporate concentration of foreign patenting activity in the U.S. and provided an indication of the growth and evolution of the major firms' U.S. technical activities over time. I turn finally to a consideration of the *technological* evolution of these firms' U.S. activities, i.e., whether and in what direction their technological foci and fields of specialization have changed over time. This issue is particularly important to the research questions addressed in this thesis, touching as it does on the idea that multinational firms might seek to develop new technological capabilities by innovating in areas of host country competence and specialization. Section 2 of the current chapter provided some evidence that firms seek to match the technical activities of their foreign subsidiaries with areas of specialization in the host country, especially at the regional, i.e., sub-national, level. However, the same analysis also revealed that, at the population level, U.S. subsidiaries tend to participate in fields of technology that represent specializations of *both* home and host countries. One explanation for this result is that the technical activities of foreign subsidiaries evolve over time away from fields of home country specialization and toward fields of host country specialization. This explanation can only be investigated at the corporate level, by examining the evolution of individual firm's technological positions over time and how this evolution relates to fields of home and host country specialization.

Table 4.12 provides some initial evidence of the extent to which the Top 20 firms have shifted the focus of their technical activities over time. For each of three time periods, Table 4.12 lists the top three fields of U.S. subsidiary patenting for the firm in rank order by number of patents in that field. Patent classes are again aggregated into broader fields of technology using the concordance listed in Zander (1994) (Appendix 3). Interestingly, Table 4.12 suggests that the top technical fields of the major firms' U.S. operations are quite stable over time. For five of the twenty firms shown, the top three technical areas in 1973-1978 remained unchanged through 1979-1984 and 1985-1990, although in some instances the rank order of the three areas did change. The five firms are Roche, Bayer, Siemens, Bull and Wellcome.

[Insert Table 4.12 Here]

The remaining fifteen firms saw the substitution of at least one new technical area in their top three. In some cases, the substitution was the result of rapid increases in patenting in technical fields not previously emphasized. In other cases, certain technical areas were de-emphasized over time and dropped off the list. Ciba-Geigy is an example of the former path, i.e., of rapid increases in a new technical field, in this case, Electrical Systems. Interestingly, this new capability is the result of acquisition activity, in particular its acquisition of the U.S. electronics firm Spectra-Physics. This is a recurrent pattern. For example, Nestle's shift into Other Instruments in the last period shown is clearly the result of its acquisition of Alcon Laboratories. ICI's expansion into agricultural chemicals technology in the U.S., also in the final period, is explained partly by its acquisition of Stauffer Chemicals.

Royal Dutch Shell is an example of the latter evolutionary path, i.e., of technical reorientation by de-emphasizing or dropping altogether particular fields of technology. In the 1973-1978 time period, Shell's facilities in Houston and California were engaged in a considerable amount of pharmaceutical-related technical activity. The Houston facility received a number of patents for its work on lipogenesis inhibitors. However, after about 1984, this work disappears from the patenting record. Similarly the work of Shell's California facility in pesticides technology (which often is patented in Patent Class 514, Drug, Bio-Affecting and Body Treating Compositions) does not appear in the patenting record in the later part of the 1980s. In contrast, patenting by the Houston facility in the company's more traditional area of focus, Coal and Petroleum Products, increased during this period, from only 68 patents in the twelve year period from 1973-1984 to 87 patents in the six years between 1985 and 1990. The California facility also appears during this time to have reoriented itself around the area of organic chemistry, again a more traditional technical focus of the firm. As a result of these changes, Pharmaceuticals is dropped from the company's top 3 areas after the initial 1973-1978 period, and Other Organic Chemicals, and Coal and Petroleum products are added.

Table 4.13 provides a more general set of measures to illustrate the degree to which the Top 20 firms' U.S. technical activities have changed over time. The numbers shown in the middle three columns are phi-square distance measures, which capture the dissimilarity of the technological distribution vectors of each firm's U.S.

patenting activities across three time periods[10]. Higher numbers indicate greater distance. The final column provides explanatory comments that highlight the nature and source of significant changes in the technological focus of the firms' U.S. operations.

[Insert Table 4.13 Here]

The phi-square measures highlight a somewhat different set of companies with highly stable technological positions over time than does the "Top 3" analysis contained in Table 4.12. This is because the phi-square measure captures changes in the overall patenting profile of the firm's U.S. operations, not just changes in the top three fields. Hoechst, Philips, Unilever, Siemens, Henkel, and Nestle emerge from this analysis as firms with quite stable technological positions over time (phi-square measures less than .40 across all period to period comparisons). Firms with more variable positions include GEC (due entirely to its acquisition of Picker International), Akzo, ICI, Ciba-Geigy, and Roche.

Overall, Table 4.13 shows that the technological positions of the firms' U.S. patenting activities were most stable across the middle and late periods, i.e., between 1979-84 and 1985-90 (average phi-square, 0.43). The periods furthest apart in time, 1973-78 and 1985-90, are also the most technologically distant (average phi-square, 0.49). In fact, the modal pattern across firms is one of considerable change between the first and second periods, followed by relative stability between the middle and late periods, i.e., the new position developed in the middle period is sustained and/or reinforced in the final period. Thus, the first and last periods tend to be most technologically distant. Acquisitions clearly play an important role in major shifts in technological position. However, in the case of firms like Shell, ICI, and Roche, changes in technological position are also driven by the reorientation of greenfield subsidiaries, either through expansion, contraction, or both (i.e., contraction in some areas, expansion in others).

The data presented so far provide some evidence that the U.S. activities of the Top 20 firms have evolved technologically over time, although the extent of this evolution varies considerably across firms and time periods. This raises two important questions. First, whether the evolution is toward fields of technology that are new to the overall firm, not just to the U.S. organization. And second, whether the technological evolution is away from fields that represent traditional specializations of the home country and toward fields that represent fields of host country expertise.

Table 4.14 provides some indication of the extent to which entry into new technical fields by U.S. subsidiaries also represents entry into distinctly new areas of technology for the firm. Table 4.14a lists the new technical fields entered into by U.S. subsidiaries of the Top 20 firms during the 1979-84 period. In other words, the fields shown represent areas in which U.S. subsidiaries of these firms had no presence in the earlier 1973 to 1978 period. The far right column indicates with an asterisk whether or not the headquarters organization of the parent firm (defined as any technical unit in the home country) had any activity in this field during the entire period through 1979. Overall, Table 4.14a suggests that there is little entry by U.S. subsidiaries into fields of technology that are distinctly new for the firm. Areas that are new to the firm (indicated by the asterisk) tend to be those in which the U.S. organization patents rather lightly. Schlumberger's entry into semiconductors is perhaps an exception, and stems from its acquisition of Fairchild.

[Insert Table 4.14a and 4.14b Here]

Table 4.14b presents the same set of indicators for the 1985-90 period. Technical fields listed are those in which U.S. subsidiaries had no technical presence during the twelve prior years from 1973-1984 period. The asterisk in the far right column again indicates the absence of any headquarters' patenting in that field for the entire 1973-1990 period. U.S. subsidiaries of the British companies BOC and GEC stand out as providing a relatively high level of new technical field entry, and in the case of BOC in Inorganic Chemicals, a fairly sizable number of patents. Most of the other fields of significant subsidiary patenting, such as Ciba-Geigy's patenting in Electrical Systems, and Siemens's patenting in Motor Vehicles and General Industrial Equipment are in areas in which the parent organization has at least some technical presence.

Table 4.15 provides a more general set of measures of technological distance between U.S. subsidiaries and headquarters organizations for the twenty largest firms, and how that distance has changed over three time periods. The measure used is again the phi-square distance measure which captures the dissimilarity of the technological distribution of patenting by the two organizations (all of a firm's U.S. subsidiaries' patents are pooled for the purposes of this analysis) across thirty-three fields of technology. As before, larger numbers indicate greater distance between the technological positions of the headquarters organization and the U.S. organization. So, for example, the results for Siemens show that the U.S. organization was in the initial 1973-1978 period quite technologically similar to the parent organization (phi-square = .10), but that over time the two organizations moved further apart in terms of the techological focus of their patenting activities: in the middle 1979-1984 periods, the phi-square measure is .17; by the latest period (1985-1990), the measure was .27. Across all twenty firms, the average technological distance between U.S. and headquarters organizations remains relatively constant (phi-square measures of .32, .33, .34, for the three periods). However, these aggregate scores once again mask considerable variation at the level of the firm. The modal pattern is one of *increasing* technological differentiation over time: about half of the firms exhibit this pattern. A smaller number of firms (6) exhibit the opposite pattern: decreasing differentiation, i.e., the two organizations occupy closer technological space over time. The remaining four firms (Hoechst, Schlumberger, Nestle, and Wellcome) do not exhibit a clear secular evolution.

[Insert Table 4.15 Here]

Finally, Table 4.16 provides an indication of the extent to which the technological evolution of the major firms' U.S. operations coincides with fields of home and/or host country specialization. For each of three locations -- home country, host country (i.e., the U.S.) and host state -- the columns show the proportion of each company's U.S. subsidiary patents that are in fields of technological specialization of that particular location. As before, a location is deemed to specialize in a particular technical area when its proportion of total U.S patents in that area is greater than its proportion of total U.S. patents in all technical areas. This is the measure of "revealed technological advantage" discussed earlier in Section 4.2.

[Insert Table 4.16 Here]

Table 4.16 shows an overall modest evolution away from fields of home country specialization and toward fields of host country and host state specialization. However, the overall pattern, reflected in the average scores at the bottom of the table, hides considerable variation across firms in the directionality of their technological evolution. Only nine of twenty firms decreased the percentage of U.S. subsidiary patents in areas of home country specialization. However, fifteen firms (3/4 of the top 20) increased the proportion of patenting in fields of U.S. specialization. This movement also shows up in the quite large secular increase in the average proportion of patenting in fields of U.S. specialization: from 33.1 percent in 1973-78 to 45.1 percent in 1985-90. Ten firms increased the proportion of patenting in fields of host state specialization, although the proportions at the state level remain quite high across all three time periods.

4. Conclusion

This chapter has presented descriptive information and some preliminary analysis of the patenting activities of U.S.-based subsidiaries of foreign multinationals. The objective of the chapter was to provide the background information needed to place the citation analysis contained in the remaining empirical chapters into perspective, and to provide context for the results that follow.

Overall it was shown that technical activity conducted by U.S. subsidiaries has increased considerably over time, both as the result of the expansion of greenfield subsidiaries and as a result of the acquisition of U.S. technology firms by foreign multinationals. U.S. subsidiary patenting is concentrated, both technologically and geographically. Chemicals-related technologies compose the largest number of U.S. subsidiary patents, followed by Drugs and Medical Technology, Electronics Arts, and Mechanical Arts. Overall, U.S. subsidiaries have tended to over-emphasize Chemicals (Excluding Drugs), and Drug and Medical Technology relative to the overall pattern exhibited by U.S. inventors. Electronics has experienced the most rapid growth over time in terms of number of U.S. subsidiary patents. Geographically, patenting subsidiaries are concentrated in the "Metro Northeast" region, California, and the industrial states of Illinois, Michigan, and Ohio. Regions experiencing rapid growth in the amount of foreign technical activity include the "New South", especially the area around Research Triangle, North Carolina, and the Dallas-Ft. Worth area, especially in electronics activity. The San Francisco-Oakland-San Jose area also experienced a large increase in the volume of U.S. subsidiary technical activity, especially in electronics-related fields.

It was shown that U.S. subsidiary patenting is dominated by about twenty major firms, mostly chemicals firms, and all from Europe. Most of these firms have had U.S. technical units for many years, some dating back to the period of World War II. In recent years, Japanese firms have rapidly increased their U.S. technical presence, both through acquisitions and direct greenfield investment.

During the 1973-1990 period covered by the data, most of the twenty largest firms expanded their U.S. technical activities, and in some cases the U.S. emerged as the single largest country in terms of number of patents generated by the worldwide organization. However, even as recently as 1985-1990, half of the Top 20 firms generated more than 50 percent of their total patents in the home base.

The patenting record of the Top 20 firms reveals both stability and change in the technological foci and specializations of their U.S. technical organizations. About one-quarter of the firms remained heavily focused in the same areas of technology over the entire eighteen year period. Others experienced much more change in their technological positions, both as the result of acquisition activity and of reorientation - decreasing activity in some areas and increasing it in others. Overall, there is little evidence to suggest that U.S. subsidiaries were responsible for introducing distinctly new areas of technology to the parent firm during this period. However, some evidence was provided showing that the direction of these firms' technological evolution tends to be away from areas of home country specialization and toward areas of host country and host state specialization. Again, however, the overall pattern masked considerable variation across firms in this regard.

Endnotes

[1] It should be noted that the chart indicates the number of *successful* patent applications, i.e., applications for patents that were eventually issued by USPTO through 1992. There are no data on unsuccessful patent applications.

[2] The phrase "all U.S.-based inventors" does not imply that these are only patents issued to individuals. Although patent applications require the name and address of the inventor (an individual), the vast majority of patents are assigned to the companies that these individuals work for. In other words, firms are not excluded

[3] This understates the xxxxxxxxx Dof Commerce definition [xxx see paper 3].

[4] "New parent firm entry" is defined as xxxxx.

[5] Obviously, the date of first patent application does not correspond to the actual entry date of the subsidiary. Entry here means "entry into the population of patenting subsidiaries" rather than physical establishment of the unit. It would, of course, be interesting to know the actual date of establishment and to examine the lag between establishment and first patent. However, establishments dates for a large sample of subsidiaries is impossible to obtain.

[6] Note that many of the subsidiaries in the 1973 cohort will actually be much older than is indicated by their first patent, since the database contains patents going back only as far as 1975. Hoffman la Roche, for example, established a U.S. R&D facility in xxxxx as a way of xxxxxxxxxxxxxxx.

[7] The decrease from 1989 to 1990 is once again most likely due to the fact that not all of the patents applied for in 1990 had been issued by the end of 1992, the latest point in the main patent dataset.

[8] It should be borne in mind that the numbers do not control for differences in the propensity to patent across technical fields. For example, the finding that 60 percent of Swiss firms' U.S. subsidiary patents originate in the New York area is due, in part, to the high propensity to patent in chemicals and pharmaceuticals, where the major Swiss firms specialize. Ideally, one would provide an analogous comparison using a pure "input" measure of technical activity, such as R&D expenditures. Unfortunately, such data are simply not available at the level of the subsidiary.

[9] The formula is:

[10] For each period, the firm's U.S. subsidiary patents are classified into 33 fields of technology using the concordance in Zander (1994). The resulting distribution vectors are then compared. The phi-square measure is appropriate for the count data contained in each vector. It is similar to the chi-square measure of dissimilarity except that it attempts to take sample size (i.e., total number of patents) into account to decrease the effect of the actual observed frequencies on the value of the measure.

Table 4.1 U.S. Subsidiary Patenting by Home Base of Firm, 1973-1990

	Total Patents	Percent of Total	Cumulative Percent	Average Annual Growth	Percent Acquisitions	Total Patenting Subsidiaries	Total Parent Firms	Major Firms
Germany	5060	22.9	22.9	18.8	43.5	387	100	BASF, Bayer, Daimler-Benz, Henkel, Hoechst, Schering, Siemens
Great Britain	3846	17.4	40.3	10.3	43.3	408	85	BOC, ICI, GEC, Glaxo, Siebe, Unilever†, Wellcome
Netherlands	3831	17.3	57.7	10.4	8.8	133	12	Akzo, Philips, Shell‡
Switzerland	3603	16.3	74.0	0.8	13.5	204	37	Ciba-Geigy, Nestle, Roche, Sandoz, Sulzer Brothers, Swiss Aluminium
France	1907	8.6	82.6	18.8	37.4	146	26	Alcatel, Bull, Elf Aquitaine, L'Air Liquide, Rhone Poulenc, Schlumberger, Thomson
Japan	1508	6.8	89.4	22.7	12.3	342	139	Aisin Seiki, Bridgestone, Hitachi, Ricoh, Sony, Toshiba, Yamaha
Canada	825	3.7	93.2	6.0	6.7	137	35	Alcan, Moore, Northern Telecom, Polysar
Sweden	727	3.3	96.5	21.5	34.3	168	35	ABB§, Alfa-Laval, Electrolux, Esselte, Ericsson, Kamyr, Sandvik
Italy	252	1.1	97.6	17.7	40.1	49	14	Fiat, Montedison, Pirelli
Belgium	199	0.9	98.5	17.9	81.4	22	4	Petrofina, Solvay

† Unilever is Anglo-Dutch. It is classified here as a British firm because the UK is the company's largest patenting location.

‡ Royal Dutch Shell is Anglo-Dutch. It is classified here as a Dutch firm because the Netherlands is the company's largest patenting location.

§ ABB is Swiss-Swedish. It is classified here as a Swedish firm because Sweden is the company's largest patenting location.

Table 4.2 Patents Issued to U.S. Affiliates, by Technical Field and Year of Application

	1973-1978			1979-1984			1985-1990		
	A	B	C	A	B	C	A	B	C
Technical Field	Foreign %	U.S. %	A÷B	Foreign %	U.S. %	A÷B	Foreign %	U.S. %	A÷B
Chemical processes	38.41	16.77	2.29	16.07	11.08	1.45	9.84	8.52	1.15
Pharmaceuticals	9.73	2.27	4.30	9.72	3.61	2.69	10.64	4.40	2.42
Other instruments	6.07	9.64	0.63	8.04	10.33	0.78	11.39	12.41	0.92
Other organic chemicals	5.82	1.79	3.25	15.07	5.78	2.61	18.69	5.56	3.36
Metallurgical processes	3.96	3.18	1.25	2.98	2.78	1.07	1.75	2.51	0.70
Specialized industrial equipment	3.96	6.68	0.59	3.10	5.54	0.56	2.90	5.02	0.58
Other metal products	2.61	7.39	0.35	2.73	6.85	0.40	2.76	7.88	0.35
Telecommunications	2.59	4.41	0.59	3.51	4.14	0.85	3.66	4.16	0.88
Electrical systems	2.57	6.44	0.40	5.82	6.58	0.88	6.24	6.91	0.90
General industrial equipment	2.25	6.40	0.35	1.87	5.67	0.33	2.74	4.60	0.59
Chemical and allied equipment	2.23	3.86	0.58	3.38	4.11	0.82	3.77	3.84	0.98
Non-metallic mineral products	2.04	2.78	0.73	2.29	3.22	0.71	2.91	3.67	0.79
Mining equipment	1.88	1.11	1.69	1.67	1.33	1.26	1.20	1.11	1.09
Assembly equipment	1.77	2.71	0.65	1.52	2.96	0.51	0.97	2.66	0.36
Image and sound equipment	1.71	1.12	1.52	2.41	1.58	1.52	1.97	1.56	1.26
Food and tobacco products	1.69	1.08	1.56	2.06	0.96	2.13	1.65	0.99	1.67
Metal-working equipment	1.37	2.50	0.55	1.23	2.44	0.50	1.13	2.18	0.52
Office equipment	1.20	2.34	0.51	5.30	3.97	1.33	4.87	4.31	1.13
Agricultural chemicals	1.07	0.65	1.66	1.14	0.63	1.81	0.86	0.48	1.80
Other transport equipment	1.05	2.13	0.49	1.12	1.70	0.66	0.59	1.95	0.30
General electrical equipment	0.97	2.67	0.36	1.21	2.89	0.42	1.73	2.35	0.74
Rubber products	0.80	1.00	0.80	0.91	0.97	0.93	1.19	0.82	1.44
Coal and petroleum products	0.78	0.94	0.83	1.21	1.41	0.86	1.02	1.05	0.98
Inorganic chemicals	0.76	0.86	0.88	1.04	0.86	1.22	0.76	0.57	1.33
Motor vehicles	0.70	1.75	0.40	0.97	1.43	0.68	0.94	1.36	0.69
Bleaching and dyeing processes	0.63	0.43	1.46	1.20	0.64	1.88	1.11	0.64	1.74
Other manufacturing	0.48	3.10	0.16	0.54	2.84	0.19	0.53	3.67	0.14
Semiconductors	0.29	0.48	0.61	0.38	0.43	0.90	1.21	1.31	0.93
Photographic instruments	0.25	0.78	0.33	0.63	0.75	0.84	0.27	0.63	0.43
Textiles and wood products	0.21	1.30	0.16	0.46	1.17	0.39	0.19	1.59	0.12
Power plants	0.13	0.94	0.13	0.23	0.68	0.34	0.35	0.59	0.59
Nuclear reactors	0.00	0.02	0.00	0.15	0.28	0.54	0.15	0.31	0.49
Aircraft	0.00	0.48	0.00	0.05	0.39	0.12	0.04	0.43	0.09

Table 4.3 Revealed Technological Advantage (RTA) of U.S. Subsidiary Patenting for Home and Host Country Locations

	1973-1978			1979-1984			1985-1990		
Home Base	Average Home RTA (% RTA>1)	Average US RTA (% RTA>1)	Average State RTA (% RTA>1)	Average Home RTA (% RTA>1)	Average US RTA (% RTA>1)	Average State RTA (% RTA>1)	Average Home RTA (% RTA>1)	Average US RTA (% RTA>1)	Average State RTA (% RTA>1)
Belgium	1.06 (50.0)	0.97 (32.8)	2.39 (53.4)	1.66 (62.1)	1.06 (55.2)	1.68 (60.9)	2.76 (68.5)	1.11 (59.3)	2.03 (83.3)
Canada	1.51 (56.1)	1.00 (48.1)	2.45 (72.4)	1.28 (51.6)	0.99 (44.4)	2.26 (75.8)	1.19 (50.3)	1.10 (66.6)	2.17 (73.4)
France	1.12 (55.1)	1.09 (73.9)	3.68 (76.7)	0.97 (35.3)	1.05 (66.3)	2.53 (85.2)	1.07 (45.8)	1.00 (52.8)	2.25 (77.4)
Germany	1.17 (60.3)	0.93 (30.9)	1.99 (68.7)	1.16 (57.7)	0.99 (46.7)	2.51 (70.5)	1.22 (61.5)	0.97 (41.4)	2.45 (77.0)
Great Britain	1.16 (62.1)	0.96 (39.6)	2.45 (72.2)	1.22 (53.6)	0.98 (46.1)	3.28 (75.4)	1.28 (57.3)	0.99 (45.9)	2.04 (73.3)
Italy	1.03 (34.7)	1.04 (53.3)	5.83 (86.7)	1.21 (50.6)	1.04 (60.5)	6.12 (82.7)	1.37 (50.0)	1.00 (45.8)	2.60 (67.7)
Japan	1.57 (69.8)	1.01 (66.7)	1.44 (72.3)	1.60 (72.5)	0.91 (34.8)	1.47 (61.9)	1.30 (58.2)	0.92 (39.1)	1.66 (63.3)
Netherlands	1.32 (48.3)	1.00 (43.5)	2.46 (61.5)	1.71 (56.3)	1.03 (56.1)	2.37 (71.1)	1.87 (58.2)	1.00 (48.3)	2.41 (76.0)
Sweden	2.51 (68.5)	0.98 (41.7)	1.54 (51.9)	2.02 (59.5)	1.03 (53.8)	2.11 (63.0)	1.93 (56.1)	1.06 (60.3)	2.07 (72.4)
Switzerland	1.98 (83.3)	0.90 (13.8)	1.74 (79.1)	2.04 (76.2)	0.95 (34.0)	2.09 (79.1)	1.68 (61.0)	0.98 (40.2)	2.84 (75.4)

Table 4.4 U.S. Subsidiary Patenting by State, 1973-1990

Number of Patents					Number of Patenting Subsidiaries*				
	State	Total	%	Cumulative %		State	Total	%	Cumulative %
1.	New Jersey	4142	18.8	18.8	1.	California	196	9.8	9.8
2.	Texas	2716	12.3	31.1	2.	New York	139	7.0	16.8
3.	California	2656	12.0	43.1	3.	New Jersey	138	6.9	23.7
4.	New York	1752	7.9	51.0	4.	Pennsylvania	120	6.0	29.7
5.	Michigan	1392	6.3	57.3	5.	Ohio	98	4.9	34.6
6.	Pennsylvania	1112	5.0	62.3	6.	Massachusetts	94	4.7	39.3
7.	North Carolina	820	3.7	66.1	7.	Illinois	89	4.5	43.7
8.	Ohio	802	3.6	69.7	8.	Michigan	88	4.4	48.1
9.	Illinois	757	3.4	73.1	9.	Connecticut	80	4.0	52.2
10.	Connecticut	655	3.0	76.1	10.	Texas	78	3.9	56.1
11.	Indiana	653	3.0	79.0	11.	Florida	62	3.1	59.2
12.	Massachusetts	581	2.6	81.7	12.	Georgia	62	3.1	62.3
13.	South Carolina	361	1.6	83.3	13.	North Carolina	58	2.9	65.2
14.	Florida	337	1.5	84.8	14.	Maryland	56	2.8	68.0
15.	Georgia	293	1.3	86.2	15.	Virginia	50	2.5	70.5
16.	Delaware	263	1.2	87.3	16.	Washington	48	2.4	72.9
17.	Minnesota	231	1.0	88.4	17.	South Carolina	44	2.2	75.1
18.	Virginia	219	1.0	89.4	18.	Wisconsin	44	2.2	77.3
19.	Kentucky	202	0.9	90.3	19.	Indiana	34	1.7	79.0
20.	Tennessee	188	0.9	91.2	20.	Missouri	34	1.7	80.7

*Including greenfield sites, acquired U.S. firms, joint ventures

Table 4.5 U.S. Subsidiary Patenting by BEA Region and Major Technical Field, 1973-1990

Chemicals (Excluding Drugs)

	Patents				Patenting Subsidiaries			
Location	A Total	B 1973-1978	C 1979-1984	D 1985-1990	E Total	F 1973-1978	G 1979-1984	H 1985-1990
NY-NJ-Long Island	2671	1073	669	929	74	30	40	49
Houston	937	180	256	501	22	5	8	17
Detroit-Ann Arbor	508	180	175	153	23	4	8	17
Philadelphia-Wilmington-Atlantic City	440	109	117	214	41	12	19	28
San Francisco-Oakland-San Jose	299	28	79	192	30	6	12	25
Cleveland-Akron	155	26	30	99	26	5	9	19
Los Angeles - Riverside - Orange County	138	46	36	56	34	5	16	23
Chicago-Gary-Kenosha	130	24	49	57	30	9	12	16
Boston	129	29	45	55	31	9	16	18
Atlanta, GA	53	6	5	42	17	4	4	13

Drugs and Medical Technology

	Patents				Patenting Subsidiaries			
Location	A Total	B 1973-1978	C 1979-1984	D 1985-1990	E Total	F 1973-1978	G 1979-1984	H 1985-1990
NY-NJ-Long Island	954	287	231	436	39	14	19	31
San Francisco-Oakland-San Jose	226	23	58	145	23	4	12	21
Philadelphia-Wilmington-Atlantic City	189	30	36	123	19	6	7	18
Raleigh-Durham-Chapel Hill, NC	160	19	40	101	10	1	4	8
Los Angeles - Riverside - Orange County	106	1	12	93	24	1	8	21
Houston	52	9	16	27	8	1	1	6
Boston	44	5	11	28	19	2	9	13
Chicago-Gary-Kenosha	30	7	7	16	14	5	4	9
New Haven, CT	21	1	5	15	12	1	3	10
Atlanta	14	1	1	12	9	1	1	8

Table 4.5 U.S. Subsidiary Patenting by BEA Region and Major Technical Field, 1973-1990 (cont'd)

Electronic Arts

	Patents				Patenting Subsidiaries			
Location	A Total	B 1973-1978	C 1979-1984	D 1985-1990	E Total	F 1973-1978	G 1979-1984	H 1985-1990
San Francisco-Oakland-San Jose	737	66	269	402	69	16	27	53
NY-NJ-Long Island	644	129	194	321	69	22	28	47
Los Angeles - Riverside - Orange County	337	94	133	110	61	19	32	36
Boston	326	31	121	174	42	11	20	32
Chicago-Gary-Kenosha	247	21	82	144	35	10	15	21
Philadelphia-Wilmington-Atlantic City	152	18	56	78	46	9	18	32
Dallas-Fort Worth, TX	146	1	27	118	16	1	4	13
Detroit-Ann Arbor	114	13	34	67	26	4	10	18
New Haven, CT	79	21	20	38	23	7	9	14
Atlanta	78	0	15	63	16	0	4	14

Mechanical Arts

	Patents				Patenting Subsidiaries			
Location	A Total	B 1973-1978	C 1979-1984	D 1985-1990	E Total	F 1973-1978	G 1979-1984	H 1985-1990
Detroit-Ann Arbor	264	61	59	144	39	7	15	29
NY-NJ-Long Island	262	90	77	95	80	24	35	48
Philadelphia-Wilmington-Atlantic City	158	38	59	61	36	11	14	23
Chicago-Gary-Kenosha	120	7	25	88	36	4	12	28
Los Angeles - Riverside - Orange County	117	35	30	52	36	11	18	20
San Francisco-Oakland-San Jose	91	6	52	33	33	5	17	14
Cleveland-Akron	88	16	20	35	29	9	12	14
Boston	72	22	19	31	29	7	11	17
Pittsburgh	61	4	8	49	20	4	6	14

Table 4.6 Location of U.S. Subsidiary Patenting, by Home Base of Firm, 1973-1990

	Canada	Switzerland	Germany	France	Great Britain	Japan	Netherlands	Sweden
New York-New Jersey-Long Island	16.8%	60.0%	19.8%	13.4%	20.9%	8.2%	10.5%	13.1%
Houston-Galveston	0.8	0.5	0.6	15.6	0.7	0.7	46.0	2.2
San Francisco-Oakland-San Jose	0.4	6.7	4.9	12.0	5.7	17.4	5.5	3.0
Philadelphia-Wilmington-Atlantic City	3.3	1.7	5.3	6.3	12.6	2.5	0.8	4.4
Detroit-Ann Arbor	15.5	0.1	12.7	0.5	4.5	4.7	0.4	0.8
Los Angeles-Riverside-Orange County	0.1	1.3	3.4	2.1	3.0	19.5	2.4	2.2
Boston	5.5	2.6	1.2	11.5	2.1	3.4	0.5	4.4
Chicago-Gary-Kenosha	5.8	2.1	2.0	2.9	1.8	6.4	3.0	2.9
Cleveland-Akron	1.1	0.5	0.9	0.2	7.6	4.2	0.1	3.7
Raleigh-Durham-Chapel Hill	1.9	0.1	0.3	1.8	6.3	0.6	0.4	0.7
Pittsburgh, PA	0.7	0.1	3.8	0.2	1.5	0.9	0.4	2.3
Dallas-Ft. Worth	1.7	2.2	0.4	7.3	0.4	0.5	0.2	0.0
New Haven, CT	1.8	2.9	0.7	1.0	1.6	0.5	1.1	7.1
Total	55.5%	79.8%	56.0%	74.8%	68.7%	69.7%	71.4%	46.9%

Table 4.7 U.S. Subsidiary Patenting by Top 20 Firms, 1973-1990

Parent Company	Home Base	Total Patents	% of U.S. Sub Total	Cumulative Percent	Average Pats Per Year	Total Subsidiaries	Average Subs Per Year
1. Royal Dutch Shell	Netherlands	2142	10.9	10.9	119	30	8.9
2. Hoechst	Germany	1226	6.2	17.1	68	39	8.8
3. Roche	Switzerland	1210	6.1	23.2	67	20	4.8
4. Philips	Netherlands	1202	6.1	29.3	67	50	15.6
5. Ciba-Geigy	Switzerland	1180	6.0	35.3	66	45	11.1
6. Bayer	Germany	1012	5.1	40.5	56	31	10.7
7. BASF	Germany	870	4.4	44.9	48	34	8.7
8. Schlumberger	France	776	3.9	48.8	43	27	7.3
9. Unilever	Great Britain	717	3.6	52.5	40	25	4.8
10. Siemens	Germany	661	3.4	55.8	37	42	11.2
11. ICI	Great Britain	567	2.9	58.7	32	23	4.9
12. Sandoz	Switzerland	523	2.7	61.3	29	24	5.0
13. Akzo	Netherlands	356	1.8	63.2	20	29	7.1
14. Bull	France	274	1.4	64.5	15	6	1.4
15. GEC	Great Britain	266	1.4	65.9	15	20	4.1
16. Thomson	France	265	1.3	67.2	15	18	2.7
17. Henkel	Germany	260	1.3	68.6	14	16	3.6
18. Nestle	Switzerland	251	1.3	69.8	14	22	5.7
19. BOC	Great Britain	236	1.2	71.0	13	23	4.4
20. Wellcome	Great Britain	233	1.2	72.2	13	9	2.0

Table 4.8 U.S. Subsidiary Patenting by Period of Entry of Parent Firm

Early Cohort (<1979)			Middle Cohort (1979-1984)			Late Cohort (>1984)		
Parent Company	Home Base	Patents	Parent Company	Home Base	Patents	Parent Company	Home Base	Patents
Shell	Netherlands	2142	Bull	France	276	Siebe	Great Britain	146
Hoechst	Germany	1226	Thyssen	Germany	143	ABB	Sweden	100
Roche	Switzerland	1210	Dainippon Ink	Japan	88	Smith & Nephew	Great Britain	54
Philips	Netherlands	1202	Automotive Products	Great Britain	85	SmithKline Beecham	Great Britain	42
Ciba-Geigy	Switzerland	1180	Alcatel	France	81	Sulzer	Switzerland	32
Bayer	Germany	1012	Alfa-Laval	Sweden	76	Colin Electronics	Japan	30
BASF	Germany	870	Toshiba	Japan	75	Elopak	Norway	25
Schlumberger	France	776	Bridgestone	Japan	74	Framatome	France	24
Unilever	Great Britain	717	Boehringer Mann.	Germany	69	Grand Metropolitan	Great Britain	19
Siemens	Germany	661	Aisin Seiki	Japan	61	Cookson	Great Britain	17
ICI	Great Britain	567	L'Air Liquide	France	53	Valor	Great Britain	15
Sandoz	Switzerland	523	Pacific Dunlop	Australia	47	Samsung	South Korea	15
Akzo	Netherlands	356	Jefferson Smurfit	Ireland	46	Nippon Sheet Glass	Japan	14
GEC	Great Britain	266	Ahlstrom	Finland	40	Juki	Japan	13
Thomson	France	265	Fanuc	Japan	31	Komatsu	Japan	13
Henkel	Germany	260	Rolls Royce	Great Britain	31	Labinal	France	12
Nestle	Switzerland	251	Ryobi	Japan	29	Sumitomo Electric	Japan	10
BOC	Great Britain	236	Elkem	Norway	25	Veba	Germany	8
Wellcome	Great Britain	233	YKK	Japan	23	Landis & Gyr	Switzerland	7
Swiss Aluminium	Switzerland	178	Olympus	Japan	23	Tosoh	Japan	7
BAT	Great Britain	177	Pirelli	Italy	17	Nippon Mining	Japan	7
Petrofina	Belgium	171	Nissan	Japan	16	Maplan	Austria	7
Inco	Canada	158	Euroceltique	Switzerland	14	L'Oreal	France	7
Northern Telecom	Canada	149	Murata	Japan	14	Alps	Japan	7
Fiat	Italy	143	Elscint	Israel	13	Continental AG	Germany	7
Rhone Poulenc	France	142	Scandpower	Norway	12	Metallgesellschaft	Germany	6
Moore	Canada	139	Hamamatsu	Japan	12	Konica	Japan	6
Babcock Intl	Great Britain	135	BICC	Great Britain	12	Labatt	Canada	5
Electrolux	Sweden	126	Kobe Steel	Japan	12	Shiseido	Japan	5
BP	Great Britain	108	Sunds AB	Sweden	12	ENI	Italy	5

Table 4.9 Growth of U.S. Subsidiary Patenting by Top 20 Firms, 1973-1990

	Patents			# of Patenting U.S. Subsidiaries			Average Patents per Subsidiary		
Parent Company*	1973-1978	1979-1984	1985-1990	1973-1978	1979-1984	1985-1990	1973-1978	1979-1984	1985-1990
1. Royal Dutch Shell	482	691	969	14	17	26	32.1	38.4	37.3
2. Hoechst	95	259	872	13	16	29	8.7	16.2	30.1
3. Roche	667	312	231	12	8	9	53.0	34.7	23.1
4. Philips	201	400	601	18	35	40	10.5	11.1	14.7
5. Ciba-Geigy	420	229	531	24	26	28	17.7	8.5	19.0
6. Bayer	134	440	438	17	22	23	10.2	19.1	18.3
7. BASF	263	317	290	13	20	22	19.1	15.1	12.6
8. Schlumberger	118	356	302	9	16	20	10.8	20.9	14.4
9. Unilever	171	177	369	8	7	22	21.8	22.1	16.0
10. Siemens	28	236	397	12	29	34	2.9	7.9	11.7
11. ICI	144	96	327	10	12	13	16.3	8.0	23.4
12. Sandoz	318	105	100	12	9	14	26.2	11.7	6.7
13. Akzo	119	116	121	12	14	21	10.4	8.3	5.5
14. Bull	0	120	154	0	4	5	NA	30.0	25.7
15. GEC	4	43	219	2	7	18	2.8	6.1	11.5
16. Thomson	6	40	219	2	7	15	3.0	5.7	13.7
17. Henkel	27	117	116	2	9	12	14.7	13.0	8.9
18. Nestle	37	53	161	9	12	16	4.2	4.4	10.1
19. BOC	17	57	162	5	11	20	4.4	5.2	7.7
20. Wellcome	47	73	113	7	5	5	8.3	14.6	18.8

*Ranked by total patents, combined 1973-1990 period

Table 4.10 Geographic Distribution of Patenting for Top 20 Firms

	1973-1978				1979-1984				1985-1990			
Company	Total Patents	% USA	% Home	Herf	Total Patents	% USA	% Home	Herf	Total Patents	% USA	% Home	Herf
Royal Dutch Shell	814	59.2	27.5	4406	1100	62.8	26.5	7067	1614	60.0	29.3	6903
Hoechst	2089	4.5	84.6	7272	2181	11.9	76.1	7078	2879	30.3	59.7	6638
Roche	1106	60.3	33.1	4740	690	45.2	43.8	6464	527	43.8	39.1	5985
Philips	2415	8.3	58.6	3786	2910	13.7	50.2	4237	4057	14.8	44.9	3933
Ciba-Geigy	2306	18.2	65.8	4782	1956	11.7	67.0	5829	2264	23.5	55.6	5579
Bayer	3339	4.0	87.5	7735	3211	13.7	82.1	8116	3450	12.7	81.9	7991
BASF	1572	16.7	82.9	7150	1882	16.8	82.9	8555	2311	12.5	86.3	8707
Schlumberger	176	67.0	32.4	5544	427	83.4	12.6	8508	457	66.1	19.5	7135
Unilever	410	41.7	34.9	3178	454	39.0	38.5	5570	707	52.2	29.1	6201
Siemens	2678	1.0	93.5	8752	3032	7.8	87.7	8473	3533	11.2	82.5	7934
ICI	1447	10.0	82.9	6994	1011	9.5	78.3	7141	1305	25.1	61.1	6287
Sandoz	750	42.4	48.8	4196	396	26.5	57.1	5977	316	31.6	50.3	5763
Akzo	363	32.8	42.4	3275	410	28.3	31.0	5044	402	30.1	34.3	4901
Bull	168	0.0	82.1	7008	266	45.1	41.4	6395	279	55.2	30.5	6653
GEC	142	2.8	95.1	9051	253	17.0	81.4	8330	566	38.7	58.0	7233
Thomson	628	1.0	95.9	9200	1069	3.7	88.1	8174	1602	13.7	57.4	5098
Henkel	309	8.7	90.6	8288	432	27.1	72.9	8025	674	17.2	80.0	8118
Nestle	118	31.4	56.8	4249	184	28.8	39.1	4692	335	48.1	29.0	5799
BOC	59	28.8	67.8	5438	99	57.6	26.3	6580	237	68.4	27.4	7594
Wellcome	111	42.3	55.9	4914	137	53.3	42.3	7135	179	63.1	34.1	7478

Table 4.11 Major Acquisitions of Patenting U.S. Firms by Foreign Multinationals*

Parent Company	Home Base	Acquired U.S. Company
ABB	Sweden	Combustion Engineering, Inc.
Alfa-Laval	Sweden	Technicon Instruments Corporation
Babcock International	Great Britain	American Chain & Cable Company, Inc.
BASF	*Germany*	*Wyandotte Chemicals*
BAT	Great Britain	Brown & Williamson Tobacco Corporation
Bayer	*Germany*	*Miles Laboratories, Inc.*
Bayer	*Germany*	*Cutter Laboratories, Inc.*
BOC	Great Britain	Airco, Inc.
BP	Great Britain	The Standard Oil Company (Ohio)
Bridgestone	Japan	Firestone, Inc.
Bull	*France*	*Honeywell Information Systems Inc.*
Ciba-Geigy	*Switzerland*	*Spectra-Physics, Inc.*
Coats Patons	Great Britain	Coats & Clark, Inc.
DIC	Japan	Polychrome Corporation
DIC	Japan	Sun Chemical Corporation
Electrolux	Sweden	White Consolidated Industries, Inc.
Fiat	Italy	Hesston Corporation
Fiat	Italy	Ford New Holland, Inc.
GEC	*Great Britain*	*Picker International, Inc.*
GEC	*Great Britain*	*A. B. Dick Company*
Henkel	*Germany*	*Amchem Products, Inc.*
Hoechst	*Germany*	*Celanese Corporation*
ICI	*Great Britain*	*The Glidden Company*
ICI	*Great Britain*	*Stauffer Chemical Company*
Jefferson Smurfit	Ireland	Container Corporation of America
Nestle	*Switzerland*	*Alcon Laboratories, Inc.*
Pechiney	France	American National Can Company
Pechiney	France	Howmet Corporation
Petrofina	Belgium	Cosden Technology, Inc.
Philips	*Netherlands*	*Signetics Corporation*
Philips	*Netherlands*	*The Magnavox Company*
Philips	*Netherlands*	*Laser Magnetic Storage International*
Rhone Poulenc	France	Rorer Pharmaceuticals Inc.
Roche	*Switzerland*	*Genentech, Inc.*
RTZ	Great Britain	United States Borax & Chemical Corporation
Saint Gobain	France	Norton Company
Schering AG	Germany	Sherex Chemical Company, Inc.
Schlumberger	*France*	*Fairchild Camera & Instrument Corporation*
Siebe	Great Britain	Robertshaw Controls Company
Siemens	*Germany*	*Gammasonics*
Siemens	*Germany*	*Siemens-Bendix Automotive Electronics L.P.*
Beecham PLC	Great Britain	SmithKline
Swiss Aluminium	Switzerland	Maremont Corporation
Thyssen	Germany	The Budd Company
Unilever	*Great Britain*	*National Starch and Chemical Corporation*

*Italics indicate Top 20 Firm

Table 4.12 Top 3 Technical Fields for U.S. Subsidiary Patenting, by Top 20 Firm and Time Period

Company	1973-1978	1979-1984	1985-1990
Royal Dutch Shell	Chemical processes, Mining equipment, Pharmaceuticals	Other organic chemicals, Chemical processes, Chemical and allied equipment	Other organic chemicals, Chemical and allied equipment, Coal and petroleum products
Hoechst	Other organic chemicals, Non-metallic mineral products, Specialized industrial equipment	Pharmaceuticals, Other organic chemicals, Chemical processes	Other organic chemicals, Chemical processes, Pharmaceuticals
Roche	Chemical processes, Pharmaceuticals, Other organic chemicals	Chemical processes, Other organic chemicals, Pharmaceuticals	Pharmaceuticals, Other organic chemicals, Chemical processes
Philips	Electrical systems, Telecommunications, Other instruments	Electrical systems, Other instruments, Chemical processes	Electrical systems, Image and sound equipment, Office equipment
Ciba-Geigy	Chemical processes, Pharmaceuticals, Other organic chemicals	Other organic chemicals, Chemical processes, Pharmaceuticals	Other organic chemicals, Pharmaceuticals, Electrical systems
Bayer	Chemical processes, Pharmaceuticals, Other organic chemicals	Pharmaceuticals, Other organic chemicals, Chemical processes	Other organic chemicals, Pharmaceuticals, Chemical processes
BASF	Chemical processes, Other organic chemicals, Non-metallic mineral products	Other organic chemicals, Chemical processes, Pharmaceuticals	Other organic chemicals, Chemical processes, Non-metallic mineral products
Schlumberger	Other instruments, Mining equipment, Telecommunications	Other instruments, Office equipment, Telecommunications	Other instruments, Telecommunications, Office equipment
Unilever	Chemical processes, Pharmaceuticals, Other organic chemicals	Chemical processes, Other organic chemicals, Food and tobacco products	Chemical processes, Other organic chemicals, Pharmaceuticals
Siemens	Telecommunications, Electrical systems, Other instruments	Other instruments, Electrical systems, Telecommunications	Other instruments, Electrical systems, Telecommunications

Company	1973-1978	1979-1984	1985-1990
ICI	Chemical processes, Other organic chemicals, Other manufacturing	Other organic chemicals, Pharmaceuticals, Chemical processes	Other organic chemicals, Pharmaceuticals, Agricultural chemicals
Sandoz	Chemical processes, Pharmaceuticals, Other organic chemicals	Pharmaceuticals, Other organic chemicals, Chemical processes	Pharmaceuticals, Other organic chemicals, Agricultural chemicals
Akzo	Chemical processes, Specialized industrial equipment, Electrical systems	Chemical processes, Other organic chemicals, Electrical systems	Other organic chemicals, Chemical processes, Pharmaceuticals
Bull		Office equipment, Telecommunications, Electrical systems	Office equipment, Electrical systems, Telecommunications
GEC	Photographic instruments, Other metal products	Other instruments, Chemical processes, Office equipment	Other instruments, Office equipment, Telecommunications
Thomson	Image and sound equipment, Telecommunications, Other instruments	Office equipment, Electrical systems, Image and sound equipment	Electrical systems, Image and sound equipment, Semiconductors
Henkel	Chemical processes, Other organic chemicals, Inorganic chemicals	Other organic chemicals, Chemical processes, Metallurgical processes	Other organic chemicals, Chemical processes, Metallurgical processes
Nestle	Food and tobacco products, Pharmaceuticals, Chemical processes	Food and tobacco products, Pharmaceuticals, Chemical processes	Food and tobacco products, Other instruments, Pharmaceuticals
BOC	Other instruments, General electrical equipment, Chemical processes	Chemical processes, Other instruments, Metallurgical processes	Chemical processes, Other instruments, Other organic chemicals
Wellcome	Pharmaceuticals, Chemical processes, Other organic chemicals	Pharmaceuticals, Other organic chemicals, Chemical processes	Pharmaceuticals, Other organic chemicals, Chemical processes

Table 4.13 The Technological Evolution of U.S. Subsidiary Activity among Top 20 Firms, 1973-1990

Parent Company	Home Base	Phi-Square Distance Measures: 1973-78 and 1979-84	1979-84 and 1985-90	1973-78 and 1985-90	Comments
Royal Dutch Shell	Netherlands	.53	.34	.64	Houston facility rapidly increased activity in organic chemistry, esp. in late 1980s. Decreased pharmaceuticals activity.
Hoechst	Germany	.35	.24	.33	Acquisition of Roussel increases presence in pharmaceuticals. Acquisition of Celanese reinforces existing presence in organic chemistry in late 1980s.
Roche	Switzerland	.38	.51	.62	Major decrease in patenting in chemical processes and instruments. Increase in pharmaceuticals activity.
Philips	Netherlands	.27	.32	.33	Acquisitions of Signetics Corporation (California) and Laser Magentics Storage (Colorado) increase existing capabilities in office equipment technology.
Ciba-Geigy	Switzerland	.47	.35	.65	Move into electrical systems and instruments via acquisition of Spectra-Physics.
Bayer	Germany	.36	.23	.54	Move into pharmaceuticals via acquisition of Miles Laboratories and Cutter Laboratories.
BASF	Germany	.45	.28	.55	Michigan facility begins patenting in pharmaceuticals (esp. vitamins) in early 1980s.
Schlumberger	France	.51	.39	.42	Acquisition of Fairchild increases presence in Office Equipment, Electrical Systems, and Semiconductors.
Unilever	Great Britain	.35	.19	.30	Acquisition of National Starch and Chemical increases technical presence in Food and Tobacco Products.
Siemens	Germany	.30	.39	.26	Increase in automotive patenting by Michigan and Virginia facilities (throttle and fuel injection technology) in late 1980s.

Parent Company	Home Base	Phi-Square Distance Measures 1973-79 and 1979-84	1979-84 and 1985-90	1973-79 and 1985-90	Comments
ICI	Great Britain	.51	.47	.74	Move into agricultural chemicals in 1980s via acquisition of Stauffer Chemicals. Also increased pharmaceutical activity in California (fungicides and pesticides), Delaware (dentifrice, sunscreen), and Pennsylvania (central nervous system)
Sandoz	Switzerland	.48	.29	.56	Major decreases in patenting in chemical processes and pharmaceuticals. Illinois and California facilities increased patenting in agricultural chemicals.
Akzo	Netherlands	.42	.56	.64	NY facility expanded organic chemistry activity in 1980s.
Bull	France	NA	.22	NA	Acquisition of Honeywell's computer business.
GEC	Great Britain	.81	.41	.82	Move into instruments via acquisition of Picker International.
Thomson	France	.54	.26	.28	Indiana, Texas, and New Jersey facilities increase activity in electrical systems, image and sound equipment, and semiconductors in early 1980s.
Henkel	Germany	.27	.23	.30	Very stable technological position over time.
Nestle	Switzerland	.34	.27	.29	Acquisition of Alcon Laboratories increases capabilities in instruments and pharmaceuticals technology.
BOC	Great Britain	.47	.59	.55	NJ facility began patenting in pharmaceuticals and organic chemistry in mid-1980s.
Wellcome	Great Britain	.28	.30	.48	Shift out of chemical processes and into organic chemistry in late 1980s.
Average		.43	.34	.49	

Table 4.14a Patenting in New Technical Fields by U.S. subsidiaries of Top 20 firms (1979-1984)*

Company	Technical Field	Number of Patents	Number of HQ Patents 73-84
Akzo	Other metal products	3	
Akzo	Inorganic chemicals	3	
Akzo	General industrial equipment	2	
BASF	Agricultural chemicals	5	
BASF	Rubber products	2	
BASF	Mining equipment	2	*
Bayer	Food and tobacco products	7	
Bayer	Metallurgical processes	4	
Bayer	Chemical and allied equipment	3	
Bayer	Office equipment	3	
Bayer	Specialized industrial equipment	2	
Bayer	Electrical systems	2	
BOC	Other organic chemicals	4	*
BOC	Metal-working equipment	2	*
Bull	Office equipment	93	
Bull	Telecommunications	11	
Bull	Electrical systems	8	
Bull	Metallurgical processes	3	*
Bull	Chemical processes	2	*
Bull	Other metal products	2	*
Ciba-Geigy	Photographic instruments	2	
GEC	Other instruments	11	
GEC	Chemical processes	7	
GEC	Office equipment	6	
GEC	Telecommunications	5	
GEC	Specialized industrial equipment	4	*
GEC	Electrical systems	2	
GEC	Other organic chemicals	2	*
GEC	Image and sound equipment	2	
Henkel	Metallurgical processes	11	
Henkel	Specialized industrial equipment	2	
Hoechst	Bleaching and dyeing processes	6	
Hoechst	Rubber products	4	
Hoechst	Assembly equipment	2	
ICI	Telecommunications	4	

Company	Technical Field	Number of Patents	Number of HQ Patents 73-84
Nestle	Other organic chemicals	4	
Philips	Specialized industrial equipment	7	
Philips	Inorganic chemicals	3	*
Sandoz	Rubber products	2	*
Schlumberger	Metallurgical processes	27	
Schlumberger	General electrical systems	12	
Schlumberger	Semiconductors	8	*
Schlumberger	Assembly equipment	4	
Schlumberger	Motor vehicles	2	*
Schlumberger	Non-metallic mineral products	2	*
Shell	Other transport equipment	7	
Shell	Office equipment	4	*
Shell	Bleaching and dyeing processes	3	
Shell	Other manufacturing and non-industrial	2	*
Siemens	Chemical processes	5	
Siemens	Image and sound equipment	3	
Siemens	Assembly equipment	3	
Siemens	Metal-working equipment	3	
Siemens	Other metal products	3	
Siemens	Textiles and wood products	2	
Siemens	Specialized industrial equipment	2	
Thomson	Office equipment	12	
Thomson	Electrical systems	10	
Thomson	Assembly equipment	3	*
Wellcome	Other instruments	3	*
Wellcome	Bleaching and dyeing processes	2	*

* Minimum 2 patents

Table 4.14b Patenting in New Technical Fields by U.S. subsidiaries of Top 20 firms (1985-1990)*

Company	Technical Field	Number of Patents	Number of HQ Patents 73-90
BOC	Inorganic chemicals	8	*
BOC	Textiles and wood products	2	*
BOC	Bleaching and dyeing processes	2	*
Bull	Assembly equipment	2	
Bull	Photographic instruments	2	
Bull	Specialized industrial equipment	2	*
Ciba-Geigy	Electrical systems	67	
Ciba-Geigy	General electrical systems	3	
GEC	Metal-working equipment	5	*
GEC	Non-metallic mineral products	2	
GEC	General industrial equipment	2	*
GEC	General electrical systems	2	*
Henkel	Coal and petroleum products	4	
Hoechst	Inorganic chemicals	6	
Hoechst	Office equipment	5	
Hoechst	Metallurgical processes	5	
Hoechst	Electrical systems	4	
Hoechst	Metal-working equipment	3	
Hoechst	Food and tobacco products	2	*
Hoechst	Telecommunications	2	*
ICI	Electrical systems	2	*
Nestle	Office equipment	4	
Nestle	General industrial equipment	2	*
Roche	Bleaching and dyeing processes	3	
Roche	Metal-working equipment	2	
Siemens	Motor vehicles	33	
Siemens	General industrial equipment	16	
Siemens	Rubber products	3	
Siemens	Other manufacturing and non-industrial	3	
Siemens	Chemical and allied equipment	3	
Siemens	Bleaching and dyeing processes	2	
Thomson	Specialized industrial equipment	5	
Thomson	Chemical and allied equipment	4	*
Thomson	Other metal products	4	
Thomson	General electrical systems	3	

Company	Technical Field	Number of Patents	Number of HQ Patents 73-90
Unilever	Rubber products	5	
Unilever	General industrial equipment	2	

* Minimum 2 patents

Table 4.15

Evolution of Technological Distance Between U.S. Subsidiaries and Headquarters for Top 20 Multinationals

		Phi-Square Distance Measures		
Parent Company	Home Base	1973-78	1979-84	1985-90
Royal Dutch Shell	Netherlands	.35	.38	.24
Hoechst	Germany	.24	.26	.22
Roche	Switzerland	.10	.25	.30
Philips	Netherlands	.18	.22	.23
Ciba-Geigy	Switzerland	.20	.19	.44
Bayer	Germany	.22	.26	.25
BASF	Germany	.30	.24	.26
Schlumberger	France	.38	.27	.36
Unilever	Great Britain	.45	.42	.33
Siemens	Germany	.09	.17	.27
ICI	Great Britain	.28	.30	.40
Sandoz	Switzerland	.26	.35	.41
Akzo	Netherlands	.56	.55	.35
Bull	France	NA	.40	.56
GEC	Great Britain	1.00	.55	.46
Thomson	France	.17	.28	.35
Henkel	Germany	.26	.36	.32
Nestle	Switzerland	.39	.35	.41
BOC	Great Britain	.52	.53	.47
Wellcome	Great Britain	.19	.37	.22
Average		.32	.33	.34

Table 4.16 Locational Specialization of U.S. Subsidiary Patenting, by Top 20 Multinational, 1973-1990

	% Home Country Specialization			% U.S. Specialization			% Host State Specialization		
Company	1973-78	1979-84	1985-90	1973-78	1979-84	1985-90	1973-78	1979-84	1985-90
Akzo	41.2	43.1	52.9	31.9	56.9	52.1	65.5	71.6	49.6
BASF	52.9	67.5	75.9	32.7	60.9	43.1	65.0	64.0	69.0
Bayer	67.2	59.8	56.6	29.1	49.3	62.3	76.9	74.8	77.4
BOC	35.3	43.9	52.5	41.2	63.2	56.8	47.1	64.9	61.7
Bull	NA	8.3	14.8	NA	85.8	81.3	NA	95.0	90.0
Ciba-Geigy	85.0	71.2	55.6	10.0	38.0	29.8	63.3	71.2	79.5
GEC	NA	20.9	50.2	25.0	44.2	52.1	100.0	34.9	54.8
Henkel	74.1	78.6	62.9	33.3	53.8	42.2	29.6	54.7	62.9
Hoechst	78.9	62.5	72.7	6.3	21.6	18.9	81.1	81.9	83.7
ICI	61.1	67.7	66.4	25.7	36.5	26.0	87.5	80.2	66.4
Nestle	70.3	88.7	59.0	70.3	56.6	71.4	51.4	50.9	68.3
Philips	64.7	65.8	65.6	46.8	43.0	34.8	66.7	71.3	74.4
Roche	86.7	86.5	74.5	11.7	26.3	37.7	88.5	93.9	83.5
Sandoz	93.4	90.5	87.0	6.9	21.0	20.0	95.9	81.0	65.0
Schlumberger	52.5	38.2	61.6	80.5	66.9	65.6	83.9	82.9	78.1
Shell	42.5	52.7	64.5	44.2	61.4	54.7	58.5	70.2	80.2
Siemens	21.4	35.6	35.5	60.7	47.9	53.4	78.6	56.8	73.0
Thomson	100.0	32.5	30.6	33.3	60.0	35.6	66.7	85.0	81.3
Unilever	72.5	55.4	61.0	38.0	55.9	51.2	92.4	89.3	87.0
Wellcome	83.0	72.6	88.5	2.1	23.3	13.3	12.8	60.3	86.7
Average	65.7	57.1	59.4	33.1	48.6	45.1	69.0	71.7	73.6

Figure 4.1 Patenting by U.S. Subsidiaries, 1973-1990

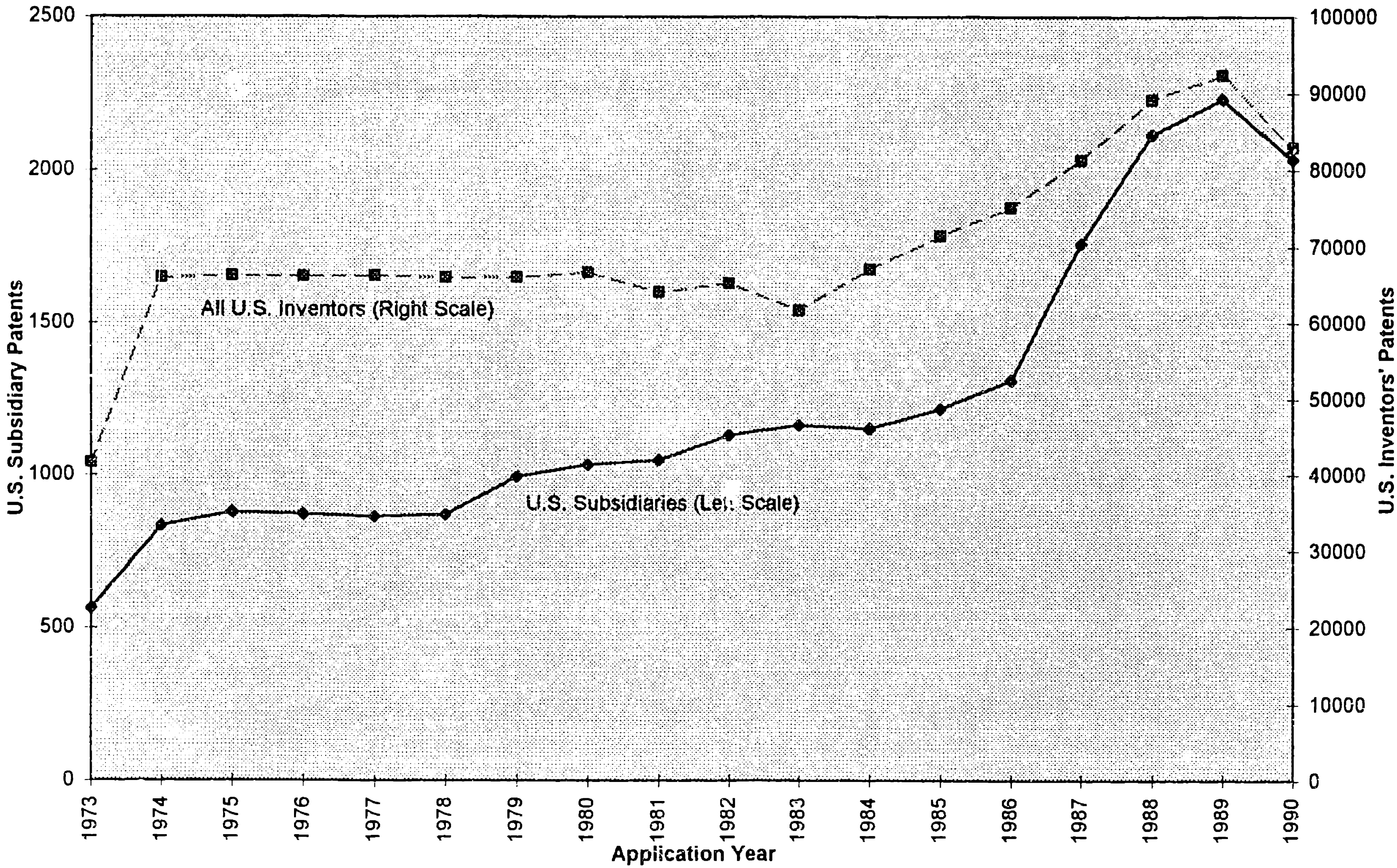


Figure 4.2 Growth in Patenting by Subsidiary Cohort

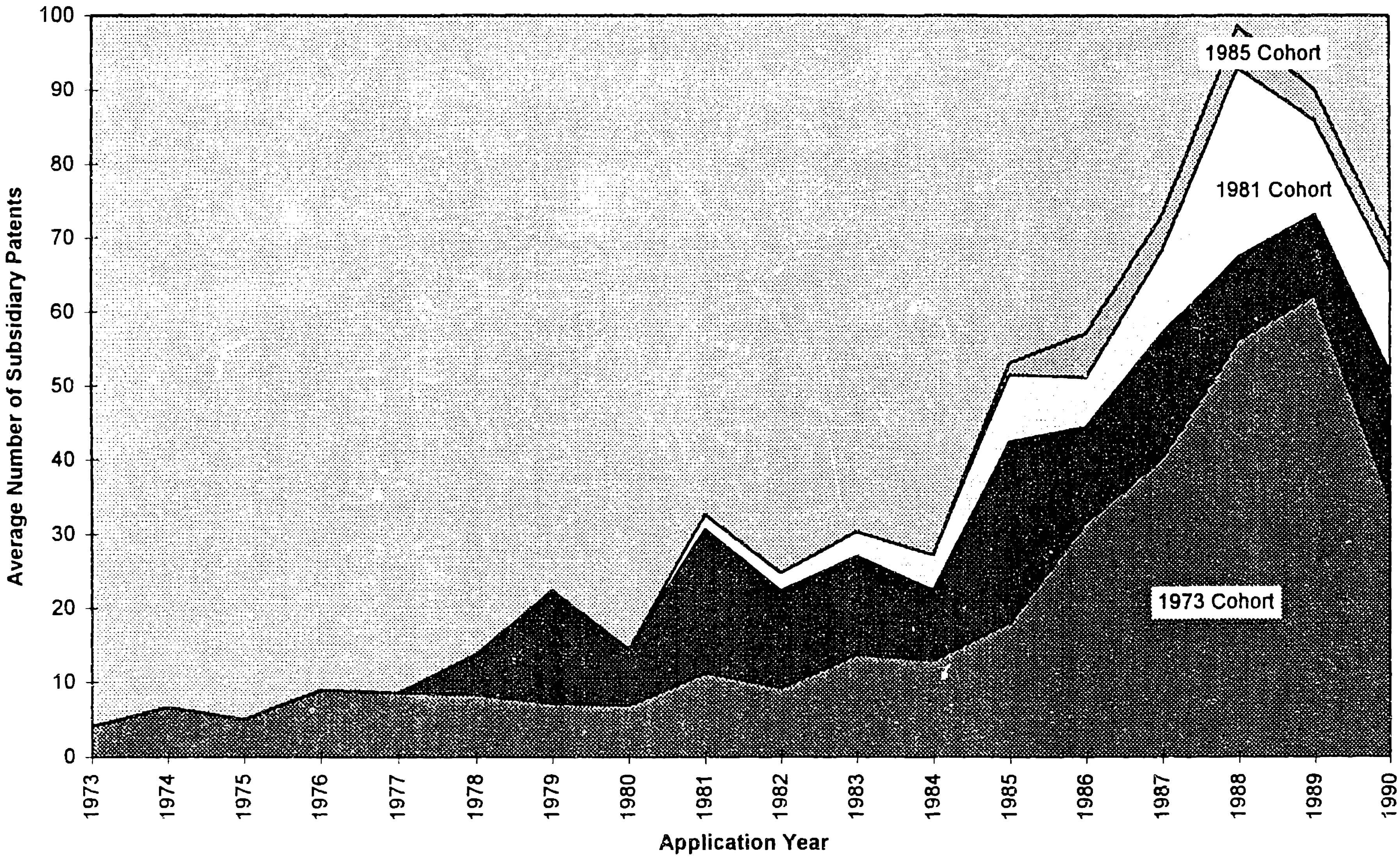


Figure 4.3 Growth in Number of Patenting Subsidiaries and Parent Firms, 1973-1990

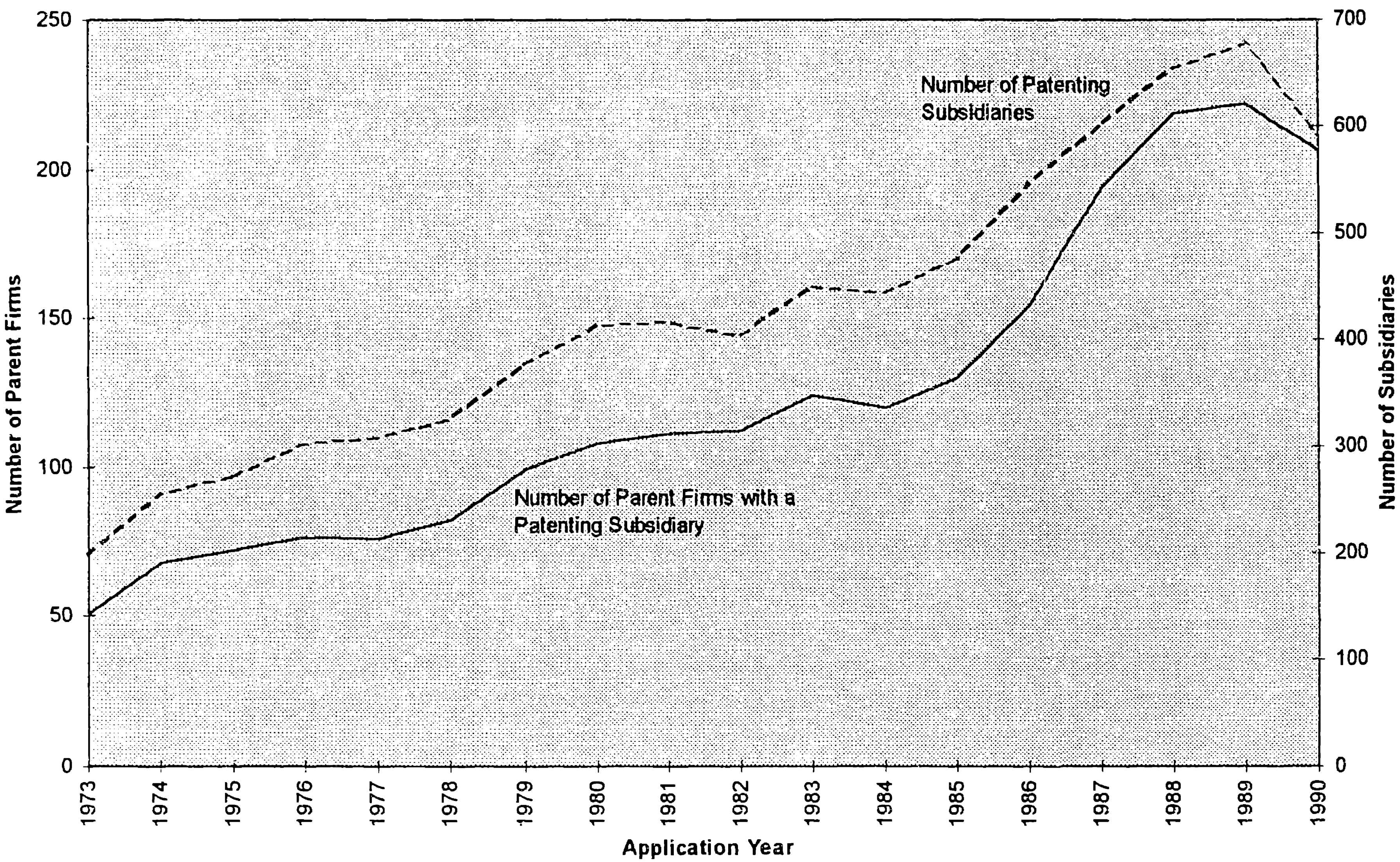


Figure 4.4 U.S. Subsidiary Patents by Mode of Entry, 1973-1990

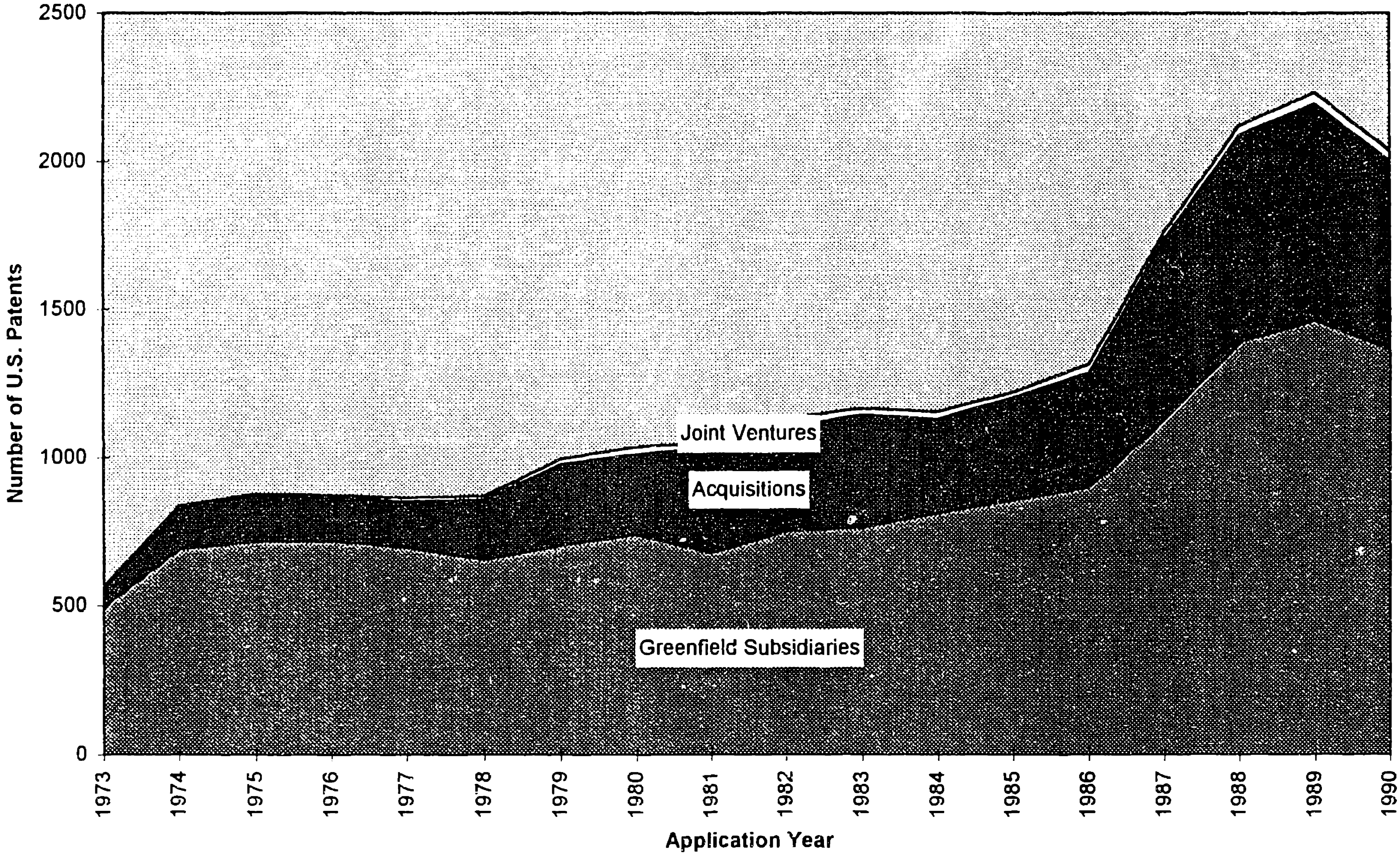


Figure 4.5 U.S. Subsidiary Patents by Home Base (Greenfield Subsidiaries), 1973-1990

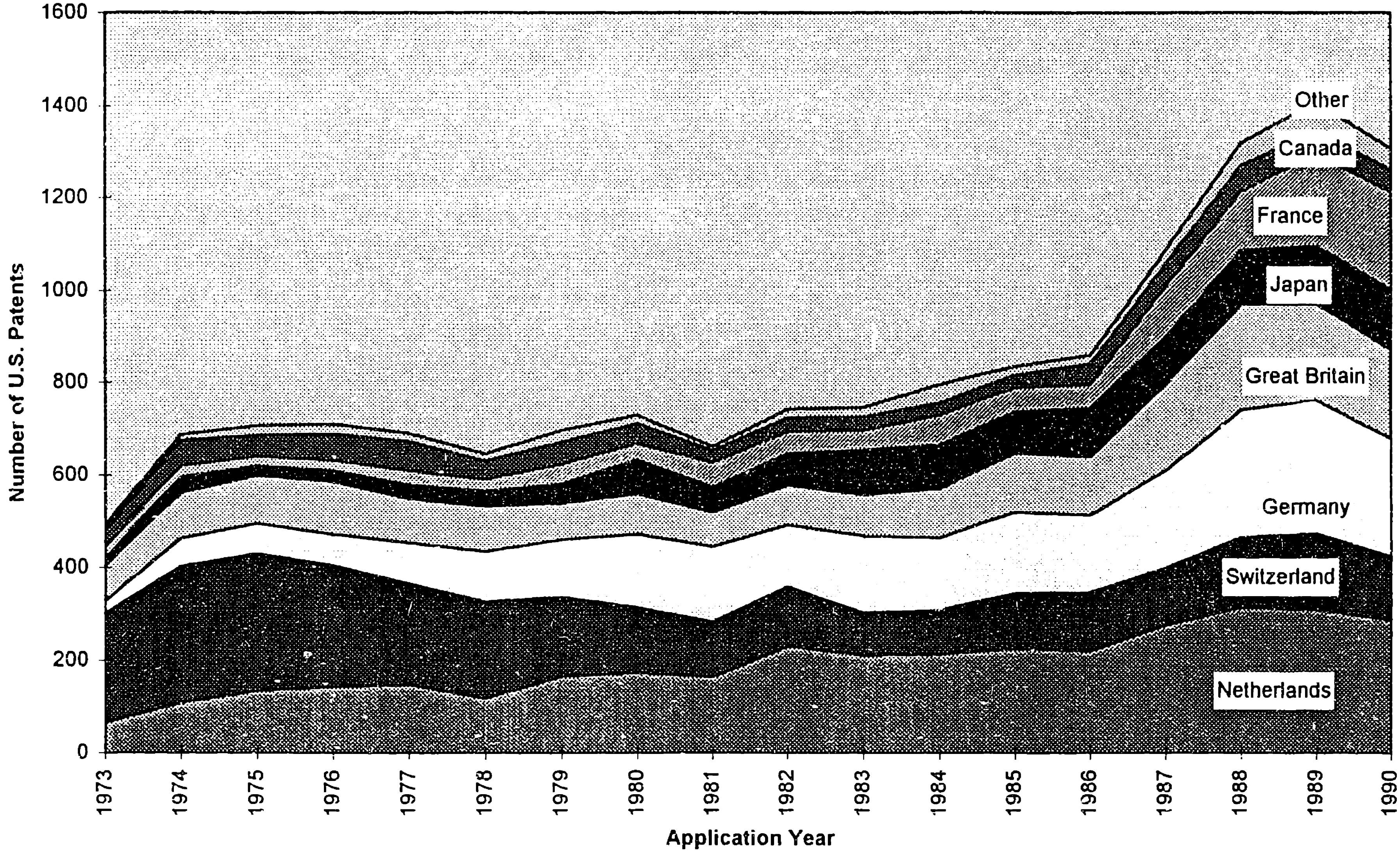


Figure 4.5 U.S. Subsidiary Patents by Home Base (Greenfield Subsidiaries), 1973-1990

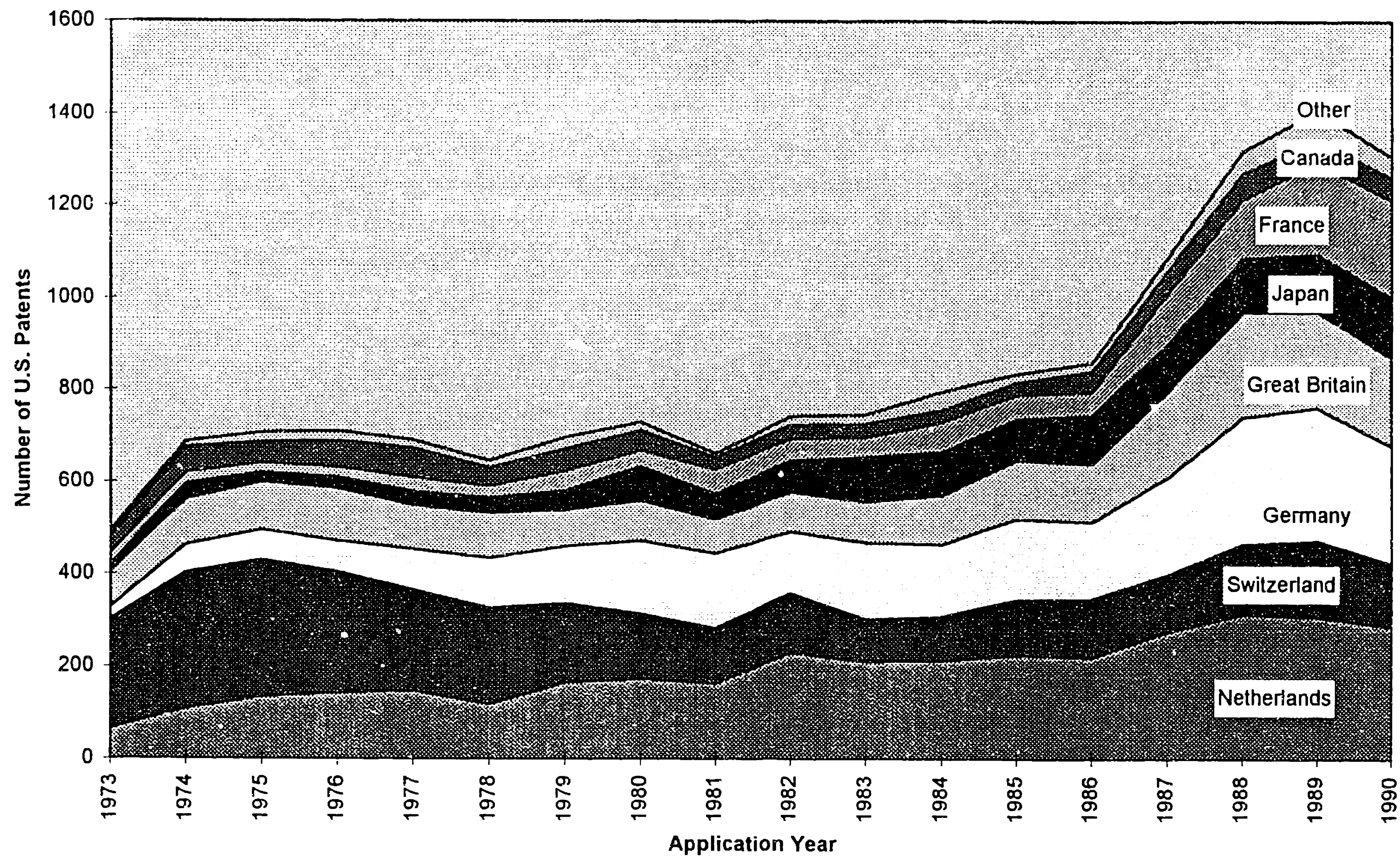


Figure 4.7 U.S. Subsidiary Patents by Broad Technical Field

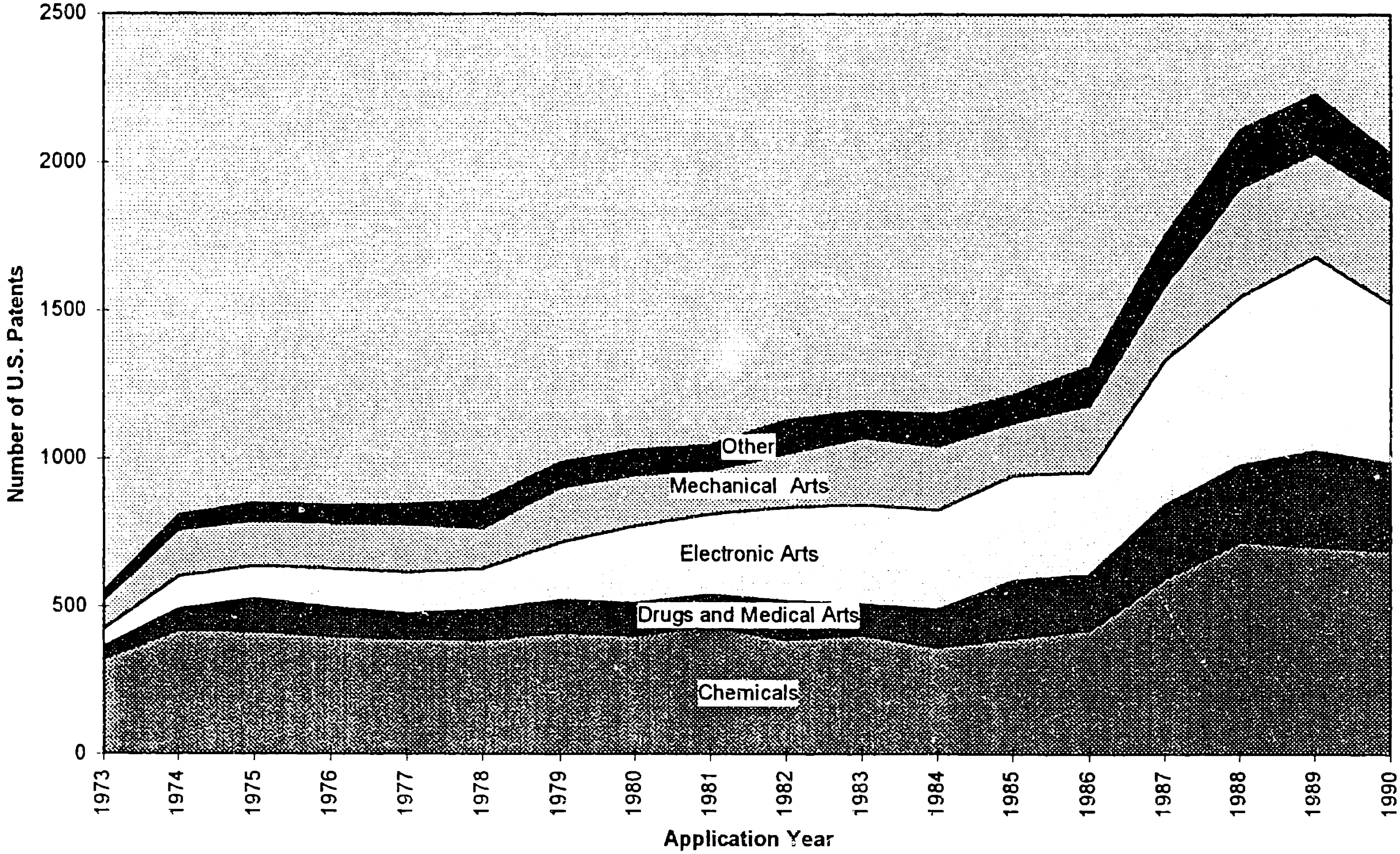


Figure 4.8 Patents Issued to All U.S. Inventors by Broad Technical Area, 1973-1990

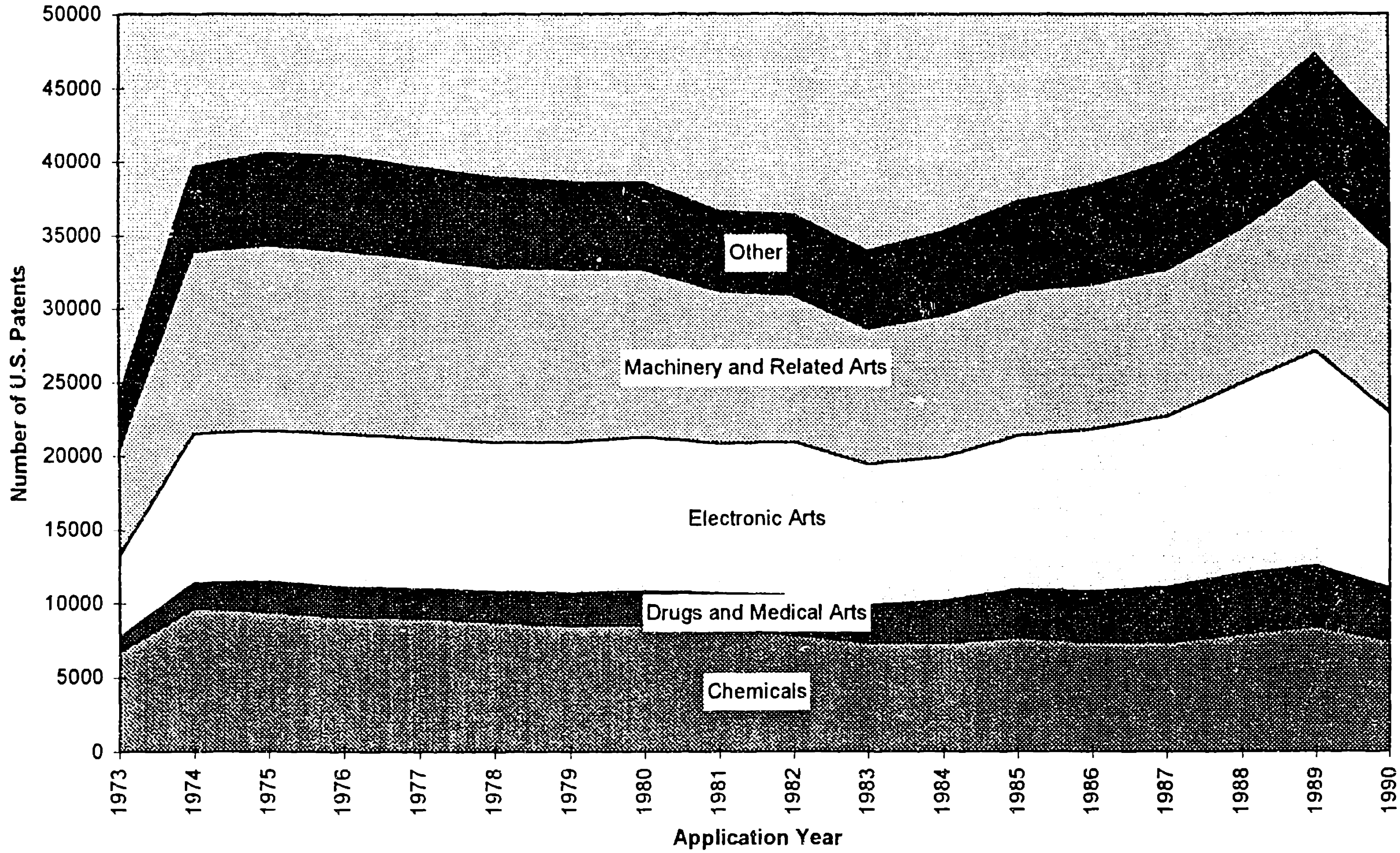


Figure 4.9 Growth in U.S. Subsidiary Patenting in Electronics, 1973-1990

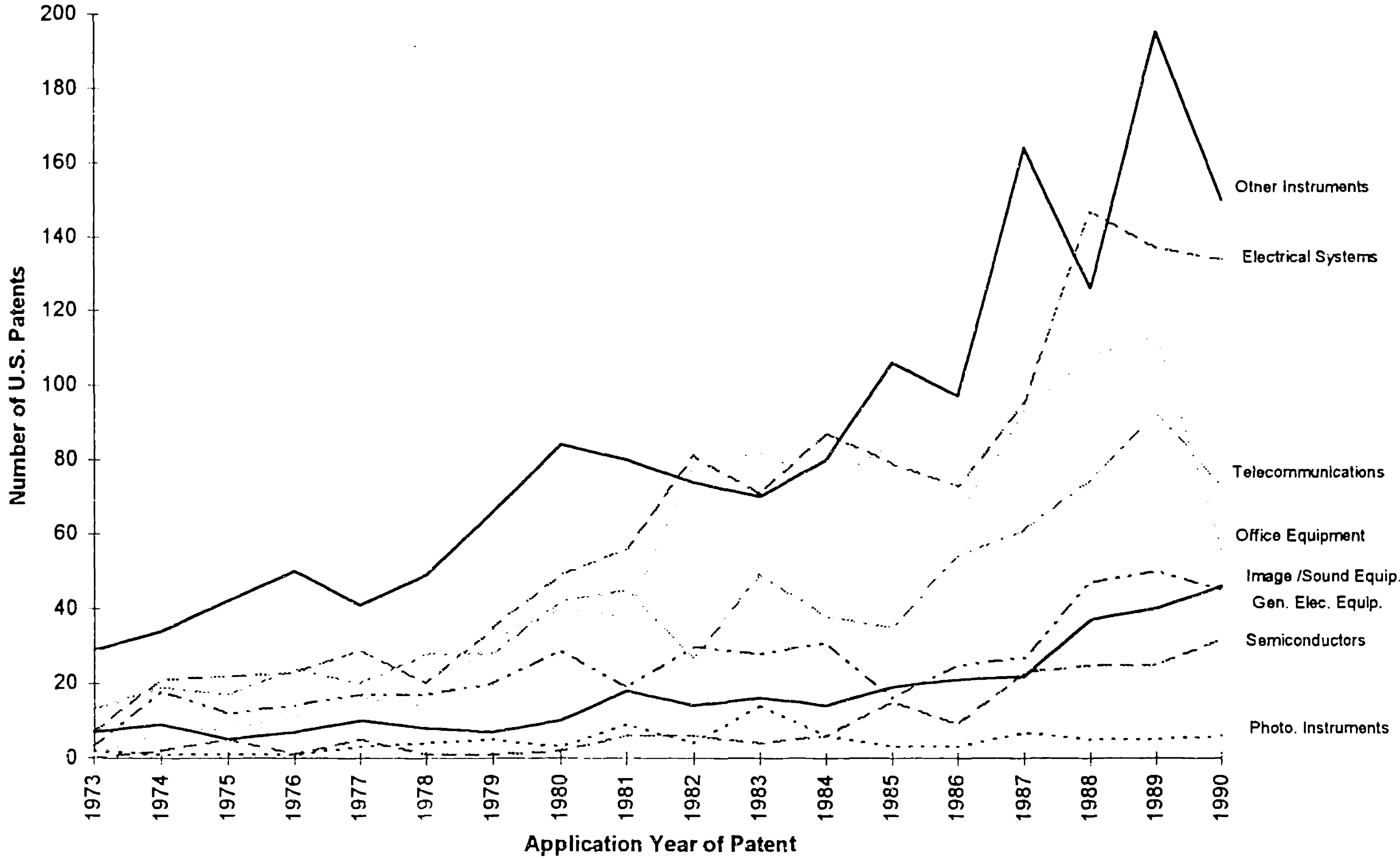


Figure 4.10 U.S. Subsidiary Patents in Chemicals by Home Country of Parent Firm, 1973-1990

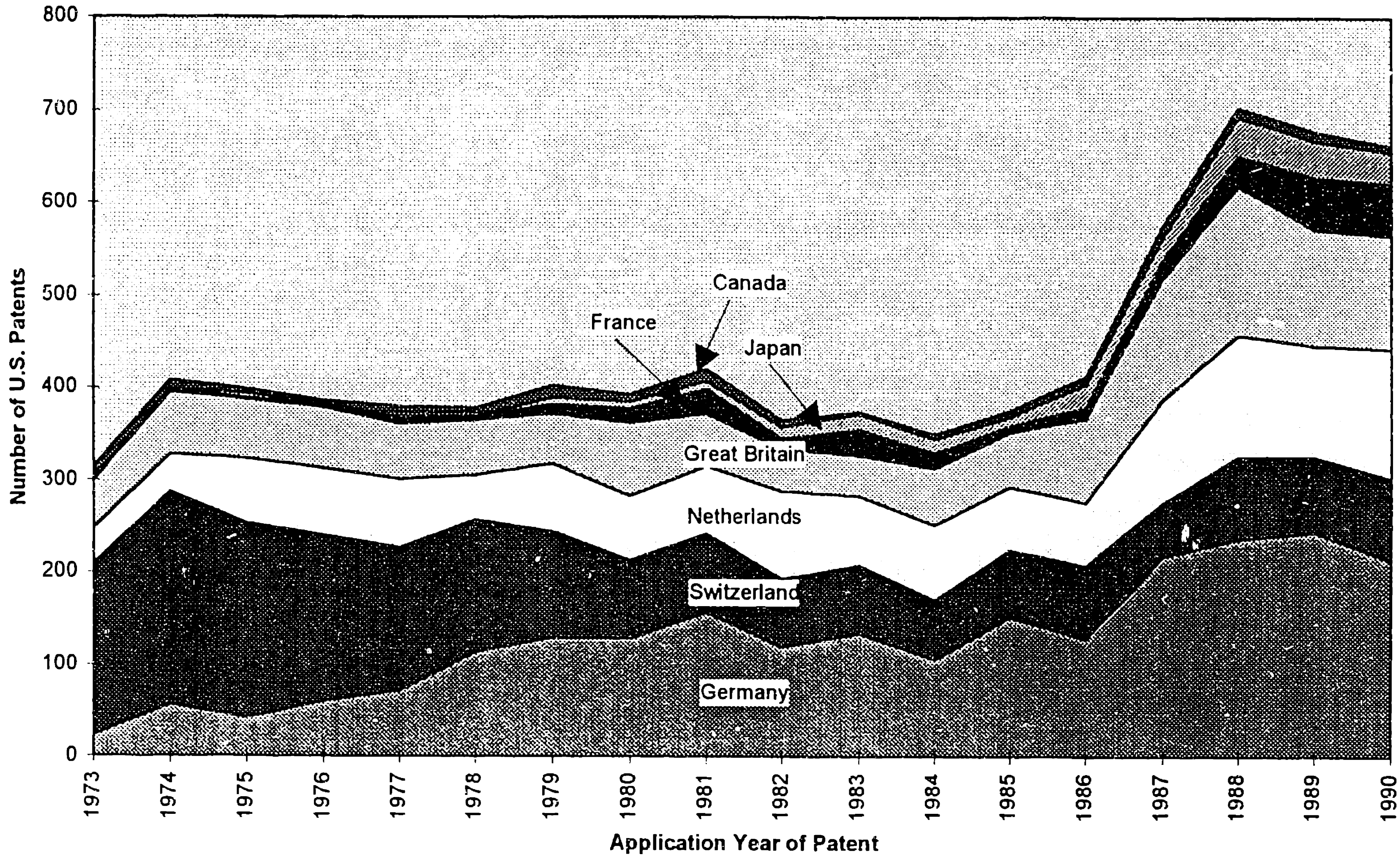


Figure 4.11 U.S. Subsidiary Patents in Drugs and Medical Arts by Home Country of Parent Firm, 1973-1990

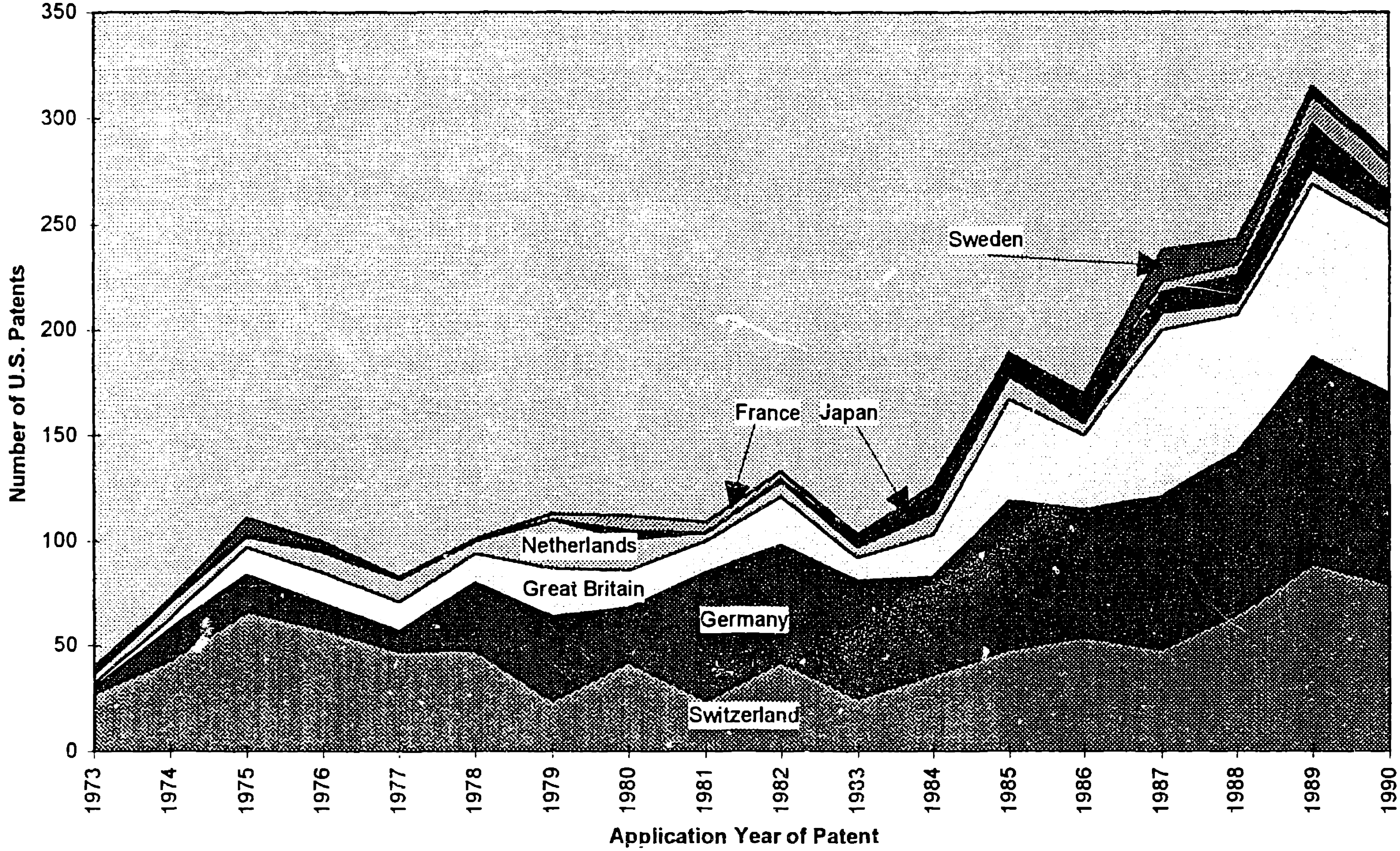


Figure 4.12 U.S. Subsidiary Patents in Electronics Arts by Home Country of Parent Firm, 1973 1990

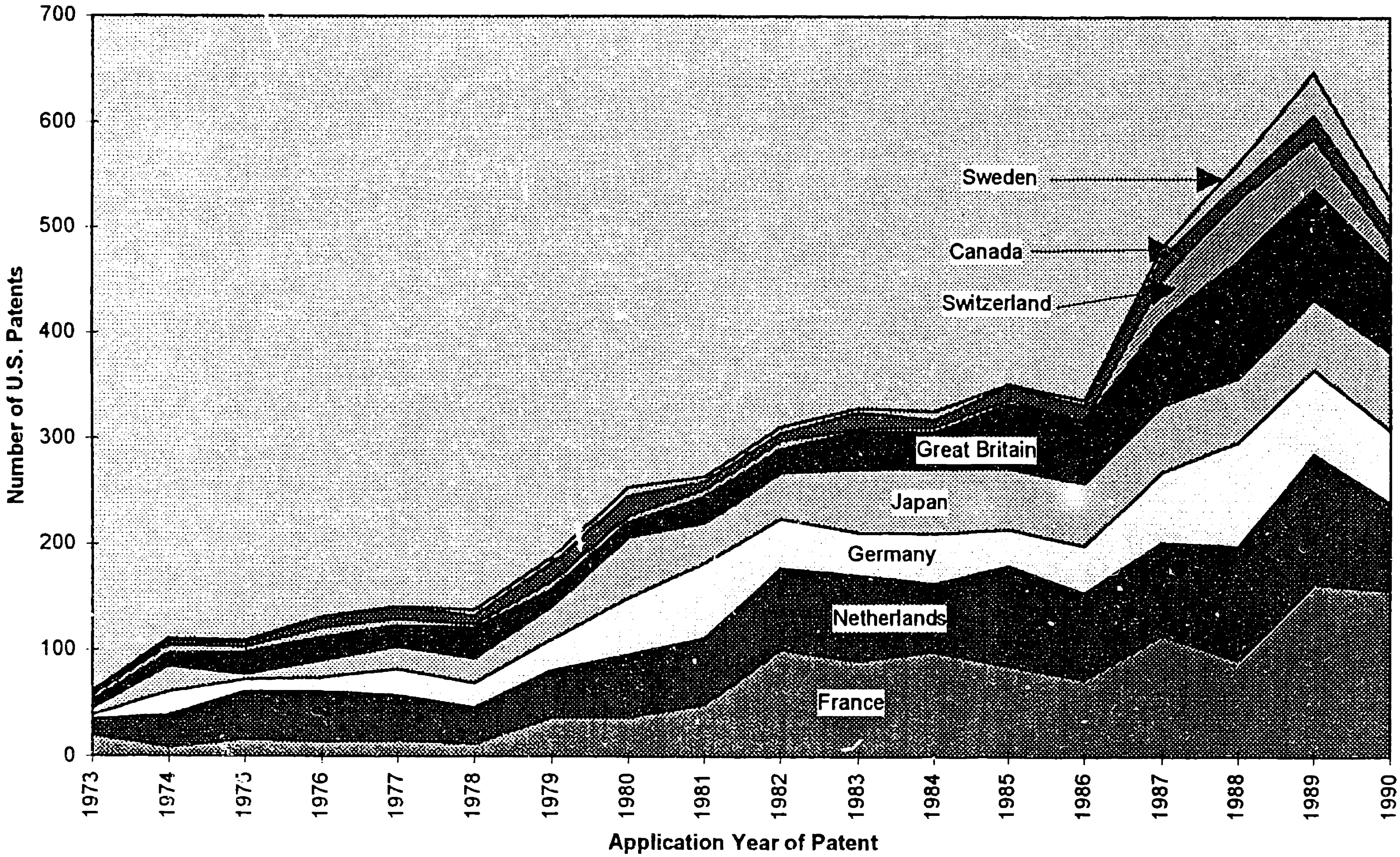
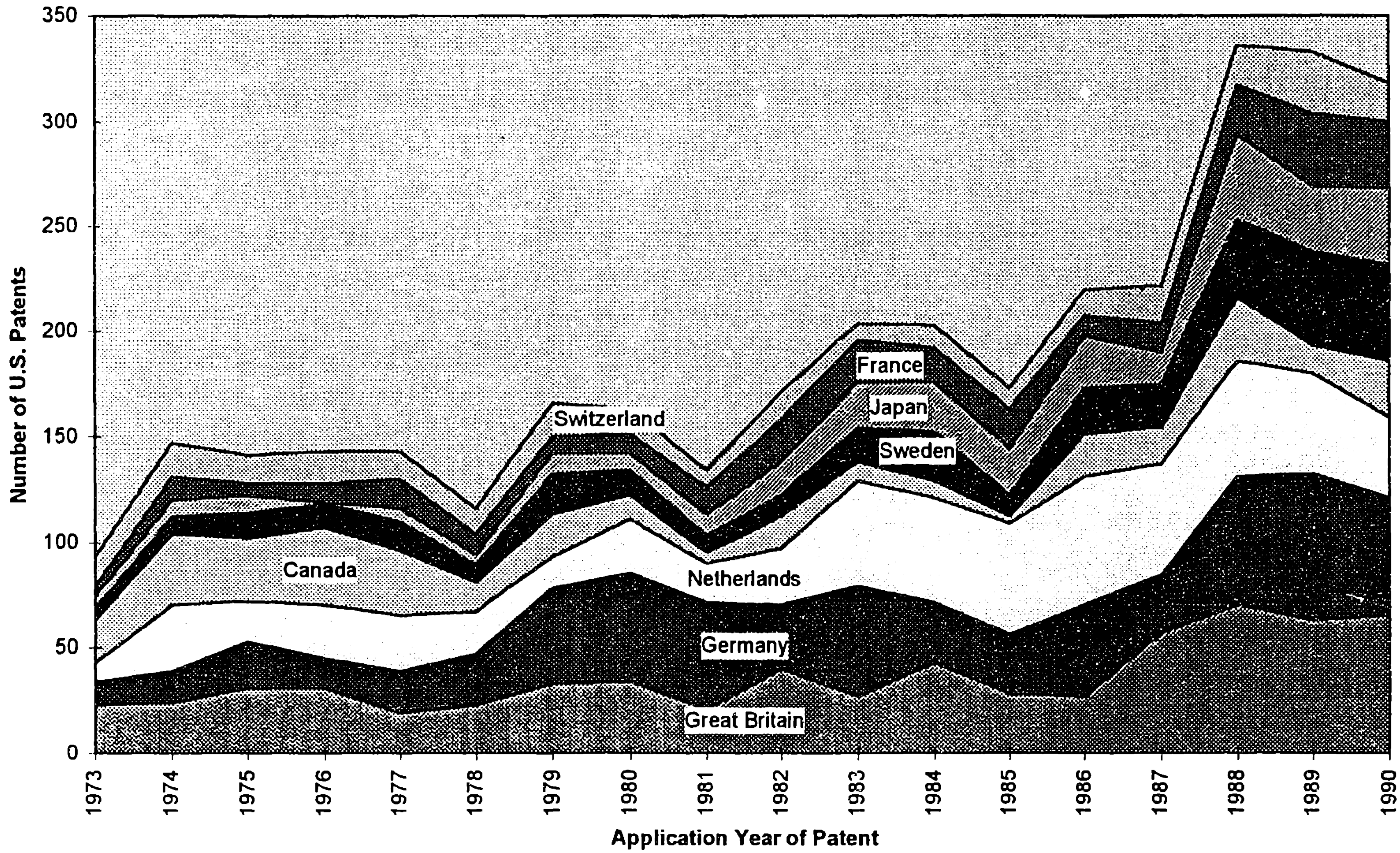


Figure 4.13 U.S. Subsidiary Patents in Mechanical Arts by Home Country of Parent Firm, 1973 1990



Chapter 5 The Geographic Sources of Foreign Subsidiaries' Innovations

1. Overview and Objectives

The previous chapter provided descriptive statistics and background information on the patenting activities of U.S.-based subsidiaries of foreign multinationals. In this chapter, I turn to the first research question, "Where, geographically, do foreign subsidiaries derive their scientific and technical ideas from during the process of technological innovation?"

To answer this question, I constructed a purposefully simple quasi-experiment. The research design is based around a geographic analysis of the citations listed on matched patents issued to three comparison groups: (1) U.S. subsidiaries of foreign multinationals, the focal organizational unit in this study; (2) headquarters (i.e., home country) units of these same firms; and (3) U.S. firms located in the same U.S. state as the subsidiary. The objective of this design is to provide a *relative* measure of the extent to which innovations generated by foreign subsidiaries build upon sources of knowledge resident in host country locations, and/or their home base[1]. The comparison groups provide the benchmarks against which the geography of the subsidiary citations are measured. I discuss the motivation for each comparison group in the following section.

The remainder of the chapter is structured as follows. The next section discusses the research design and presents descriptive statistics. Section 3 presents the main geographic results. Section 4 discusses the results, explores several alternative explanations, and offers additional evidence in support of the proposition that proximity to sources of innovation enables U.S. subsidiaries to assimilate localized knowledge from these sources during the process of technological innovation. Section 5 concludes and outlines the next steps in the thesis.

2. Research Design

The research question addressed in this chapter presupposes the existence of a meaningful measure of the absolute amount of knowledge assimilated by foreign subsidiaries from various sources (locations) during the process of technological innovation. Even if such a measure could be developed conceptually, in practice it would be difficult if not impossible to obtain. The solution adopted here is to establish a *relative* measure by examining the geographic sources of subsidiary innovations in comparative context. Specifically, I compare the geography of the citations listed on U.S. subsidiaries' patents with the geography of the citations listed on patents issued to two reference groups: the headquarters unit of each subsidiary[2]; and domestic (i.e., U.S.) firms located in the same U.S. state as the subsidiary. Figure 5.1 provides an overview of the main features of the research design.

[Insert Figure 5.1 here]

The objective of the subsidiary-headquarters comparison is to provide a basic benchmark of the extent to which foreign subsidiaries draw upon host country knowledge sources during the process of technological innovation. It also provides a test of the more specific proposition that knowledge assimilated by foreign subsidiaries during the innovation process is location-bound, i.e., it does not diffuse rapidly across spatial and institutional boundaries. Stated the opposite way, if knowledge travels seamlessly across borders then subsidiaries located near to its place of origin should not gain a learning advantage over geographically distant headquarters organizations. In fact, the subsidiary-headquarters comparison actually provides a double test of this "geography matters" hypothesis: first by determining whether subsidiaries draw more heavily upon host country sources of knowledge; and second by a similar assessment of their relatively likelihood of drawing upon *home* country sources. In the host country test, the subsidiary has the proximity advantage (to the extent one exists); in the home country, the situation is reversed -- headquarters has the advantage of geography.

To control for factors other than geographic location, I compare matched patents issued to the two groups. The matching process controls for the technical field of the invention and the time period in which the technical activity leading to the patented invention was performed[3]. For each of the 16,209 patents issued to U.S. subsidiaries between 1980 and 1990, I extracted from the patent database all of the parent firm's patents issued to inventors in the home country (the definition of a headquarters patent adopted here) that had the same primary patent class (3-digit level) and same application year as the subsidiary patent. I then selected the headquarters patent whose application date was closest to the subsidiary patent's. The matching process was performed without replacement, meaning that a headquarters patent could only be selected as a match once. Subsidiary patents that did not have a unique technical analogue in the parent organization that year were dropped from the sample. The process yielded 8,444 subsidiary patents and a corresponding sample of matched patents issued to headquarters organizations.

It is interesting to note that nearly half of all subsidiary patents did not have a unique headquarters analogue in the same year. As a prior, one would expect the dropped subsidiary patents to differ importantly from those included in the sample. Specifically, drawing on the reasoning in Chapter 2, one might expect that the dropped patents would be *more* likely to draw upon local (host country) sources of innovation than patents for which a headquarters analogue exists. In fact, this was the main thrust of the fourth hypothesis laid out in Chapter 2:

> *Subsidiary innovations in technical fields that are not major foci of the headquarters organization indicate a logic of exploration, and will be positively associated with external sources of knowledge located in the host country*

If this argument is correct, then the process of comparing only matched headquarters-subsidiary patents (i.e., patents for which a headquarters analogue exists) in this chapter pushes *against* a finding of local knowledge assimilation by U.S. subsidiaries. Thus, if the matching process does introduce a systematic bias into the research design, the results of the geographic analysis are likely to be biased in a conservative direction - away from a finding of localization. Although this is a desirable characteristic from a research design standpoint, the sheer number of dropped patents, as well as the suggestion that they may be systematically different, motivates an explicit empirical consideration of sample selection bias. I take up this issue in the discussion section immediately following the main presentation of results.

Once the sample of matched pairs was constructed, I then assembled a dataset containing all of the citations listed on each subsidiary and headquarters patent. As discussed in Chapter 3, these citations constitute the basic unit of measurement used to trace the location of the intellectual underpinnings of a particular patent. To clarify with an example, I am testing whether patents issued to inventors in Ciba-Geigy's Ardsley, New York research facility are systematically different in terms of the geography of the prior patents they cite as references from technologically and temporally matched patents issued to inventors located in

Ciba-Geigy's Swiss facilities. Do patents issued to the New York facility have a higher propensity to cite U.S. sources? New York sources? Is the reverse true for home country sources, i.e., Do patents issued to the New York facility have a significantly *lower* propensity to cite patents originating in Switzerland than patents issued to inventors based in Ciba-Geigy's Swiss facilities – as is implied by the "geography matters" hypothesis?

The second comparison is between U.S. subsidiaries and domestic (i.e., U.S.) firms. U.S. firms provide a direct and obvious benchmark against which to compare the extent of local citing by U.S. subsidiaries of foreign multinationals. This comparison also pushes to the heart of the "embeddedness" argument outlined in Chapter 2. That is, if participation in local knowledge sharing networks is conditioned, in part, on being an "insider" – an organization recognized as a legitimate member of the network – then it follows that U.S. firms should have an advantage over their foreign counterparts in assimilating knowledge resident in these networks, *ceterus paribus*. Clearly, there are many factors other than corporate nationality that will matter, as was argued in Chapter 2. The purpose of the subsidiary-U.S. firm comparison in this chapter is to establish an initial benchmark of the extent of local knowledge assimilation by U.S. subsidiaries. In this sense, results of this comparison will provide a basis for a more finely-grained exploration of the conditions under which home and/or host country sources of innovation are important to technical subsidiaries – the subject of Chapter 6.

The subsidiary-U.S. firm comparison is also interesting in the context of knowledge sources located in the subsidiary's home base. For example, a finding that U.S. subsidiaries draw upon sources of innovation resident in their home country to a greater extent that do U.S. firms would be an interesting (if expected) result from the perspective of the theory of the multinational firm. Such a finding would also cut against a deterministic conception of the role of geography, i.e., that the *only* factor that influences the technical signals received by an innovating organization is its physical location. In particular, such a finding would provide at least some basis for the proposition that the characteristics of the innovating organization also influence the location of the technical signals it receives - an important assumption implicit in the hypotheses developed in Chapter 2.

To construct the U.S. subsidiary-U.S. firm sample, I began with the subset of subsidiary patents obtained from the previous headquarters-subsidiary matching process. For each subsidiary patent, I then sought a patent belong to a U.S. firm that had the same technological and temporal profile[4]. To facilitate a comparison at sub-national levels, I further stipulated that the U.S. firm's patent had to originate in the same state as the subsidiary patent with which it is matched[5,6]. To return to the Ciba-Geigy example, for each patent issued to the company's New York facility I selected a matching patent originating in New York that was filed by a U.S. firm in the same year as the Ciba-Geigy patent. The question, then, is whether there exist systematic differences across the matched samples in terms of the geography of the prior patents they cite as references. As before, if a unique patent could not be found to meet these criteria, the subsidiary patent (along with its headquarters match) was dropped from the sample. Thus, the final outcome of this process was a sample of matched patents issued to the three comparison groups. Out of the 8,444 matched pairs of subsidiary-headquarters patents, I was able to find 7,751 matching patents issued to U.S. firms. Thus a further 693 subsidiary patents was dropped from the final sample.

As a final control feature in the design of this study, I also constructed a test of how the geographic citation frequencies exhibited by U.S. subsidiaries' patents compare with the "expected" citation rates based on the actual geography of patenting activity as it is reflected in the U.S. patent database. As discussed in Chapter 3, the inclusion of this control is motivated by two considerations. First, patenting activity is highly geographically concentrated in the real world, meaning that, even in the absence of systematic geographic patterns of knowledge assimilation by foreign subsidiaries, we would expect to see considerable geographic concentration in the trails left by patent citations. Drug patents, for example, can be expected to cite a large number of New Jersey patents because that is where a large amount of the world's drug research occurs. Second, the geography of patenting has changed substantially over time (fewer patents originating in the U.S. and more in Japan, for example), meaning that the "expected" proportion of citations to a particular technology-location will be time variant. The test constructed here seeks to eliminate the possibility of drawing spurious conclusions about the geographic sources of foreign subsidiaries' innovations based on citation patterns that could be replicated by a random drawing of patents with the same technological and temporal profile as the cited patents.

To reiterate the mechanics of the controls (discussed in more detail in Chapter 3), each citation listed on a subsidiary patent is matched with a patent that has the same 3-digit primary class and the same application year as the citation. From the set of all such patents, the chosen patent is the one that is closest in terms of its application date to the cited patent[7]. Following Jaffe, Tratjenberg, and Henderson (1993), I compare the geographic pattern exhibited by foreign subsidiaries' citations to the geographic established by the control patents. The control citations thus provide a "baseline expectation" against which to compare the geography of the subsidiary citation trails. To the extent that the geography of the citations listed on U.S. subsidiary patents deviates significantly from the geography of the control citations, a pattern of knowledge sourcing that cannot be explained by chance is implied. Specifically, if the observed pattern is significantly more localized than expected, the implication is that subsidiaries are systematically drawing on sources of innovation in their local (host country) environment. Conversely, the opposite result – less local citing than expected – would suggest that, at the population level, there is no evidence that foreign subsidiaries are systematically "tapping into" sources of innovation in the host country. Either result would have important implications for the questions addressed in this study, and for current debates about the nature and evolution of the multinational enterprise.

2.1 Descriptive Statistics

Before turning to the results of the geographic analysis, I first present descriptive statistics pertaining to the patents used in this chapter. As discussed earlier, the subsidiary patents used here represent a sub-sample of the total population of U.S. subsidiary patents. This is due both to the matching process, which results in a large number of subsidiary patents being dropped from the sample, and to the fact that only subsidiary patents with application years between 1980-1990 are late enough to contain a critical mass of post-1975 citations (the beginning point of the main patent database). The purpose of the present section, then, is twofold. First, to give an indication of the extent and nature of any differences in the actual sample of subsidiary patents used in this chapter from the overall population of subsidiary patents – the subject of the descriptive analysis presented in Chapter 4. And second, as a prelude to the geographic analysis, to provide a basic set of comparative summary statistics on the three groups of matched patents that form the basis of this chapter's experimental design.

Table 5.1 compares the technical composition of the U.S. subsidiary patents used in the this chapter with the composition of the overall population of U.S. subsidiary patents. As in

Chapter 4, subsidiary patents are broken down into five broad technical classes using the concordance in Jaffe (1986, 1989) (Appendix 2). So, for example, Table 5.1 indicates that between 1980 and 1990, 34.3 percent of all U.S. subsidiary patents were in chemicals-related technologies versus a sample population in the current chapter of 39.9 percent. Thus chemical patents are somewhat over-represented in the analysis that follows. In contrast, subsidiary patents in Mechanical Arts are quite under-represented, accounting for only 9.9% of the sample versus a population level proportion of 16.6%. The sample of electronics patents tracks the overall population quite closely in most years, and in the overall proportion (28.0 percent versus a population of 27.6 percent). Drugs and Medical patents are somewhat over-represented. The reason for the deviations from the population proportions stem mostly from differences in the propensity to patent across technical fields. Major chemicals firms typically receive large numbers of patents every year, meaning that a given subsidiary patent in chemicals is more likely to find a headquarters match than a subsidiary patent in, say, the mechanical arts, where the propensity to patent is much lower.

[Insert Table 5.1 Here]

Table 5.2a and 5.2b show the home country and host state composition of subsidiary patenting, respectively, for the sample used in this chapter and for the overall population. Rather than showing the breakdown for each year, Tables 5.2a and 5.2b simply show the pooled representation over the eleven years from 1980 to 1990. Deviations from the population proportions are driven largely, although not completely, by the technological composition of the subsidiary sample. For example, German and Swiss firms are over-represented in the sample, as are the states of New York and New Jersey. This is explained by the fact that these firms and these locations are heavily involved in chemical and pharmaceutical-related technical activity. Other factors that drive these deviations include (1) the size of the parent firms from the various home countries (the larger the firm, the more likely that a matching headquarters patent exits); and (2) the extent to which U.S. subsidiaries of firms from different home countries are differentiated technologically from the parent firm. Both of these factors no doubt influence the over-representation of Japanese firms in the sample: parent firms such as Toshiba, Hitachi and Ricoh receive huge numbers of patents every year, increasing the likelihood of a match; and U.S.-subsidiaries of Japanese firms tend to frequent technical areas that are close to the main areas of specialization of the parent firm (Florida and Kenney 1995; Westney 1993), again increasing the likelihood of a headquarters match. Simply put, fewer subsidiary patents generated by Japanese firms are dropped from the sample than firms from countries such as Belgium, Sweden, and Canada.

[Insert Table 5.2a and 5.2b]

It is difficult to state a priori whether and how these deviations in the sample patents' technological and geographic characteristics will bias the results. In large part, this will depend on how the nature and geography of knowledge diffusion differs across sectors, an issue for which there is virtually no research to draw upon for guidance. I return to this issue later in the chapter where I check explicitly for sample bias through a modification of the research design which allows for the analysis of a much greater proportion of the population of U.S. subsidiary patents.

I turn now to the presentation of some initial descriptive statistics on the characteristics of the patents issued to the three comparison groups: U.S. subsidiaries, headquarters, and U.S.

firms. Since the patents are matched by technical field and time period, and in the case of the subsidiary-U.S. firm pairing, by state location, I concentrate on a different set of indicators intended to check for any "uncontrolled" differences in the groups' patents that might bias the geographic results in one way or another.

Tables 5.3a and 5.3b present information on the "importance" of the patents issued to the three groups based on an analysis of the number of citations they have received by later patents up until the end of 1992, the end point of the database. In the absence of detailed information on the technological and commercial significance of a specific invention, many scholars have turned to patent citation counts as one measure of the impact of a particular invention (see Narin and Olivastro 1988; Henderson, Jaffe, Tratjenberg 1994; Tratjenberg 1990). Studies by Tratjenberg (1990) and Narin and Olivastro (1988), have validated the use of citation counts as measures of patent importance. Table 5.3a shows the average number of citations received by the year-cohorts for each group. Not surprisingly, the numbers are larger for the early years of the sample due to the fact that the older a patent is the more time it has "at risk" of being cited by a subsequent patent. The relevant comparison is thus across groups holding the application year of the patent constant. The right hand side of Table 5.3a presents the results of paired-sample t-tests that test whether the pairs come from populations with the same mean.

Table 5.3a uncovers some modest differences in patent importance across the three groups. Subsidiary patents are generally cited less in each year than U.S. firms' patents, although the difference is significant in only three of eleven years (Test of A=C). However, headquarters patents do appear to be cited less frequently than either subsidiary patents or U.S. firms' patents, although the effect is significant mostly for the late cohorts, i.e., for patents with application years after 1985. It would probably be unwise to make too much of the differences since the average number of citations received by *any* of the group's late-1980s patents is small – less than one citation after about 1988. However, one intriguing explanation for these results is that headquarters patents tend to be cited *later* than U.S. subsidiaries' or U.S. firms' patents – perhaps because knowledge of headquarters' inventions does not reach the U.S. as quickly (where most patents still originate) as does knowledge of inventions generated in the U.S. by local firms or foreign subsidiaries.

Table 5.3b provides a further analysis of inter-group differences in patent importance. The left hand side of the table shows the number of highly cited patents ("winners"), while the right hand side shows the number of patents that have never received a citation through 1992 ("losers"). Again, the comparison is structured across groups rather than across time periods[8]. Modest differences in the importance of headquarters patents relative to the other two groups are again uncovered. Overall, headquarters patents have significantly fewer winners ($p < .001$ compared to either subsidiaries or headquarters) and more "losers" (again, $p < .001$). As in Table 5.3a, matched patents issued to U.S. subsidiaries and U.S. firms do not appear to differ meaningfully from each other in terms of either of these measures of patent importance.

Table 5.4 presents a set of non-geographic statistics on the *citations* referenced by the matched groups' patents for each of three years, 1980, 1985, and 1990 – the beginning, middle, and end points in the series. Overall, characteristics of the groups' citations do not appear to differ markedly from one another. However, headquarters' patents do consistently cite fewer total patents than either of the other two comparison groups. In the 1990 sample, this difference is close to two citations per patent less than U.S. firms (6.03 average citations versus 4.26) and about 1.5 citations per patent less than U.S. subsidiaries (5.82 versus 4.26).

The remaining characteristics of headquarters' citations are roughly similar to the other two: there is little difference in the average age of the citations, in the overall proportion of intra-firm cites (i.e., citations to earlier patents of the same firm), or in the technological diversity or importance of the patents they cite as references. One interesting difference that distinguishes U.S. firms' citation patterns is the negligible number of *international* intra-firm citations (around 1 percent or less versus 3 to 6 percent for the other groups). One explanation is simply that about one-quarter of the U.S. firms' patents in the sample do not belong to major multinational firms, i.e., firms that might conceivably have a network of international affiliates. However, even after controlling for this, a substantial difference remains: in 1990, only about 1.8 percent of the citations on major U.S. multinationals' patents were to their own international affiliates (versus 4.7 percent for U.S. subsidiaries and 3.7 percent for headquarters). One very speculative suggestion is that these results suggest that U.S. multinationals have much less well developed networks for technical knowledge sharing than do non-U.S. multinationals. Clearly, however, such a conclusion requires greater substantiation and thus must await future research.

3. Analysis and Main Geographic Results

By way of introduction to the geographic analysis, Table 5.5 presents information on the citation patterns exhibited by U.S. subsidiaries' patents for selected locations in the U.S. The top section of Table 5.5 shows the proportion of foreign subsidiary patents originating in various locations in the U.S. in 1980, 1985, and 1990. The second section shows the fraction of all *citations* listed on U.S. subsidiaries' patents that originate in these locations. The third section shows the percentage of citations that originate in the same location as the citing subsidiary patent, which I refer to as the *Patent-Citation Matching Frequency*. This measure provides an initial indication of the extent to which U.S. subsidiaries are drawing on technical ideas that originate in their immediate geographic locale. For example, while 10.4% of *all* citations by 1980 subsidiary patents were to prior California patents (second section of Table 5.5), a much higher proportion of California patents was referenced by subsidiary patents that themselves originated in California: 27.1% in 1980. In other words, patents originating in California are nearly three times as likely to cite prior California patents as the total sample of subsidiary patents.

[Insert Table 5.5 Here]

One possible explanation for this result is that U.S. subsidiaries based in California are simply engaged in different kinds of technical activities (in semiconductors, say) than subsidiaries based in other U.S. locations, and therefore could be expected to have distinctive geographic and technological citation patterns. Put slightly differently, inventors in California-based subsidiaries may be citing technology that is relevant to them – technology that just happens also to be concentrated geographically in California. Of course, this is part of the argument underlying this thesis, namely that multinationals are attracted to locations where technologically similar firms cluster together. However, the more specific question being examined here is whether there is evidence that foreign subsidiaries derive a particular kind of agglomeration benefit, namely the ability to assimilate localized knowledge - knowledge that does not diffuse rapidly across spatial boundaries – during the process of technological innovation. In terms of the methodology used here to evidence such spillover localization, I am looking for a pattern of subsidiary citations that is significantly more concentrated than could be explained by the underlying geography of patenting activity.

The measure of this baseline geographic concentration is given by the *Control Matching Frequency*, shown in the bottom section of Table 5.5. This represents the proportion of control patents – patents with the same technical and temporal features as the cited patent – that originate in the focal location. A comparison of the *Patent-Citation Matching Frequency* and the *Control Matching Frequency* reveals that U.S. subsidiaries' patents do indeed exhibit a disproportionately high rate of local citations. Returning to the California example, whereas 27.1% of California citations were from subsidiary patents that themselves originated in California, only 9.1% of the control citations originated there. In other words, it appears that California-based subsidiaries are citing California patents much more frequently that would be expected from a random citation process. I now turn to the comparative analysis of the citation patterns exhibited by the three comparison groups and a more formal set of tests of the claim that U.S. subsidiaries are drawing upon localized knowledge during the process of technological innovation.

Tables 5.6-5-8 present the main geographic results for the host country (i.e., the U.S.), host state, and home country, respectively. The years shown indicate the application year of the citing patent. The left side of each table shows the proportion of each group's citations that originate in the focal location. The right side of each table shows t-statistics for tests of equality in the citation proportions across the various comparison groups.

The host country results (Table 5.6) indicate that patents issued to U.S. subsidiaries are significantly more likely than headquarters' patents to cite prior art originating in the U.S. This pattern holds across all eleven years of patents ($p < .001$ for all years). Surprisingly perhaps, the results also indicate that foreign subsidiaries' patents do not generally differ in their U.S. citation frequency from patents issued to U.S. firms. Only in the case of 1982 patents are the two groups' citation frequencies significantly different from each other -- and there the subsidiary frequency is actually higher. Table 5.6 also shows that the host country citation frequency exhibited by U.S. subsidiary patents is significantly greater than the expected citation frequency derived from the control sample. This pattern again holds for all eleven years of subsidiary patents. The magnitude of the difference is quite large: for the pooled 1980-1990 patents, the subsidiary citation frequency of 65.1 percent is over 7 percentage points higher than the figure for the control sample (58.0 percent). These results, then, are *not* consistent with a citation pattern that could be predicted from a random drawing of patents that have the same technological and temporal characteristics as the subsidiary citations; the subsidiary citations are significantly more localized.

[Insert Table 5.6 Here]

Results from the state-level analysis are presented in Table 5.7. A similar, if somewhat more variable, pattern emerges. Overall, the proportion of subsidiary citations originating in the host state is about 1.7 times higher than it is for headquarters patents (11.1 percent versus 6.6 percent). Differences between the two groups are significant ($p < .01$) in every year but two, 1982 and 1985. To return to the Ciba-Geigy example discussed earlier, these results imply that patents issued to Ciba-Geigy's New York technical facility are much more likely to cite prior patents originating in New York than are patents granted to inventors in Ciba-Geigy's headquarters organization in Switzerland. Recall, too, that subsidiaries' and headquarters' patents are matched for technology and time: differences in citation frequencies cannot be explained by the two organizations innovating in different technical fields or in different time periods and thus systematically citing different kinds of technology.

[Insert Table 5.7 Here]

At the state level, the pattern of local citing exhibited by U.S. subsidiaries' patents again shows little difference from that of U.S. firms. Across all eleven years of citing patents, U.S. subsidiaries' patents actually exhibit a slightly higher (but still significantly different) host state citation frequency. However, the magnitude of the difference is small: 11.1 versus 10.6 percent (Test of A=C). Finally, the state level results presented in Table 5.7 also demonstrate that the pattern of local citing is not consistent with a random citation process: for the combined eleven years, the host state citation frequency exhibited by subsidiary patents is nearly double the expected rate, as reflected in Column D. The test of equality between the proportions is rejected at the $p < .001$ level in ten of eleven years (Test of A=D). Only with 1985 subsidiary patents are the host state citation frequencies close, and even then they are still significantly different from each other ($p < .05$), and in the same direction, i.e., the subsidiary citation frequency is higher.

Before moving on, the results can be summarized as follows. I find a consistent pattern of disproportionately high local (host country and state) citing by patents issued to U.S.-based subsidiaries of foreign multinationals. Across the eleven years of subsidiary patents, the rate of local citing is generally greater than (1) matched patents granted to the headquarters unit of the same firm; and (2) a control sample based on a random citation model. In addition, U.S. subsidiaries appear to be just as "embedded" in local technical networks as U.S. firms, based on the roughly equal propensities of the two organizational groups to cite prior patents originating in the U.S., and in the U.S. state in which they are both located. These results provide a strong initial indication that U.S. subsidiaries draw upon localized sources of knowledge in the host country during the process of technological innovation.

Before exploring several alternative explanations for these results, I turn first to the analysis of home country citation patterns. Whether and to what extent subsidiaries draw upon the home base as a source of scientific and technical knowledge adds an important dimension to the host country findings. Table 5.8 presents the home country results. It differs from the previous tables only in that it contains two measures of home country citation frequency for subsidiary patents: the first measure (Column A) excludes *all* intra-firm citations, i.e., subsidiary patents are not permitted to cite prior patents belonging to the same firm; the second measure (Column B) includes intra-firm citations that are not *direct* self-cites, defined as citations to patents issued to the same innovating unit. So, for example, a citation by a U.S. subsidiary patent to a prior patent issued to the headquarters organization would be included in the calculation of Column B, but excluded in Column A. The purpose of examining home country citation patterns both with and without intra-firm citations is to shed light on the importance of the headquarters unit itself as a source of intellectual input to innovating subsidiaries.

[Insert Table 5.8 Here]

Several interesting findings emerge from Table 5.8. First, with intra-firm citations excluded, subsidiary patents have a consistently lower propensity to cite the home country than do headquarters patents (Test of A=C). For the pooled years, 10.6 percent of all citations by headquarters' patents are to patents originating in the firm's home base. In contrast, only 5.8

percent of subsidiary citations are to home base patents. The difference between headquarters and subsidiary patents is significant in all eleven years ($p < .01$). This finding is consistent with the host country and host state results in the sense that it supports the basic argument that "geography matters". In the home country case, headquarters has the advantage of geographic proximity, and this advantage shows clearly in the citation patterns exhibited by headquarters organizations.

Second, with intra-firm citations *included* in the frequency calculations, the proportion of citations by subsidiary patents to the home base increases substantially, from 5.8 to 10.9 percent overall. *Across the 1980 to 1990 time period, this increase translates into a total of well over two-thousand citations by U.S. subsidiaries to prior headquarters patents.* This result demonstrates the importance of the headquarters organization as a source of knowledge to foreign subsidiaries engaged in technological innovation, a longstanding assumption in the multinational literature that has not been widely tested[9].

Third, U.S. subsidiaries' patents do not appear to cite the home base more than either U.S. firms or more than the "expected" rate indicated by the controls - when intra-firm citations are excluded (Test of A=D and A=E). However, when citations to headquarters patents are added back into the calculations, subsidiary patents show a significantly higher likelihood of citing the home base than either of these benchmarks (Test of B=D, and B=E). These patterns hold across all eleven years of citing subsidiary patent. This finding extends the "geography matters" finding noted previously in an important way, by showing that geography is not the sole determining variable influencing the technical signals received by innovating subsidiaries. Organization also matters. In particular, these results suggest that cross-border knowledge flows are facilitated to an important degree by firm boundaries.

Whereas each of the organizational comparison groups exhibits a strong tendency to capture knowledge originating outside the firm in its immediate geographic locale, foreign subsidiaries also rely upon distant sources of knowledge when that knowledge originates within other parts of the firm (in the case explored here, within the headquarters organization in the home base of the firm).

With the exception of the intra-firm results, the findings presented so far suggest that U.S. subsidiaries look much more like U.S. firms in terms of the location of the knowledge sources they build upon than they do like headquarters units. It is again important to keep in mind that these results are not readily explainable by differences in the kinds of technologies being developed by the three organizational groups. The patents being compared are matched for technical field at a fairly precise level (3-digit patent class).

Surprisingly, perhaps the results presented so far provide no evidence of any time trends in the pattern of home or host country citing: differences across the groups in the geography of their patent citations are consistent in their orientation and stable in their magnitude over time. However, two caveats are in order. First, it is important to realize that these results are generalizable up to the level of the population of subsidiaries and not down to the level of the subsidiary or the firm. That is, the stable temporal pattern exhibited in Tables 5.6-5.8 may mask evolutionary processes (toward a more local orientation, say) at the level of the subsidiary or the parent firm, or even the technical area. Whether there is significant variation across subsidiaries, or within subsidiaries across technical areas, are questions that I explore in a preliminary way in the next section, and more extensively in Chapter 6. What the results do say is that, overall, foreign subsidiaries in the U.S. exhibit a systematic pattern of local knowledge assimilation over the eleven years covered by the study.

Second, it is important to note that the apparent lack of a time trend may also be due to methodological problems, specifically, from a possible truncation bias resulting from the fact that 1980 patents are only able to cite earlier patents dating back five years (to 1975), whereas 1990 patents are able to cite a full fifteen years of prior art. To the extent that the geography of the three comparison groups' citations vary differentially by the age of the citations, this bias could, in theory, mask a time trend. I explore this possibility in the next section of the paper.

4. Discussion and Alternative Explanations

The findings presented so far provide a substantial amount of support for the proposition that foreign subsidiaries systematically build upon sources of knowledge resident in the host country during the process of technological innovation -- a key conjecture in academic debates about the nature and evolution of the multinational firm. Although such a finding accords with recent discussions of the multinational as an organization specializing in the assimilation and creation of knowledge on a worldwide scale, what is striking about the results is their overall strength and robustness over time. Yet, interestingly, in the *home* country citation patterns, I also find evidence to support a more traditional conception of the multinational firm. The large number of citations by subsidiary patents to earlier headquarters' work, as well as the apparently deep embeddedness of the headquarters organization in home country technical networks, are results that are consistent with views of the origins and expansion of multinational firms that date back to Vernon (1966).

Before moving on, it is also worth noting that the results presented so far suggest a more complex picture of the inter-relationship between knowledge, location, and organization than is commonly seen in the literature. Clearly these results, especially the subsidiary-headquarters comparison, strongly suggest that knowledge does not diffuse seamlessly across spatial boundaries – i.e., geography matters. However, the results of the home country analysis extend the argument beyond a simple, mono-causal story about the importance of geography. In the large number of citations exhibited by subsidiary patents to the parent organization, the results suggest that firms also matter, especially, it would appear, as mechanisms through which locally embedded knowledge travels across borders. What remains to be shown is whether knowledge originating in the subsidiary's local environment is also diffused across border internally, i.e., within the boundaries of the multinational firm, in this case from subsidiary to headquarters or subsidiary to subsidiary. I take up this issue in Chapter 7. The results presented so far also extend the conventional understanding of the multinational firm as a mechanism for transferring *firm-specific* knowledge. Much of the knowledge transferred may indeed be specific to the firm, but the results presented here suggest that such knowledge is also derived from external sources (i.e., outside the firm) that are also highly localized. I return to the localization issue later in the chapter through several extensions of the analysis presented so far.

4.1 Alternative Explanations

Having established that the observed citation pattern is consistent with an argument about local knowledge sourcing, I turn now to a consideration of several alternative explanations for these results. The first possibility is sample selection bias: the sample of subsidiary patents used in the chapter is systematically different from the overall population in terms of the geography of its citations. A second possibility (and another form of sample selection bias) is that the presence of acquisitions (i.e., subsidiaries established through the acquisition of a U.S. firm) in the subsidiary sample is biasing the results toward a finding of host country citing. A third possibility is that the basis for matching the three groups patents technologically may not be finely grained enough to control for differences in technological trajectories at the micro level. To the extent that systematic differences in technology exist across the three groups, this could lead to biased results. The fourth possibility stems from the truncation of pre-1975 citations, which is far greater for 1980 citing patents than it is for 1990 citing patents. Such truncation could, in theory, be responsible for the apparent absence of any time trend in the subsidiary citation patterns.

I turn first to the sample selection problem. Although there are several alternative ways to deal with this problem, I chose the most straightforward one. As discussed earlier, the main reason that so many subsidiary patents were dropped from the sample was due to the inability to find a unique matching headquarters patent. In contrast, there were typically several U.S. firm patents that met the matching criteria. To explore for sample selection bias, I took advantage of this fact and performed a citation analysis comparing only U.S. subsidiaries' and U.S. firms' patents. By dropping the headquarters comparison group, I was able to find matches for nearly 90 percent of the population of 1980-1990 subsidiary patents versus only 48 percent in the earlier analysis. As before, each subsidiary patent was matched with a technologically, temporally, and spatially (same state) similar U.S. firm patent.

The results of this "near population" comparison are presented in Table 5.9. Citation frequencies to all three locations – host country, host state, and the subsidiary's home country – are shown in the table, as are tests for differences in the citation proportions. Overall, there are only modest changes from the earlier analysis, and none of the main findings is challenged.

Subsidiary patents cite U.S. and host state sources with almost exactly the same propensity as U.S. firms' patents, 65.1 percent versus 64.7 percent at the national level, and 10.9 versus 11.2 percent at the state level. Tests for differences in the population proportions are generally insignificant across the eleven years, and the pooled 1980-1990 patents show the same result: no difference in citation frequencies at either level.

[Insert Table 5.9 Here]

The propensity of both groups' patents to cite the subsidiary's home country also changes only marginally in moving to the "near population" results, although for both groups the overall propensity decreases somewhat[10]. Comparing Columns E and G (with intra-firm citations excluded), the pooled citation frequencies are virtually identical for the two groups of patents[11]. The pooled results mask some variation across years, but there is no clear direction in this variation and, in any case, the differences are quite small. Interestingly, when intra-firm citations are added back into the calculation of home country citation frequency (Column F), the extent of home country citing by U.S. subsidiary patents once again increases dramatically. As before, the difference between subsidiary and U.S. firms in terms of their propensity to cite the subsidiary's home base reaches significance in every year ($p < .001$) with intra-firm citations included. Thus the main conclusion produced from the earlier analysis does not appear to be an artifact of the sample used: the headquarters organization, itself highly embedded in its local technical environment, acts as an important source of knowledge for U.S. subsidiaries engaged in technical activities.

Having established that the reduced subsidiary sample used in the main analysis does not materially change the results, I turn now to another possible source of sample selection bias: the inclusion of acquired U.S. firms ("acquisitions") as part of the subsidiary sample, which might create a bias toward isomorphism between U.S. subsidiaries' and U.S. firms' citation patterns – a key finding from the earlier analysis[12]. Although this explanation does not contradict the argument being advanced here *per se*, (i.e., acquisitions may be an important mechanism through which multinationals gain access to localized knowledge in the host country) such a result would be far less interesting than, say, a finding that *greenfield* subsidiaries are building upon localized sources of knowledge during the process of developing new technology.

To assess the influence of acquisitions on the observed results, I re-calculated the home and host country citation frequencies separately for patents issued to acquired U.S. firms and patents issued to greenfield subsidiaries[13]. In the interests of space, I summarize and discuss the main findings rather than present a further set of tables. Overall, the results show very little difference across acquisitions and greenfield subsidiaries in terms of the geography of their citations. For the pooled eleven years of data, patents issued to acquired U.S. firms cited U.S. sources 65.6 percent of the time compared to 64.4 percent for greenfield subsidiaries. At the host state level, the figures were 9.6 percent for acquisitions versus 10.9 percent for greenfield subsidiaries. More importantly, results of the matched comparisons (subsidiary-headquarters-U.S. firms) were essentially unchanged when the analysis was performed separately for greenfield subsidiaries and for acquisitions. In eight of eleven years, there were no significant differences between greenfield subsidiaries and U.S. firms in terms of the propensity of their patents to cite U.S. or host state sources. Results of the acquisition-U.S. firm comparisons were similar: no difference in eight of eleven years at the host country level; no difference in six of eleven years at the host state level. However, acquisitions did show a somewhat higher propensity to cite host state sources in the last half of the 1980s compared to their matched U.S. firm counterparts, a results that did not emerge from the greenfield-U.S. firm comparison.

Home country results were also similar across acquisition and greenfield subsidiary patents, with one exception. When intra-firm citations were included in the subsidiary citation frequencies, the effect was clearly greater for greenfield subsidiaries than for acquisitions. Including citations to prior headquarters patents caused the rate of home country citing by greenfield subsidiaries to nearly double. For acquisitions, the home country citation rate did increase by a significant degree, albeit much less in terms of absolute number of citations. In fact, over the 1980 to 1990 time period, patents issued to greenfield subsidiaries were responsible for about 85 percent of all citations to prior headquarters' patents. In other words, greenfield subsidiaries appear to derive a significantly greater learning benefit from the headquarters organization than do acquired U.S. firms. I explore this finding further below.

I turn now to a third possible explanation for the observed pattern, which stems from what is, at root, a research design problem. Although patents issued to the three organization groups are matched by primary patent class, it is possible that the 3-digit matching level utilized does not capture subtle differences in technical field that may be driving the results[14]. That is, it may be the case that subsidiary patents, say, are systematically closer in terms of their technological characteristics to U.S. firms' patents they are matched with than to headquarters' – a situation that could produce the host country citation patterns observed earlier. Given the nature of the matching process, a *systematic* bias such as this seems unlikely. In fact, *a priori*, one would expect that subsidiary and headquarters patents might be more closely matched technologically because of their common organizational affiliation.

Despite its low probability, I checked for such a bias by constructing a measure of technological proximity between the matched patents issued to the three comparison groups. The proximity measure takes advantage of the 9-digit patent class information listed on each U.S. patent. Because each U.S. patent is typically assigned to several 9-digit classes, the measure I use is a simple count of the number of 9-digit commonalties between each matched pair of patents. Table 5.10 presents the mean proximity measures for each of the eleven years of the study and the t-statistic for the test of equality across the comparison groups. The results are interesting, both because they do turn up significant differences in the proximity measures, and because the direction of these differences should, in theory, bias the results in the opposite direction to what was observed. Table 5.10 shows that the matching process used to create the paired comparisons apparently generates significantly closer technological matches between subsidiary and headquarters patents than the other two groups. Thus, the matching process actually biases the results against finding similarities in the citation patterns exhibited by U.S. subsidiaries and U.S. firms, making it all the more surprising that this result emerges so strongly in the earlier analysis. The conclusion from this analysis, then, is that the observed results are not driven by factors relating to the technological characteristics of the three groups' patents.

[Insert Table 5.10 Here]

Finally, I turn to a consideration of the possibility that the truncation of early citations (i.e., those with issuance dates before 1975) is masking the appearance of a time trend in the results. Recall, that the truncation problem is much more severe for 1980 citing patents than it is for 1990 citing patents. This could introduce a bias into the results to the extent that the geography of the citations of the three groups patents differ systematically from each other as a function of the age of the citation. If, for example, subsidiary patents cite a lot of nearby (host state) patents that are relatively recent inventions, and if one or both of the other groups do not exhibit this pattern, then the differential truncation levels of early and late patents will introduce biases in the geographic results. This bias will make comparisons across time periods, between say 1980 subsidiary patents and 1990 subsidiary patents, particularly problematic.

There are two possible ways to approach this problem. One way is to show that the problem does not exist, i.e., that there are no differences across groups in the relationship between the age of their citations and the geography of those citations. In fact, in the next section of the chapter, I show explicitly that there *are* differences across groups in this respect[15]. I therefore chose to deal with this problem in an alternative fashion using an approach modeled after one used by Jaffe, Tratjenberg, and Henderson (1993) to deal with a similar problem. As in that paper, I re-ran the main citation analysis with a specified maximum citation lag (six years) for *all* cohorts of citing patent, i.e., the complete 1980 to 1990 dataset. In other words, I created an "even playing field" for all citing patents by truncating all citations older than six years. Subsidiary patents applied for in 1990 can thus cite patents with application dates going back only as far as 1984. This puts them on equal footing with 1980 patents which were allowed to cite patents with application dates back through 1974.

Overall, the findings from this analysis did not materially change the main conclusions reached through the earlier analysis. The host country results did not change at all; host state and home country results were more variable - and more interesting. To illustrate time trends, I present the results of the analysis in the form of charts (Figures 5.2 and 5.3) showing the relative likelihood of U.S. subsidiary patents citing patents originating in the focal location compared to headquarters patents and to U.S. firms' patents. These likelihood ratios were derived from the results of a series of logistic regression models with host state citation / not host state citation as the dependent variable and dummy variables for the comparison groups. As controls, I included a dummy variable that is unity if the control patent corresponding to each citation also originates in the U.S., as well as a set of technology dummy variables based on a concordance between patent classes and 33 broad fields of technology (Zander 1994). Separate models were fit for each year. The logistic regression coefficients, which in their raw form represent log odds ratios, were then converted into likelihood ratios[16]. Where the coefficients on the organizational dummy variables were not significantly different from zero, this is indicated in the likelihood ratios as unity, meaning the groups in question are equally likely to cite a U.S. originating patent.

[Insert Figures 5.2 and 5.3]

Figure 5.2 presents the host state results. It shows that, with the adjustment for truncation bias noted earlier, there is some indication that the propensity of U.S. subsidiaries to cite host state sources has increased after 1985 relative to headquarters patents. For example, subsidiary patents applied for in 1988 are over three times as likely to cite the host state as headquarters patents. The (truncation adjusted) average over the entire eleven years of originating patents is slightly over twice as likely. Figure 5.3 presents home country results with intra-firm citations included. In the case of the subsidiary-U.S. firm comparison, there is some suggestion that the likelihood of U.S. subsidiary patents citing their home base has decreased over time relative to U.S. firms. Early subsidiary patents, 1980-1984, are on average nearly three times as likely to cite the home base compared to U.S. firms patents. After about 1985, this figure drops to about 1.8.

These results are suggestive, but hardly conclusive. Although the large sample sizes involved push these apparent time trends results into significance (separate analysis, not shown), the effect size is quite small. Moreover the relatively short period of time involved makes the existence of a true trend in the data difficult to discern. In addition, it is worth again noting that these results are based on an aggregate analysis of subsidiary citation patterns and may mask discernible patterns at the level of individual firms, subsidiaries, cohorts of subsidiaries, and/or technologies.

4.2 Subsidiary Innovation Sources and the Space-Time Diffusion Path of Knowledge

Having established the robustness of the main geographic results, I explore further the question of whether the knowledge foreign subsidiaries are drawing upon in the host country is *localized* to its place of origin – i.e., that it does not diffuse rapidly across spatial boundaries. This is an important aspect of the overall argument. After all, the learning advantages that accrue from geographic proximity would have to be considered much less important if it could be shown that, regardless of location, innovating organizations were able to keep abreast of the latest technical developments emerging in distant locations.

One indication of the localization of subsidiary knowledge sources has already been established in the much greater propensity of subsidiary patents to cite U.S. sources of innovation than patents issued to the geographically distant headquarters organization. However, these results capture the *overall* difference in the geographic patterns exhibited by the two groups' citations; they do not explicitly incorporate a temporal dimension. The issue under discussion can be framed in terms of a question: Does the proximity advantage gained by foreign subsidiaries over headquarters units in terms of access to knowledge sources in the host country fade over time as this knowledge is disseminated through various mechanisms?

As a first cut at this question, Figure 5.4 shows the frequency of host state citations by the three comparison groups as a function of the age of the citation[17]. Citations to recent technology are indicated by a short time lag between cited and citing patents. A time differential of zero means that the citing and cited patents were applied for in the same year. The results are striking. U.S. subsidiaries appear to be particularly likely to cite recent work originating in their host state location. A noticeable downward slope is apparent in the subsidiary citation frequency indicating that the older the citation, the less likely it is to have originated in the subsidiary's host state locale. The trend is less clear for U.S. firms, but a downward slope is still apparent. More striking is the headquarters citation path, which exhibits the opposite pattern – and thus supports the argument in the reverse direction. For headquarters' patents, the more recent the citation the *less* likely it is to have originated in the subsidiary's immediate locale. That is, headquarters organizations appear to be significantly disadvantaged in terms of their ability to draw upon recent technological advances originating in foreign locations. These results, then, are consistent with the argument that knowledge travels along a space-time diffusion path; geographic proximity does appear to provide an advantage in terms of a subsidiary's ability to assimilate knowledge of new scientific and technical developments.

[Insert Figure 5.4 Here]

Figure 5.5 presents the home country results. Again, the results are broadly supportive of the localization hypothesis. In the home country case, it is the headquarters organization that appears to derive the advantage of proximity in terms of assimilating recent technical developments. Figure 5.5 shows that the difference between headquarters' citations and the other two groups' in terms of their home country citation propensity diminishes with the age of the citation: headquarters patents show a much higher propensity than the other two groups to cite recently developed technology originating in the home base of the firm, but an only marginally higher propensity to cite older home country technology. Differences across U.S. subsidiaries and U.S. firms are again minimal[18].

[Insert Figure 5.5 Here]

As a further check on the robustness of these results and to explore differences between greenfield sites and acquisitions in this regard, I again fit a series of logistic regressions with geographic match / no match as the dependent variable. Following Jaffe et. al. (1993) I capture the space-time diffusion path by the log of the citation lag (the difference, in number of days, between the filing dates of the citing and cited patents). As controls, I again included a dummy variable that is unity if the control citation originates in the focal location, as well as a set of technological field variables. I also included the technological proximity measure discussed earlier. To assess differences across organizational groups in the rates of fading I ran separate models for each group rather than deal with interaction terms. The results are more transparent and easier to interpret. In the interests of space, I present only the host state and home country results, which the earlier analysis suggested were the most interesting cases.

Tables 5.11 and 5.12 present the host state and home country results, respectively. The negative sign on the lag variable in the U.S. subsidiary model (Model 1) in Table 5.11 captures the fading of localization of subsidiary patent citations to the host state. As suggested by Figure 5.4, the lag variable is negative and significant ($p < .001$). Also consistent with the earlier results, the lag variable is also negative and significant for U.S. firms' patent citations (Model 3), but *positive* and significant for headquarters' citations (Model 2). Again, the implication of this result is that U.S. subsidiaries and U.S. firms are drawing upon new technical developments in the state in which they are both located to a much greater extent than geographically distant headquarters organizations.

[Insert Table 5.11 and 5.12 Here]

Table 5.11 also provides separate results for citations by patents issued to greenfield subsidiaries and acquired subsidiaries. The results are interesting in that they suggest that acquired U.S. firms are especially likely to draw upon recent knowledge originating in the host state – more so than greenfield sites. Comparing Models 4 and 6 (greenfield) to Models 5 and 7 (acquisition) reveals that the coefficient on the lag variable is between two and three times as large for acquisitions as it is for greenfield subsidiaries. Although the coefficient on the lag variable remains negative and significant for both groups, this difference between groups is also highly significant (results not shown). Including intra-firm citations (Models 6 and 7) does not materially affect these results.

Finally, I turn to the home country results presented in Table 5.12. Confirming what was suggested earlier in Figure 5.5, the coefficient on the lag variable is negative and significant for all three groups (Models 1-3). However, the more important result is the magnitude of the coefficient, which is much larger for headquarters' citations than it is for either subsidiaries' or U.S. firms' implying that it is the headquarters organization that has a differential advantage in terms of its ability to assimilate knowledge of *new* technological developments originating in nearby home country locations. An even more interesting result emerges from the sub-group analysis of greenfield versus acquired subsidiaries (Model 4-7). The results show that the negative sign on the lag variable in the original subsidiary model (Model 1) is driven entirely by greenfield subsidiaries. Regardless of how intra-firm citations are handled, the coefficient on the lag variable is negative and significant for greenfield subsidiaries (Models 4 and 6). In the acquisition models, the coefficient on the lag variable drops off. The suggestion, then, is that subsidiaries established through greenfield investment appear to be significantly more in touch with new technological developments originating in their home base than are acquired U.S. firms.

5. Conclusion

The question of where foreign subsidiaries derive their ideas from during the process of technological innovation occupies an important place in a longstanding and still vital debate about the nature and evolution of the multinational enterprise. The primary objective of the analysis contained in this chapter was to shed some initial empirical light on the importance of the home and host country environments as sources of knowledge upon which subsidiary innovations build.

The empirical results contained in this chapter provide an important foundation for the remainder of the thesis. In terms of where innovating subsidiaries draw their scientific and technical ideas from, the answer uncovered in this chapter is "home *and* host". However, the importance of the host country as a source of intellectual input that was demonstrated in this chapter far exceeds what would be expected from the conventional theory of the multinational firm. To recap, I find strong support for the proposition that U.S. subsidiaries assimilate localized (within the host country) spillovers of technical knowledge during the process of technological innovation. Patents issued to U.S. subsidiaries are significantly more likely to cite prior patents originating in the host country and the host state than are matched patents issued to headquarters' units of the same firm. Overall, the pattern of host country citing exhibited by U.S. subsidiaries resembles closely that of U.S. firms, and is significantly more localized than would be predicted from a random citation process. The results are quite robust over the 1980-90 time period.

Interestingly, the geographic citation patterns of U.S. subsidiaries' and U.S. firms' were observed to differ significantly when the analysis turned to the subsidiary's home country. Not surprisingly, this difference is due quite clearly to the large role played by the headquarters organization itself. When all intra-firm citations were excluded form the analysis, U.S. subsidiaries did not demonstrate a systematically greater likelihood of citing the home base compared to U.S. firms. However, when intra-firm citations were added, the results changed dramatically. In particular, subsidiaries emerged as much more likely to cite the home base than did U.S. firms, meaning that the headquarters organization itself is the critical knowledge resource in the home base of the firm. Interestingly, it was also shown that subsidiaries established through greenfield investment were more likely than acquisitions to draw upon knowledge originating from within the headquarters organization.

The results presented in this chapter, while important in their own right, motivate further inquiry into the spatial underpinnings of foreign subsidiaries' technical activities. This chapter established that sources of knowledge in the host country can and do inform innovations generated by foreign subsidiaries in any important way. The next chapter seeks to understand the conditions under which subsidiaries draw upon these sources. In other words, whereas this chapter provided the necessary but essential population level analysis, the next chapter moves the analysis down to the level of the subsidiary, and even the level of the innovation, in search of a more contextualized explanation of the geographic sources of foreign subsidiaries' innovations.

Endnotes

[1] In the results presented below I distinguish between home country citations that are internal to the firm (i.e., citations by a subsidiary to its own headquarters organization), and those that are external to the firm (i.e., firms, universities, hospitals, etc. that are not part of the citing organization). This allows me to check whether subsidiaries are drawing upon home country sources of innovation generally, or whether it is the headquarters organization that is the critical knowledge source in the home base.

[2] For the purposes of this chapter, the "parent" or "headquarters" organization is defined as any patenting unit in the home base of the firm.

[3] Note that another factor that this comparison controls for is ownership. That is, differences across subsidiary and headquarters citation patterns cannot be readily explained by a "corporate effect". Such an effect could manifest itself in different R&D practices or possibly in different patenting policies.

[4] U.S. universities and other public or para-public organizations such as hospitals, government research labs, research foundations, etc. were excluded from the sample frame. The comparison is with U.S. *corporations*. I did not, however, control for characteristics of the U.S. firm, such as its size, age, degree of internationalization. Of course, any of the group's patents can *cite* patents issued to hospitals, universities, etc. I am only excluding these groups' citing patents from the sample frame.

[5] I match on state rather than BEA region, which for reasons discussed in the data and methods chapter is preferred, because of data availability. The patent data available to me on CD-ROM contain state-level information. Although I was able to gather BEA-level data for each subsidiary patent, this required extensive searches of a different, and more detailed, patent database. Time and cost reasons prevented the gathering of these data for the patents belonging to U.S. firms used in this chapter.

[6] In terms of methodological contributions, the matching of the subsidiary and U.S. firms' patents by their state of origin departs from the Jaffe, et. al. (1993) methodology upon which this thesis builds. In that paper, the authors matched originating patents for technology and time period, but not for originating location. The test established here is more direct, and I would argue, more challenging in terms of the probability of observing significant localization patterns.

[7] A final criterion for selecting the control patent is that it cannot itself have been cited by the subsidiary patent.

[8]In particular, because Table 5.3 shows number of winners and losers, the actual number will rise with the total number of patents in the sample. Because U.S. subsidiary patenting has increased over time, the total number of winners and losers has also risen.

[9] It should be noted that one possible explanation for this result is what might be termed a "political effect": e.g., subsidiaries cite headquarter's technology out of politeness or as a way of currying favor with the parent firm rather than because the headquarter's patent was especially important as a technological building block for the subsidiary's invention. I have no good way to test this explanation, although two points are worth making. First, in my discussions with R&D personnel, patent examiners, and fellow academics this possibility did not particularly likely. Second, the results contained in Chapter 7 show that headquarters' units do not cite prior subsidiary patents with anywhere near the same frequency as is observed the other way (i.e., in this chapter). To some extent, this reduces the plausibility of the "politeness" explanation, although it is still possible that subsidiaries, generally the weaker of the headquarters-subsidiary organizational dyad, are trying to curry favor with the strategically and institutionally more powerful arm of the firm.

[10] The decrease is expected. As discussed earlier, the reason this is expected stems from the argument in Chapter 4 that subsidiaries innovating in relatively autonomous technical areas (i.e., areas in which the headquarters may not have a significant patenting presence) can be expected to cite home country sources less and host country sources more. The home country results bear this out, although the effect size looks minor. The host country results are ambiguous: the rate of U.S. citations increases for the "near population" of subsidiary patents, but the rate of host state citations decreases (from 11.1 percent for the restricted sample to 10.9 percent for the "near population" sample). Again, however the size of these differences is minimal.

[11] In the earlier analysis, subsidiary patents actually showed an overall slightly lower propensity to cite the home base than U.S. firms' patents ($p < .01$ for the pooled years patents). In the current analysis, these differences disappear.

[12] The inclusion of acquired U.S. firms in the sample can also be expected to bias the home country results – albeit in the opposite direction. That is, it seems plausible to expect that acquired U.S. firms will be less tightly linked to sources of innovation in the parent firm's home base than would subsidiaries established through direct, greenfield investment. Again, the results presented so far are consistent with this hypothesis.

[13] Recall from Chapter 3, that each subsidiary patent was classified according to entry mode -- greenfield, acquisition, joint venture – based on the actual timing of mergers, acquisitions, and dispositions carried out by most of the world's major manufacturing firms over a 25 year period. It is this data that I used to re-run the analysis for the sub-groups.

[14] The problem noted here is analogous to the problem of matching industries using 2 digit SIC data. Four and five digit SIC data, when available, offers a much more measure of industry proximity. Unfortunately, the patent classification system contains only two levels, 3 digit, of which there are approximately 400 codes, and 9 digit, of which there are approximately 100,000 codes.

[15] Moreover, I also show that the nature of these differences supports the argument that geographic proximity to sources of innovation in the host country provides foreign subsidiaries with an advantage in terms of assimilating technical knowledge from these sources.

[16] The coefficients, B, are the natural logs of the odds ratios, e^B. These are converted to likelihood ratios for presentation in the figures and text body.

[17] The citations are from the pooled 1988-90 patents issued to the three groups. I chose a late period to avoid any biases that might be introduced by left truncation of the citations. A two year period was chosen to avoid small numbers problems and to smooth the inherent variability in the data.

[18]The noticeable downward trend exhibited by all three groups' citation patterns is, by itself, unimportant. It merely reflects the particular home country composition of the 1988-90 patents used to construct it. The important point with respect to this chart is the difference across the groups.

Table 5.1 Technical Composition of Chapter 5 Subsidiary Patent Sample Compared to Population of Subsidiary Patents

	Chemicals (Ex. Drugs)			Drugs & Medical			Electronic Arts			Mechanical Arts			Other		
Year	A Sample (%)	B Full (%)	C A÷B	A Sample (%)	B Full (%)	C A÷B	A Sample (%)	B Full (%)	C A÷B	A Sample (%)	B Full (%)	C A÷B	A Sample (%)	B Full (%)	C A÷B
1980	46.0	38.7	1.19	14.3	11.0	1.31	24.3	25.1	0.97	9.4	16.9	0.56	5.8	8.3	0.71
1981	45.3	41.3	1.10	14.8	10.4	1.43	28.7	25.9	1.11	6.7	14.1	0.48	4.5	8.3	0.55
1982	41.3	34.1	1.21	16.0	11.8	1.36	27.3	27.9	0.98	9.3	16.3	0.57	6.2	10.0	0.62
1983	39.8	34.5	1.15	14.3	9.2	1.55	29.0	28.7	1.01	12.0	19.6	0.61	5.0	8.0	0.63
1984	35.5	31.3	1.14	15.7	11.2	1.40	32.1	29.2	1.10	10.6	19.0	0.56	6.1	9.4	0.65
1985	37.1	32.2	1.15	19.4	16.2	1.20	26.8	29.3	0.92	10.6	14.6	0.73	6.1	7.8	0.79
1986	39.4	32.1	1.23	16.4	14.2	1.15	25.5	26.5	0.96	11.4	17.4	0.65	7.3	9.7	0.76
1987	40.1	33.9	1.18	16.2	14.0	1.16	25.8	28.0	0.92	9.4	14.4	0.66	8.5	9.7	0.88
1988	39.6	34.1	1.16	14.2	12.4	1.15	28.5	27.0	1.06	10.5	17.5	0.60	7.2	9.0	0.79
1989	37.0	31.5	1.18	17.3	14.6	1.19	29.7	29.4	1.01	9.7	15.7	0.62	6.3	8.8	0.71
1990	38.2	34.0	1.12	15.9	14.5	1.10	30.0	26.7	1.12	9.8	17.1	0.57	6.1	7.7	0.79
Average	39.9	34.3	1.16	15.9	12.7	1.27	28.0	27.6	1.01	9.9	16.6	0.60	6.3	8.8	0.72

Table 5.2a Home Country Composition of Sample vs. Population, Pooled 1980-1990

Home Country	A Count (Sample)	B Count (Population)	C Percent (Sample)	D Percent (Population)	E C÷D
Belgium	10	138	0.1	0.9	0.15
Canada	141	458	1.8	2.9	0.64
Switzerland	928	1843	12.1	11.6	1.05
Germany	2675	4069	34.9	25.6	1.37
France	544	1671	7.1	10.5	0.68
Great Britain	994	2850	13.0	17.9	0.72
Italy	75	157	1.0	1.0	0.99
Japan	782	1297	10.2	8.2	1.25
Netherlands	1336	2840	17.4	17.8	0.98
Sweden	174	590	2.3	3.7	0.61

Table 5.2b Host State Composition of Sample vs. Population, Pooled 1980-1990

Host State	A Count (Sample)	B Count (Population)	C Percent (Sample)	D Percent (Population)	E C÷D
California	1030	2049	16.5	16.8	0.98
Connecticut	192	442	3.1	3.6	0.85
Illinois	271	570	4.4	4.7	0.93
Michigan	513	978	8.2	8.0	1.03
North Carolina	239	638	3.8	5.2	0.73
New Jersey	1623	2542	26.1	20.9	1.25
New York	729	1196	11.7	9.8	1.19
Ohio	316	671	5.1	5.5	0.92
Pennsylvania	523	925	8.4	7.6	1.11
Texas	791	2163	12.7	17.8	0.71

Table 5.3a "Importance" of Matched Patents Issued to Three Comparison Groups

	Average Number of Citations Received			Tests for Significance		
	A	B	C	A=B	B=C	A=C
Year	Subsidiaries	Headquarters	U.S. Firms	*t*	*t*	*t*
1980	3.89	4.27	4.81	-1.28	-1.62	-2.91**
1981	4.67	3.94	4.14	2.25*	-0.66	1.68
1982	3.60	3.41	4.25	0.71	-2.99**	-2.33*
1983	3.73	3.48	4.00	0.92	-1.77	-0.93
1984	3.67	3.32	3.58	1.41	-1.03	0.33
1985	3.00	2.69	3.26	1.49	-2.66**	-1.27
1986	2.45	1.97	2.17	2.99**	-1.25	1.58
1987	1.76	1.54	1.83	1.95*	-2.53*	-0.55
1988	1.13	0.84	1.24	3.99***	-4.03***	-1.08
1989	0.60	0.41	0.70	4.51***	-4.56***	-1.50
1990	0.15	0.12	0.21	1.36	-3.66***	-2.43*

*p<.10 **p<.01 ***p<.001

Table 5.3b Number of Highly Cited and Never Cited Patents

	"Winners" (90th Percentile in Citations Received)			"Losers" (Zero Citations Received)		
Year	Subsidiaries	Headquarters	U.S. Firms	Subsidiaries	Headquarters	U.S. Firms
1980	51	70	67	115	106	81
1981	76	61	61	87	96	80
1982	58	46	76	111	126	107
1983	69	61	81	115	124	111
1984	86	73	75	149	128	129
1985	82	71	95	166	174	158
1986	79	60	69	183	218	211
1987	128	103	136	315	340	323
1988	152	102	125	503	591	531
1989	155	95	156	760	811	736
1990	99	132	166	802	815	776
Pooled	1035	874	1107	3306	3529	3243

Table 5.4 Descriptive Statistics on Citations Referenced by Matched Patents Issued to Three Comparison Groups

	Total Number of Patents Cited	Average Number of Patents Cited	Average Citation Lag (Years)	% Intra-firm Citations	% Cross-Border, Intra-firm Citations	% Citations to Same Primary Class[†]	Average # of Primary Classes Cited[‡]	Average # of 9-Digit Class Matches[§]	Average "Importance" of Cited Patents*
1980 Citing Patents									
U.S. Subsidiaries	1323	2.48	4.02	18.8	5.1	50.1	1.67	0.86	80
Headquarters	1217	2.28	3.87	22.6	4.5	48.7	1.63	1.00	79
U.S. Firms	1551	2.90	3.94	24.9	0.4	46.1	1.79	0.91	81
1985 Citing Patents									
U.S. Subsidiaries	2647	4.38	6.06	16.6	6.3	46.9	2.18	0.76	82
Headquarters	2135	3.53	5.91	19.4	3.0	46.7	2.12	0.83	81
U.S. Firms	2922	4.84	6.27	20.4	0.5	38.9	2.46	0.76	83
1990 Citing Patents									
U.S. Subsidiaries	5226	5.82	7.27	14.0	4.7	52.0	2.49	0.78	85
Headquarters	3827	4.26	7.00	20.0	3.7	50.6	2.23	0.80	83
U.S. Firms	5411	6.03	7.41	15.4	1.1	41.0	2.82	0.67	84

[†]Percent of total citations that have the same 3-digit primary class as the citing patent.
[‡]Average number of different 3-digit primary classes cited by each organization's patents.
[§]Average number of matches at the 9-digit patent class level between the citing patent and its citations
*Percentile score, based on the distribution of citation counts for patents granted in the same year.

Table 5.5 Selected Geographic Patterns of Subsidiary Patents and their Citations

Originating Location of Subsidiary Patents	1980	1985	1990
U.S.	100.0	100.0	100.0
Atlantic States Census Region	32.2	28.1	28.3
North Carolina	5.0	2.8	4.7
California	14.6	12.5	12.6
San Francisco-- Oakland -- San Jose BEA Region	7.4	7.5	7.8
Los Angeles-Riverside-Orange County BEA Region	4.3	3.5	2.5
Originating Location of Citations	**1980**	**1985**	**1990**
U.S.	70.3	65.4	65.8
Atlantic States Census Region	22.2	18.8	18.0
North Carolina	1.4	0.6	0.9
California	10.4	9.2	7.9
San Francisco-- Oakland -- San Jose BEA Region	a	a	a
Los Angeles-Riverside-Orange County BEA Region	a	a	a
Patent-Citation Matching Frequency	**1980**	**1985**	**1990**
U.S.	70.3	65.4	65.8
Atlantic States Census Region	28.5	22.7	25.8
North Carolina	2.5	3.9	2.7
California	27.1	17.6	16.6
San Francisco-- Oakland -- San Jose BEA Region	18.1	6.4	12.0
Los Angeles-Riverside-Orange County BEA Region	2.2	9.6	4.3
Control Matching Frequency	**1980**	**1985**	**1990**
U.S.	60.9	59.9	57.3
Atlantic States Census Region	17.2	19.8	18.1
North Carolina	1.7	0.6	0.5
California	9.1	12.3	10.0
San Francisco-- Oakland -- San Jose BEA Region	3.9	4.1	2.2
Los Angeles-Riverside-Orange County BEA Region	2.0	3.7	5.6

[a] Data not available

Table 5.6 Host Country Results

	Host Country Citation Frequency (%)				Tests for Significance		
Year	A Subsidiaries	B Headquarters	C U.S. Firms	D Controls	A=B t	A=C t	A=D t
1980	68.9	54.4	67.0	63.3	7.23***	1.05	3.05**
1981	66.4	55.1	63.3	59.1	5.90***	1.76*	4.22***
1982	65.1	52.2	61.6	60.4	7.13***	2.15*	2.85**
1983	64.9	53.0	65.1	59.9	7.06***	-0.10	3.30***
1984	66.3	56.8	68.1	60.6	6.00***	-1.23	4.02***
1985	63.6	53.1	63.3	59.5	7.08***	0.27	3.03**
1986	64.6	56.4	64.3	55.8	5.89***	0.28	7.08***
1987	66.0	54.3	64.8	57.5	10.02***	1.09	8.21***
1988	65.7	52.4	64.8	56.1	12.65***	0.96	10.33***
1989	64.6	51.0	65.5	58.1	13.62***	-0.96	7.25***
1990	63.4	52.1	63.6	56.7	10.28***	-0.16	6.98***
Pooled	65.1	53.3	64.7	58.0	27.50***	1.15	19.38***

*p<.05 **p <.01 ***p<.001

Table 5.7 Host State Results

	Host State Citation Frequency (%)				Tests for Significance		
	A	B	C	D	A=B	A=C	A=D
Year	Subsidiaries	Headquarters	U.S. Firms	Controls	*t*	*t*	*t*
1980	12.4	7.4	12.4	5.7	4.13***	-0.01	6.13***
1981	10.3	6.8	11.0	6.5	3.24**	-0.59	3.84***
1982	8.0	6.8	8.6	5.3	1.31	-0.63	3.22***
1983	10.8	5.6	10.9	6.2	5.78***	-0.02	5.37***
1984	11.1	6.6	10.2	5.3	5.05***	1.00	7.19***
1985	8.4	8.1	10.2	6.6	0.33	-2.24*	2.50**
1986	9.5	6.5	8.7	4.6	3.94***	1.07	7.66***
1987	11.9	7.1	12.2	5.9	7.18***	-0.39	10.15***
1988	11.6	5.8	10.9	5.6	9.94***	1.14	11.51***
1989	11.8	6.3	10.0	5.0	9.85***	3.21**	13.77***
1990	12.7	6.6	11.3	6.5	9.85***	2.29*	11.00***
Pooled	11.1	6.6	10.6	5.7	19.95***	2.38**	26.77***

*$p<.05$ **$p<.01$ ***$p<.001$

Table 5.8 Home Country† Results

	Home Country Citation Frequency (%)					Tests for Significance					
	A	B	C	D	E	A=B	A=C	A=D	A=E	B=D	B=E
Year	Subsidiaries	Subsidiaries‡	Headquarters	U.S. Firms	Controls	*t*	*t*	*t*	*t*	*t*	*t*
1980	5.1	9.4	8.3	4.9	5.9	-4.65***	-2.82**	0.15	-0.94	4.44***	2.00*
1981	7.2	13.2	10.8	5.5	6.1	-5.99***	-2.94**	1.83*	1.24	7.35***	5.48***
1982	5.3	12.6	10.5	6.4	6.1	-7.92***	-4.86***	-1.38	-1.04	6.26***	4.51***
1983	7.6	14.0	13.8	7.3	7.9	-7.13***	-5.39***	0.32	-0.39	6.94***	5.23***
1984	6.0	11.7	12.3	5.2	6.5	-7.08***	-6.20***	1.19	-0.70	7.96***	4.75***
1985	6.5	11.2	12.8	6.5	5.9	-6.43***	-6.69***	0.05	0.93	5.99***	5.69***
1986	5.3	10.6	8.0	6.5	5.3	-8.29***	-3.58***	-2.00*	0.00	5.89***	6.13***
1987	6.2	10.9	10.4	6.1	6.0	-8.45***	-6.10***	0.10	0.29	8.13***	6.55***
1988	5.2	11.3	9.9	6.1	5.9	-12.46***	-7.87***	-1.97*	-1.61	10.03***	7.88***
1989	5.0	9.3	10.2	6.9	5.3	-9.67***	-9.23***	-4.33***	-0.76	4.88***	5.95***
1990	6.2	10.1	10.9	6.5	6.7	-8.02***	-7.23***	-0.60	-1.19	6.97***	4.11***
Pooled	5.8	10.9	10.6	6.3	6.1	-26.46***	-19.76***	-2.75**	-1.41	22.32***	17.76***

*p<.05 **p <.01 ***p<.001

† Refers to the home country domicile of the subsidiary's parent firm.

‡ Intra-firm citations included

Table 5.9 Comparison of U.S. Subsidiary and U.S. Firms' Citation Patterns ("Near Population" of Subsidiary Patents)

	Host Country Citation Frequency (%)		Host State Citation Frequency (%)		Home Country Citation Frequency (%)			Tests for Significance			
	A	B	C	D	E	F	G	A=B	C=D	E=G	F=G
Year	Subsidiaries	U.S. Firms	Subsidiaries	U.S. Firms	Subsidiaries	Subsidiaries†	U.S. Firms	*t*	*t*	*t*	*t*
1980	69.8	69.1	11.7	12.4	4.4	7.9	4.7	0.49	-0.65	-0.45	4.38***
1981	68.6	65.9	10.2	11.6	5.9	10.6	3.9	2.02*	-1.55	3.20***	9.37***
1982	66.9	66.2	9.0	11.3	4.7	10.0	4.9	0.53	-2.91**	-0.40	7.57***
1983	67.2	67.9	10.6	12.0	6.2	11.1	5.7	-0.59	-1.71	0.89	8.09***
1984	67.9	68.2	10.2	10.3	5.5	10.2	4.1	-0.26	-0.17	2.90**	10.33***
1985	64.8	65.7	8.6	11.0	5.7	9.5	4.8	-0.90	-3.81***	2.05*	8.84***
1986	66.9	67.8	10.0	10.2	4.5	8.5	4.9	-1.02	-0.38	-0.92	7.46***
1987	67.0	66.7	11.5	12.1	5.1	8.7	5.0	0.49	-1.15	0.44	9.11***
1988	66.5	66.1	11.2	10.8	4.6	9.1	5.0	0.66	1.01	-1.18	11.11***
1989	65.8	67.0	11.6	10.6	4.1	7.4	5.1	-1.72	2.19*	-3.34***	6.86***
1990	64.6	66.0	12.0	11.9	5.2	8.2	5.0	-2.00*	0.18	0.62	9.02***
Pooled	66.4	66.7	10.9	11.2	4.9	8.8	4.9	-1.22	-1.56	0.34	27.47***

† Intra-firm citations included $^{*}p<.05$ $^{**}p<.01$ $^{***}p<.001$

Table 5.10 Technological Proximity of Patents Issued to Three Comparison Groups

Year	A Subsidiaries - Headquarters	B Subsidiaries - U.S. Firms	C Headquarters - U.S. Firms	A=B *t*	A=C *t*	B=C *t*
1980	0.22	0.16	0.12	1.90	4.10***	1.89
1981	0.24	0.19	0.11	1.55	4.33***	2.49*
1982	0.22	0.19	0.07	.75	6.00***	4.79***
1983	0.27	0.19	0.10	2.33*	5.68***	3.17***
1984	0.23	0.19	0.10	1.20	4.91***	3.71***
1985	0.24	0.21	0.10	1.12	5.88***	4.89***
1986	0.24	0.15	0.10	3.02**	5.76***	2.91**
1987	0.18	0.13	0.09	2.12*	4.69***	2.45*
1988	0.19	0.13	0.08	2.92**	6.06***	3.11**
1989	0.16	0.15	0.09	.36	4.19***	3.64***
1990	0.19	0.15	0.09	1.97*	4.75***	3.03**

*$p<.05$ **$p<.01$ ***$p<.001$

Table 5.11 Results of Logistic Regressions on Host State Match / No Match, Pooled 1988-1990 Citing Patents

Variable	1 U.S. Subsidiaries	2 Headquarters	3 U.S. Firms	4 Greenfield Subsidiaries	5 Acquisitions	6 Greenfield Subsidiaries†	7 Acquisitions†
Geographic Controls	1.129***	0.958***	1.142***	1.092***	1.126***	1.093***	1.156***
	(0.083)	(0.135)	(0.085)	(0.103)	(0.151)	(0.102)	(0.151)
Log (Citation Lag)	-0.145***	0.175**	-0.102**	-0.110**	-0.262***	-0.093*	-0.270***
	(0.034)	(0.058)	(0.035)	(0.042)	(0.062)	(0.042)	(0.062)
Subsidiary-Headquarters Technical Proximity	0.023	0.118		-0.096	0.185*	-0.124*	0.181*
	(0.047)	(0.067)		(0.063)	(0.079)	(0.063)	(0.078)
Subsidiary-U.S. Firm Technical Proximity	0.082		0.189***	0.104	0.002	0.100	-0.032
	(0.048)		(0.047)	(0.060)	(0.091)	(0.060)	(0.091)
Headquarters-U.S. Firm Technical Proximity		0.291**	0.035				
		(0.090)	(0.071)				
Technical Field Dummies	***	***	***	***	***	***	***
Constant	-1.193***	-4.846***	-1.773***	-1.333	-1.389	-1.530	-1.347
	(0.346)	(1.352)	(0.331)	(0.801)	(1.724)	(0.799)	(1.664)
Percent correctly predicted	87.53	93.78	93.48	94.07	95.13	88.93	87.56
Number of observations	14,443	10,217	15,542	9,870	4,192	10,641	4,388

†Intra-firm citations included *$p < .05$ **$p < .01$ ***$p < .001$

Table 5.12 Results of Logistic Regressions on Home Country Match / No Match, Pooled 1988-1990 Citing Patents

Variable	1 U.S. Subsidiaries	2 Headquarters	3 U.S. Firms	4 Greenfield Subsidiaries	5 Acquisitions	6 Greenfield Subsidiaries†	7 Acquisitions†
Geographic Controls	1.267***	1.008***	0.920***	1.291***	0.903***	1.055***	0.687***
	(0.097)	(0.098)	(0.092)	(0.117)	(0.200)	(0.092)	(0.166)
Log (Citation Lag)	-0.168***	-0.277***	-0.136***	-0.214***	0.041	-0.170***	0.126
	(0.048)	(0.041)	(0.043)	(0.056)	(0.104)	(0.040)	(0.080)
Subsidiary-Headquarters Technical Proximity	0.227***	0.177***		0.183*	0.365	0.257***	0.265**
	(0.060)	(0.053)		(0.074)	(0.122)	(0.050)	(0.087)
Subsidiary-U.S. Firm Technical Proximity	-0.073		0.119*	-0.049	-0.105	-0.004	0.253**
	(0.076)		(0.060)	(0.090)	(0.148)	(0.063)	(0.083)
Headquarters-U.S. Firm Technical Proximity		0.155	0.225**				
		(0.081)	(0.079)				
Technical Field Dummies	***	***	***	***	***	***	***
Constant	-2.160*	-0.587	-2.375***	-1.541	-5.582	-1.160	-4.723*
	(0.922)	(0.772)	(0.680)	(1.238)	(4.540)	(0.765)	(2.375)
Percent correctly predicted	94.43	89.63	93.48	89.29	95.13	88.53	91.13
Number of observations	14,443	10,217	15,542	9,870	4,192	10,641	4,388

†Intra-firm citations included *p < .05 **p < .01 ***p < .001

Figure 5.1 Schematic Overview of Research Design

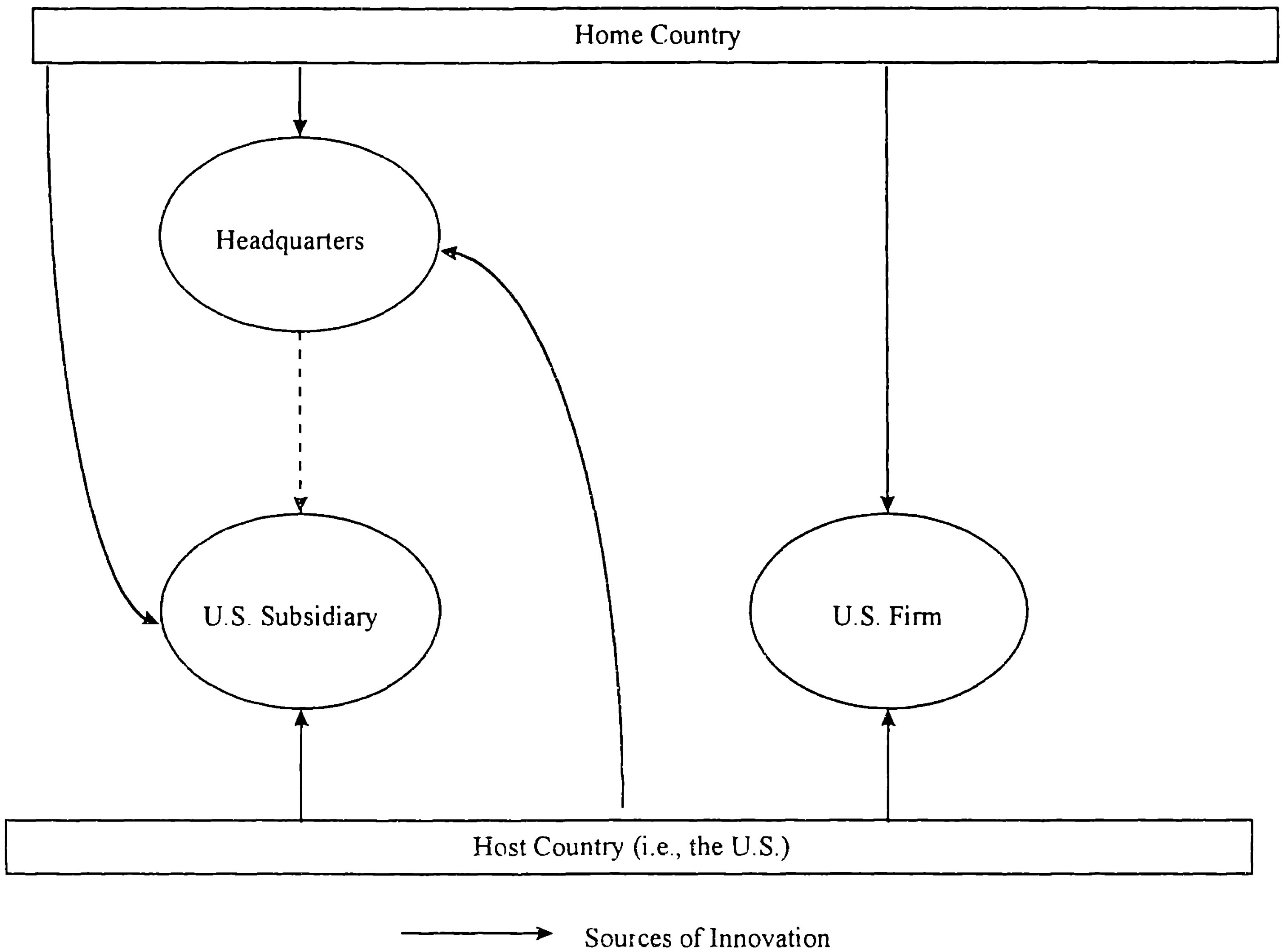


Figure 5.2 Citations to patents originating in the host state

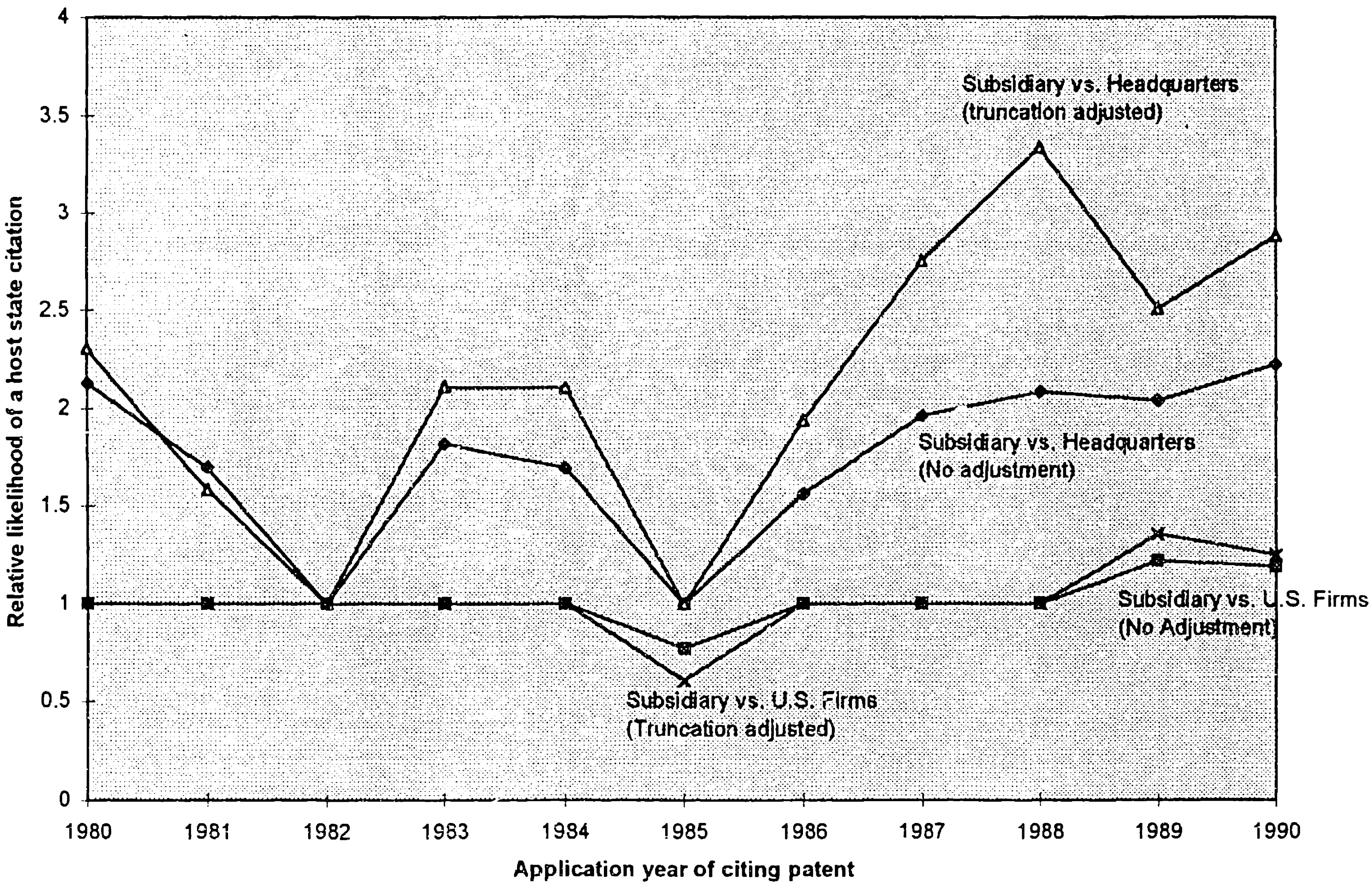


Figure 5.3 Citations to patents originating in the home country (intra-firm citations included)

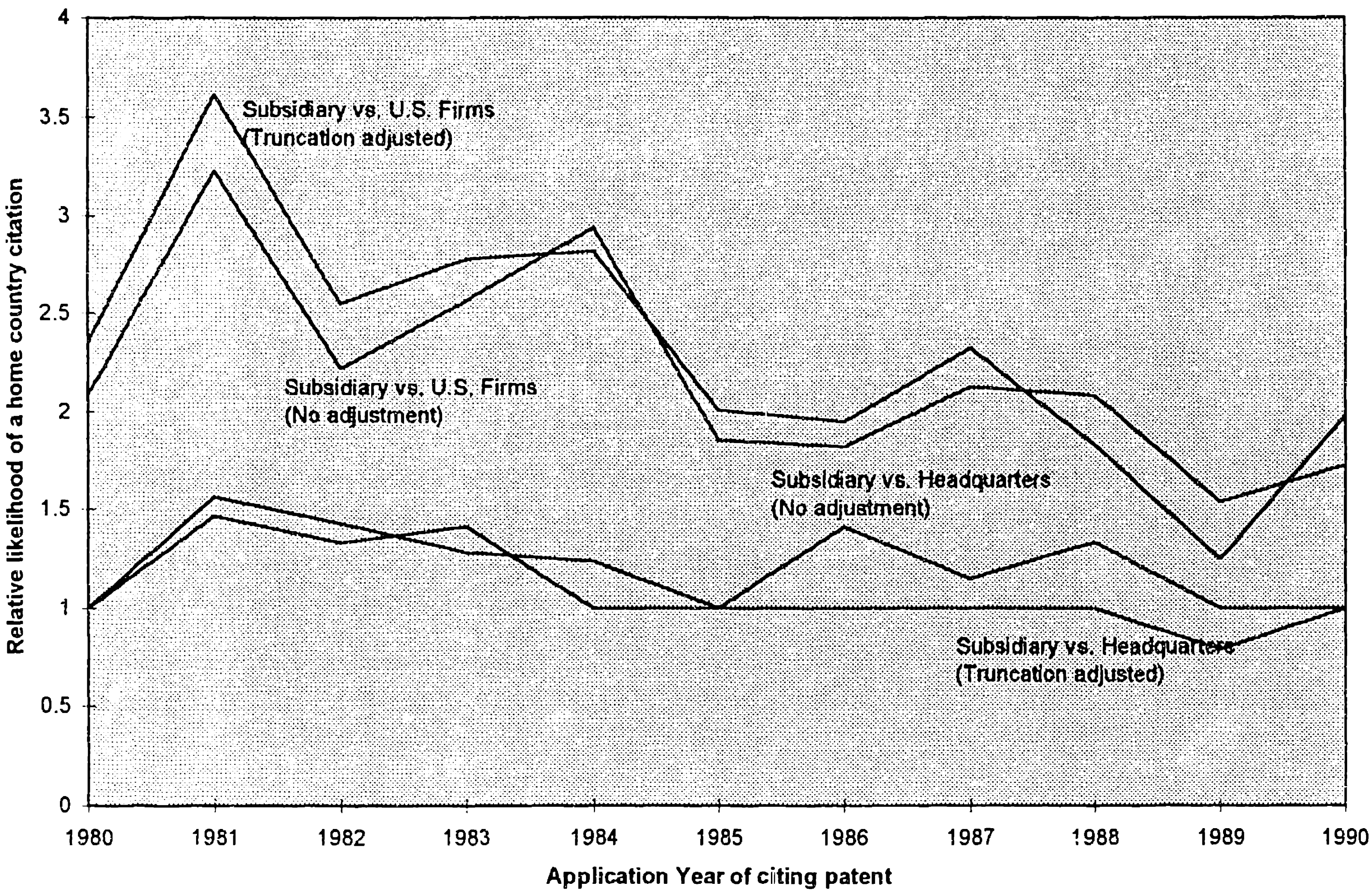


Figure 5.4 Citations to Host State, by Organization and Age of Citation, 1988 Citing Patents

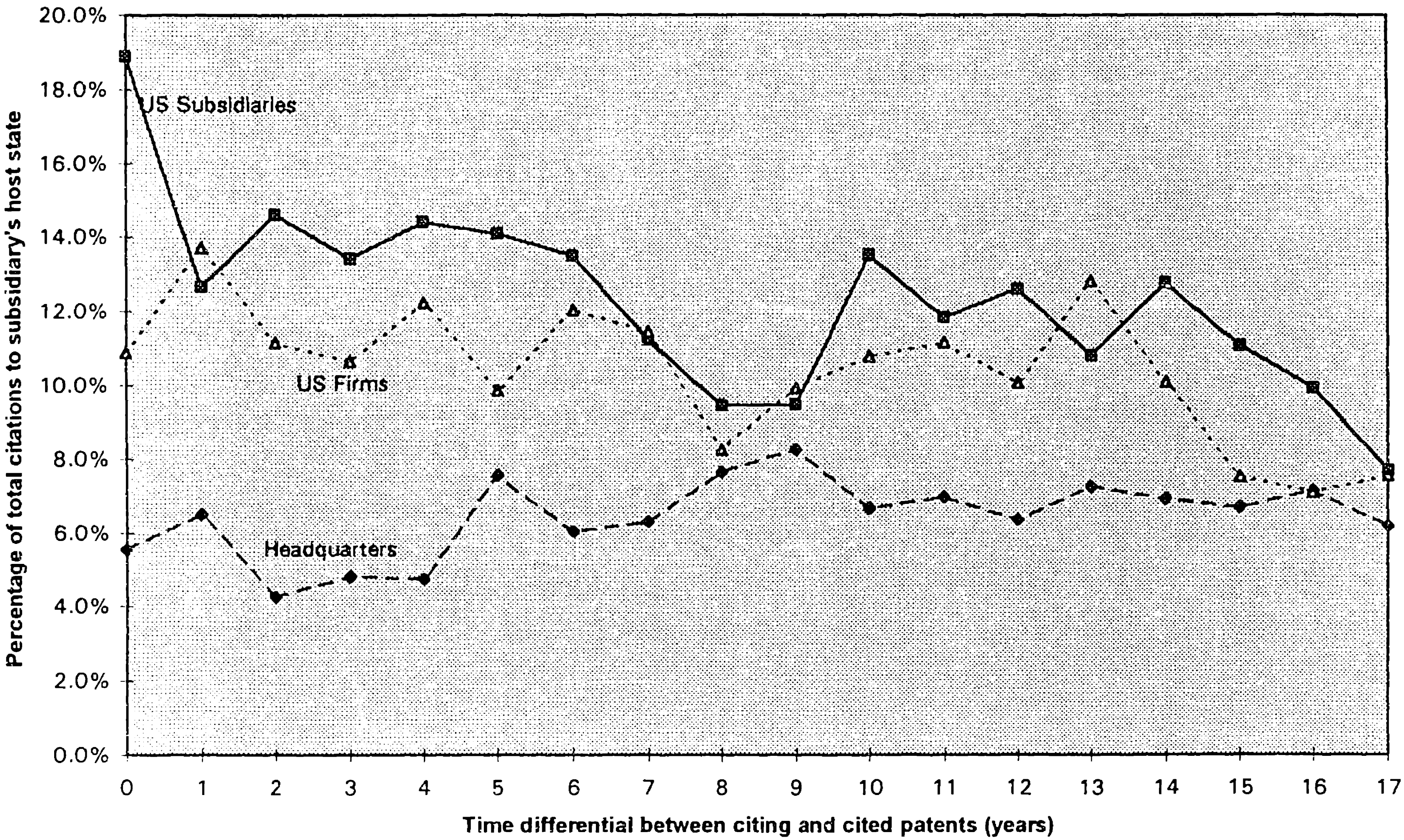
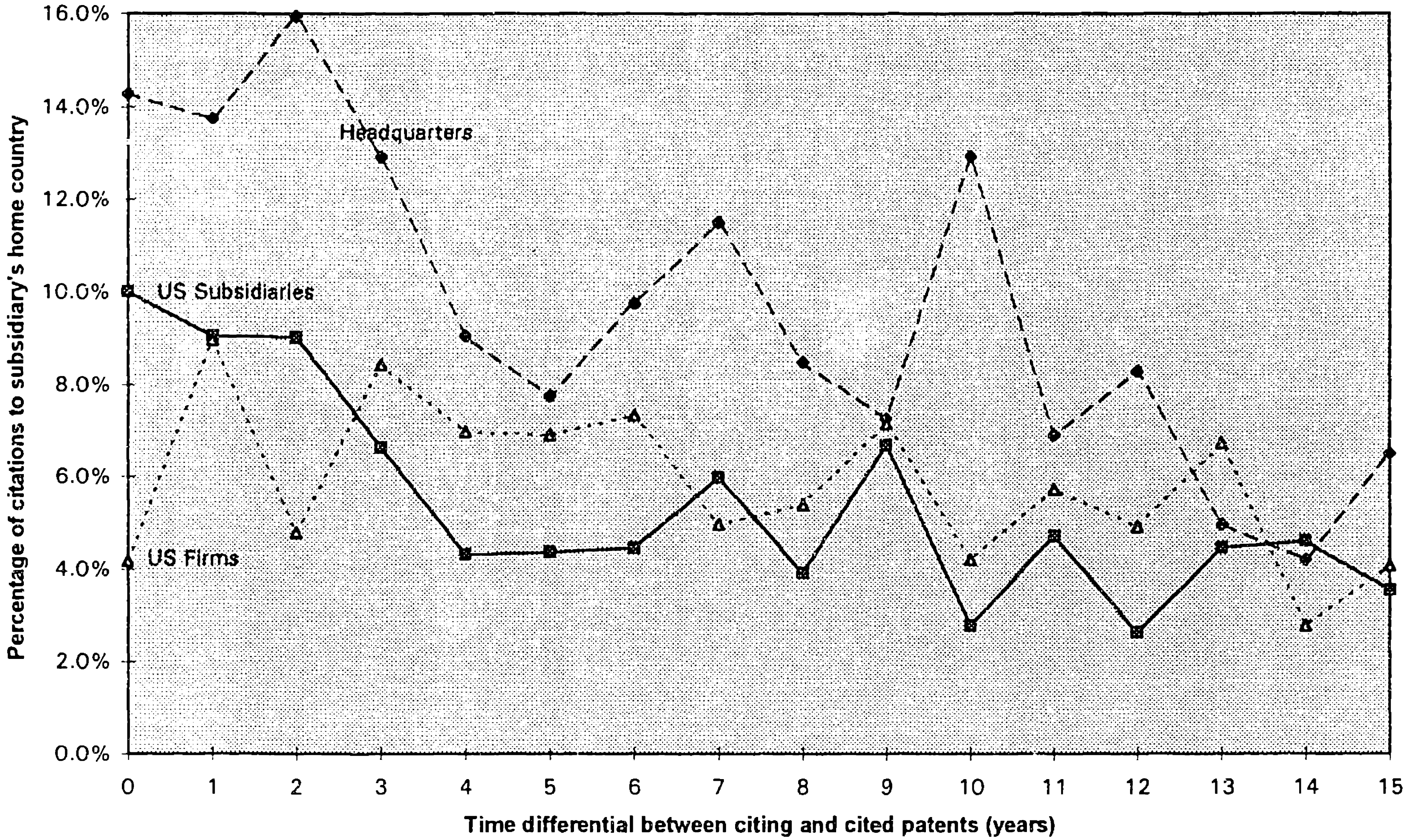


Figure 5.5 Citations to subsidiary's home country by organization and age of citation, 1988 Citing Patents



Chapter 6 Hypothesis Tests

1. Overview and Objectives

The previous chapter provided a substantial amount of evidence showing that foreign subsidiaries in the U.S. draw to an important extent upon *localized* sources of knowledge during the process of technological innovation, i.e., knowledge originating in nearby host country locations that does not spill rapidly across geographic boundaries. These results suggest that proximity to sources of innovation in the host country does indeed provide foreign subsidiaries with a significant learning advantage, a key conjecture in contemporary debates about the nature and evolution of the multinational enterprise. Interestingly, however, the results also indicated that subsidiary innovations are to an important degree grounded in knowledge originating in the home base, most fundamentally from within the parent firm itself – a result that supports a much more traditional conception of the multinational firm.

This chapter builds on these results. The finding that subsidiary innovations are underpinned by ideas originating in both home and host countries highlights the need to shift the unit of analysis from the ecological level – the level of the population of subsidiaries – to the subsidiary level, and, further, to the level of the subsidiary innovation itself. In short, the discovery of multiple geographic influences within the population of subsidiary patents motivates the second research question: "Under what conditions do innovations generated by foreign subsidiaries build upon sources of science and technology in the home and/or host country?

Recall from Chapter 2, where the hypotheses tested in this chapter were formulated, that the argument about the geographic sources of subsidiaries' innovations has two basic components. First, drawing on March's distinction between exploitation and exploration, I argued that the "logic" of subsidiary innovation would influence the location of external search: exploitation – "the refinement and extension of existing competencies, technologies and paradigms" (March, 1991: 85) – was likely to be associated with sources of knowledge in the home base of the firm, most fundamentally from within the parent firm itself. Exploration -- "experimentation with new alternatives" (1991:85) – was, I argued, more likely to be associated with local search, i.e., with knowledge sources originating in the subsidiary's host country locale. Second, drawing on what was termed the "embeddedness" perspective on external innovation networks, I argued that the ability of subsidiaries to participate effectively in local knowledge sharing communities would be conditioned on a set of subsidiary- and parent-level factors that affect the credibility and legitimacy of the subsidiary within those networks. In short, agency – the logic or strategy of subsidiary innovation – would be moderated by structure, the social and institutional barriers to network participation.

I turn now to the empirical tests of the eight hypotheses that were derived from this argument. The next section of the chapter discusses methodological issues relating to the sample of subsidiary patents used in this chapter to test the hypotheses, the operationalization of variables, and model specification. Section 3 presents the main results. Section 4 deepens the analysis through an extensive set of robustness checks on the main results, as well as further analysis designed to shed light on several anomalous findings that emerge from the main results. Section 5 summarizes and concludes.

2. Research Methods

2.1 Sample

In this chapter I restrict the sample of subsidiary patents to those issued to subsidiaries initially established through greenfield investment. Patents issued to acquired U.S. firms are thus eliminated from the sample, as are patents issued to joint ventures[1]. The motivation for this choice is, quite simply, to increase the clarity and interpretability of the results. Acquired U.S. firms may be expected to act differently from greenfield subsidiaries in terms of how their external sources of innovation will be shaped by the hypothesized factors, especially those factors relating to the embeddedness argument. By itself, such differences do not rule out the inclusion of acquisitions, of course, even though, from a theory perspective, greenfield subsidiaries may be more interesting. However, measurement and interpretability problems also provided a strong motivation for excluding acquisitions from the analysis. For example, how should the "age" of an acquired subsidiary be measured? By the date of acquisition? The date of the target's original incorporation? The arguments underpinning this hypothesis simply make much more sense for greenfield investments.

The results presented in Chapter 5 provide a further, empirical rationale for focusing only on greenfield subsidiaries, namely that doing so will apparently not inject a systematic geographic bias into the results. Recall that the evidence presented in Chapter 5 suggested that, overall, there were few differences in the overall *level* of host country citing by greenfield subsidiaries compared to acquisitions. Where the two groups differed was in their propensity to draw upon knowledge originating from within the parent organization, with greenfield subsidiaries being much higher in this regard. Including acquisitions in the sample risked attenuating the impact of the parent firm in the analysis conducted here, yet another reason for dropping them from the sample[2].

Joint ventures are more theoretically interesting, since, by definition, they bring together parties whose technical networks are likely to span borders. However, the relatively small number of patents issued to joint ventures between foreign and U.S. firms, and their concentration in a small number of ventures, would have made many of the hypotheses untestable if conducted for the joint venture sub-group. The choice then was whether to include them in the overall subsidiary sample or to drop them altogether. Again for reasons of clarity and interpretability, I chose to eliminate them from the analysis. Future work will take up the comparison of joint ventures and greenfield subsidiaries more directly.

2.2 Measures

2.2.1 Dependent Variables

The hypotheses relate the geography of the knowledge sources underpinning subsidiaries' innovations to characteristics of the innovation, the subsidiary, and the parent firm. The set of geographic dependent variables are derived from the citations on subsidiaries patents. As discussed in the data and methods chapter (Chapter 3), the fundamental unit of observation in this study is the citation. For reasons discussed there, I do not aggregate these data in the main models presented in this chapter. However, later in the chapter I test the sensitivity of the main results to aggregation of the citation data to the level of the patent[3]. To construct the dependent variables, each citation was first classified according to whether it originated in either the home base of the citing subsidiary or in the host country (i.e., the U.S.). Host country citations were further categorized according to their geographic proximity to the innovating subsidiary at two different levels: same state and/or same BEA region. Table 6.1 lists variable names and definitions.

[Insert Table 6.1 Here]

2.2.2 Independent Variables.

Hypotheses 1-5 linked March's (1991) dichotomy between exploitation and exploration to predicted geographic patterns in the external sources of knowledge that inform foreign subsidiaries' innovations. The two "logics" of subsidiary innovation are indicated by the extent to which subsidiary innovations are (1) adaptive, building on prior headquarters technology; (2) based on fields of technical specialization of the home and/or host country; (3) commercially or technologically "important"; and (4) differentiated from the parent, in the sense that the technical field of the subsidiary innovation is not a major focus of the headquarters organization. Hypotheses 5-9 linked characteristics of the subsidiary and the broader host country organization it is part of to its degree of "embeddedness" in local technical networks, which was hypothesized to moderate between the exploitation/exploration dichotomy and the geography of the subsidiary's external knowledge sources. Subsidiary embeddedness was hypothesized to be driven by (1) the tenure of the subsidiary in its local milieu; (2) the technological resources of the subsidiary; and (3) the overall size of the parent firm's presence in the U.S. in terms of its technical organization. Table 6.2 contains names and definitions of the independent variables.

[Insert Table 6.2 Here]

2.2.3 Control Variables

The methods chapter highlighted the need to control for the underlying geographic distribution of patenting activity before meaningful inferences can be drawn about the locational underpinnings of foreign subsidiaries' technological innovations. These geographic controls are again crucial in this chapter. This inclusion will tend to capture any systematic geographic patterns that exist in the main patent database and thus, the controls can be expected to "explain" much of the underlying variation in the data. In short, the controls act to create a "higher hurdle" for the independent variables to reach significance - and thus a conservative test of the hypotheses.

As in Chapter 5, the controls utilized here are derived from a set of "shadow" citations: matching patents that mimic the technological and temporal profile of each citation referenced by a subsidiary patent. Every row in the data matrix (which, recall, is composed of citation-level indicators) contains a set of geographic indicators derived from these shadow citations. Like the dependent variables, these indicators enter the models as dichotomous geographic variables that take on the value of 1 when the shadow citation originates in the particular location being modeled (home country, host country, host state, host BEA region), and 0 otherwise.

Several additional control variables were included in the models presented below. The first, *Citation Lag*, is the difference between the application dates of the citing and cited patents. As in Chapter 5, *Citation Lag* captures the space-time diffusion path of knowledge by providing an indication of the geographic location of the most recently developed innovations being cited by subsidiary patents.

Finally, I also included two sets of dummy variables to control for unobserved differences in patterns of knowledge sourcing across technical fields and across subsidiaries from different home countries. Although it is possible to develop many conjectures about home base effects (e.g., Japanese subsidiaries may be more likely to tap local knowledge) there is little by way of theoretical guidance that allows for a meaningful set of hypotheses to be derived *a priori* without looking at the data. The same problem arises with respect to hypotheses about differences in the pace and mechanisms of knowledge diffusion across industries / technical fields. Are developments in molecular biology more likely to diffuse rapidly than developments in photographic instrumentation? *A priori*, it is difficult to generate such hypotheses. However, the *suggestion* that there may be differences across these categories motivates the inclusion of dummy variables that will at least control for their effects on the hypothesized relationships.

The construction of the home base dummy variable is straightforward. The technology dummies were constructed from a concordance developed by Jaffe (1986; 1990) and reproduced in Appendix 2. Using this concordance, patent classes (of which there are approximately 300) listed on subsidiary patents were broken down into five broad areas of technology: Chemicals (Excluding Drugs), Drugs and Medical

Technology, Electronic Arts, Mechanical Arts, and Other. It is these five variables (with one dropped) that enter the equations that follow as dummies. Table 6.3 provides a correlation matrix.

[Insert Table 6.3 Here]

2.3 Specification Issues

The data are organized as a panel of citations indexed by year (1980 to 1990), subsidiary, parent firm, and home base. Ideally it would have been possible to use panel regression techniques to investigate the more dynamic hypotheses relating to changes in subsidiary tenure and resources and the evolution of the parent firm's involvement in the host country. Unfortunately, this approach runs into the problem that the citation database is severely unbalanced: many subsidiaries are not issued patents each year. Moreover, of those subsidiaries that are issued patents in a given year, many are issued very small numbers - one or two is not uncommon. These features of the dataset mean that in a "fixed effects" specification typically employed in panel regression techniques, it would have been impossible to distinguish between an unobserved "subsidiary effect" (i.e., something idiosyncratic to a particular subsidiary) and the effect of the independent variables.

The solution to these problems was twofold. First, I fit the main set of regressions using the full 1980 to 1990 series. To control for unobserved year effects, i.e., effects that vary over time but are constant across subsidiaries such as changes in patent laws, or procedures for adding citations to patents, I included a set of dummy variables for each year in the model. Second, I fit the same models in cross section using a single year of data[4]. The cross-sectional approach, which controls for fixed effects, and is intended mainly to provide a robustness check on the results from the main series of regressions.

Although the standard linear regression model places no restrictions on the values that the independent variables can take (except that they cannot be exact linear combinations of each other), it does assume that the dependent variable is continuous. Because the dependent variables used in this study are binary (geographic match / no match) and thus violate this assumption, I used logistic regression techniques as contained in the logistic regression procedure in SPSS (Version 6.1). Logistic regression has the following functional form:

$$Pi = e^{Zi} / (1 + e^{Zi})$$

Pi denotes the probability of outcome i and Z is a vector of explanatory variables.

3. Results

Tables 6.4 through 6.7 present the results of the analysis of the citations listed on 1980-1990 citing subsidiary patents. The tables are organized by geographic dependent variable: Table 6.4 contains home country models; Tables 6.5, 6.6 and 6.7 contain host country models at the national, state, and BEA region levels respectively. Interpretation of the logistic regression coefficients follows the normal pattern: positive, significant values indicate that an increase in that variable (or a movement from 0 to 1 for indicator variables) increases the odds that a citation will have originated in the particular location modeled, *ceteris paribus*. Negative values indicate the reverse. The magnitude of the logistic regression coefficients is more difficult to interpret and is discussed for selected variables below[5]. To increase the readability of the tables, the individual coefficients on the technology, home base, and year dummy variables are not reported. Their group significance is indicated in the tables. I discuss their interpretation in the text.

[Insert Tables 6.4 - 6.7 Here]

Overall, the data provide support for most of the hypotheses specified in Chapter 2 and strongly suggest that the geographic sources of foreign subsidiaries' innovations are influenced by characteristics of the subsidiaries as well as by the nature of the innovations themselves.

Hypothesis 1 predicted that "adaptive" kinds of innovative activities performed by foreign subsidiaries would be linked to technical ideas originating in the home base:

> *Subsidiary innovations that build directly upon prior headquarter's innovations indicate a logic of exploitation, and will be (a) positively associated with external sources of knowledge located in the home country; and (b) negatively associated with external sources of knowledge located in the host country.*

The positive sign on *Adaptation of HQ Technology* in Table 6.4 indicates that subsidiaries that are building directly on prior parent technology have a significantly higher likelihood of citing sources of innovation in the home base -- supporting Hypothesis 1. Note that this variable is included only in those models for which intra-firm citations are excluded (Models 1-4); thus it is not the citations to headquarters patents themselves that are driving this result. Rather, the interpretation of this finding is that when a subsidiary patent cites an earlier patent belonging to the parent firm, the odds that the *remaining* citations on that patent will reference a home country source (other than the parent firm) increase. The coefficient on *Adaptation of HQ Technology* in Models 1-4 implies that these remaining citations are between 1.4 and 1.6 times more likely to originate in the home base than citations listed on patents that do not build directly upon technology developed by the parent firm. The host country results are more variable: Table 6.5 shows that subsidiaries innovations that build upon parent technology are significantly less likely to cite U.S. sources of innovation, as hypothesized (negative sign on *Adaptation of HQ Technology* in all models). However, at the more finely grained geographic levels (state and BEA region) shown in Tables 6.6 and 6.7, this variable is indistinguishable from zero.

Building on the logic of the first hypothesis, Hypothesis 2 posited a relationship between the strength of the home country in the technical area of the subsidiary's innovation and its likelihood of being underpinned by knowledge sources originating in the home base:

> *Subsidiary innovations in technical fields that represent specializations of the home country indicate a logic of exploitation, and will be positively associated with external sources of knowledge located in the home country.*

This hypothesis is strongly supported as evidenced by the positive, significant coefficients on *Home Country Specialization* in Models 1 and 2 in Table 6.4 In technical fields in which the home country is comparatively advantaged (RTA > 1), a citation on a subsidiary patent in that field is about 1.7 times as likely to cite a home country source. Models 3 through 6 extend this finding by substituting locational variables that take into account the interaction of home and host country technical specializations on the geography of innovative search. The positive sign on *Home*

Advantaged / U.S. Disadvantaged in Table 6.4 supports Hypothesis 2. Interestingly, support for the hypothesis also comes from the *Home Disadvantaged / U.S. Advantaged* variable in Models 3-6. Here, the coefficient is *negative* and significant meaning that patents issued to subsidiaries operating in fields of home country weakness but host country strength are much less likely to cite home country sources of innovation.

Building on the second hypothesis, Hypothesis 3 posited that the *host* country's technological position (again characterized as relatively advantaged or disadvantaged in a particular technical field) would also influence the location of the knowledge sources underpinning particular subsidiary innovations:

> *Subsidiary innovations in technical fields that represent specializations of the host country (or region) indicate a logic of exploration, and will be positively associated with external sources of knowledge located in the host country.*

There is once again strong support for this hypothesis. In fact, the hypothesis is supported at all geographic levels in the host country. Table 6.5 shows that when the technical field of a subsidiary invention is one in which the U.S. (as a whole) has a comparative advantage, the odds of a citation to a U.S. source increase by almost 50 percent (Models 1 and 2). In Tables 6.6 and 6.7 *Host State Specialization* is positive and significant in Models 1 and 2 (both tables). When the host state is advantaged in a particular technical field, a subsidiary patent in that field has a greater likelihood (between 1.2 and 1.4 times as likely) of citing a previous patent originating in that state or in the same BEA region. Interestingly, at these geographic levels, the effect of the *home* country's position in the relevant technical field does not seem to matter significantly: *Home Country Specialization* fails to reach significance in Model 2 in Tables 6.6 and 6.7. The locational interaction variables (Models 3-6) generally work well in the host country regressions: signs are always in the expected direction and statistical significance is generally achieved.

It is worth noting again that the significance of the locational variables in all of these models remains even after controlling for the citation level that would be predicted from a random drawing of patents with the same technological and temporal profile as the subsidiary citations[6]. In other words, these variables are associated with a *disproportionate* level of citing to the various locations.

Hypothesis 4 predicted a relationship between the "importance" of a particular subsidiary innovation and the location of the knowledge sources that underpin it:

> *Subsidiary innovations that are technologically or commercially important indicate a logic of exploration, and will be positively associated with external sources of knowledge located in the host country. Less important subsidiary innovations will be positively associated with external sources of knowledge located in the home country.*

Support for this hypothesis is mixed. The effect of *Patent Importance* is significant and in the expected direction in the U.S. models (Table 6.5). More important subsidiary patents, measured by the number of times they are cited by subsequent patents, are more likely to build on prior knowledge originating in the U.S. However, the effect of *Patent Importance* drops off at more micro geographic levels – host state and region. The hypothesis is also supported in the opposite direction with the results of the home country models (Table 6.4), which show that less important subsidiary patents are significantly more likely to be underpinned by sources of knowledge originating in the home base. This is consistent with the underlying argument supporting the hypothesis. Part of the problem with the test of this hypothesis stems no doubt from the measure used. Although citation counts have a well established basis as a measure of patent importance (Narin and Olivastro 1988; Tratjenberg 1990), the inclusion of later years in the sample creates problems distinguishing highly cited patents from patents of average or below average importance. For comparability across years, I used percentile scores rather than the actual citation counts, but, even then, it is difficult to distinguish variation across patents that have had only a short "at risk" period of being cited[7].

Hypothesis 5 posited that the geographic sources of subsidiaries' innovations would be affected by the degree to which the subsidiary patent is differentiated technically from patents developed by the headquarters organization:

> *Subsidiary innovations in technical fields in which the subsidiary has established a distinctive technical specialization within the firm will be (a) positively associated with external sources of knowledge located in the host country; and (b) negatively associated with external sources of knowledge located in the home country.*

This hypothesis is generally supported in the host country models. At the national level (Table 6.5), the sign on *Subsidiary Specialization* is in all cases positive and reaches significance in Model 5, when intra-firm citations are included. Support is stronger at the state and BEA levels (Tables 6.6 and 6.7). *Subsidiary Specialization* is positive and significant in all but two models (Model 4 in both Tables) indicating that when the subsidiary's share of total company patents in a particular technical field rises, the more likely it is to utilize sources of knowledge originating in its immediate geographic locale[8]. The hypothesis is also supported in the home country models (Table 6.4) which, again, with the exception of Model 4, show that subsidiaries with greater ownership of a particular technical area within the firm tend to draw less upon home country sources of innovation in those areas -- including less from the parent firm itself. As in the host country models, the variable is attenuated by the inclusion of home base dummy variables in Model 4 meaning that the models cannot distinguish between *Subsidiary Specialization* and more general home base effects. This result implies that there exists systematic differences across firms from different countries in the degree to which their U.S. subsidiaries build autonomous, differentiated technical specializations.

The remaining three hypotheses link the geographic sources of subsidiary innovations to factors that may facilitate or impede the subsidiary's ability to participate in external innovation networks in the host country.

Hypothesis 6 predicted that subsidiaries with longer tenure in the host country and region would be more embedded in the local technological milieu and thus have greater access to knowledge originating in these locations. As a result, older subsidiaries would also be less dependent on home base sources of innovation, including the parent.

> *Innovations developed by older subsidiaries will be (a) positively associated with external sources of knowledge located in the host country; and (b) negatively associated with external sources of knowledge located in the home country.*

This hypothesis is not supported. The sign on *Subsidiary Age* is in the wrong direction in all host country models (Tables 6.5 - 6.7), although it is generally insignificant at the state and BEA levels (Tables 6.6 and 6.7). In addition, *Subsidiary*

Age is also *positively* related to home country sources, meaning that older subsidiaries are more likely to draw upon the home base during the innovation process - again counter to the basic logic of Hypothesis 6. I explore several possible explanations for these results in the next section.

Hypothesis 7 posited that subsidiaries with significant technological resources would be more likely to be effective functioning members of local technology networks and less dependent upon the parent firm. The argument was based primarily on the notion of reciprocity which has been observed to underpin knowledge sharing networks: receiving valuable knowledge often requires the recipient to give valuable knowledge in return. Thus:

> *Innovations developed by subsidiaries with greater technological resources will be (a) positively associated with external sources of knowledge located in the host country; and (b) negatively associated with external sources of knowledge located in the home country, including the parent firm.*

This hypothesis is supported at all levels in the host country, regardless of model specification, as indicated by the positive significant sign on *Subsidiary Resources* in all models shown in Tables 6.5-6.7. Citations on subsidiary patents are more likely to originate in the host country, the host state and the host region as the number of patents issued to the subsidiary increases. Larger subsidiaries thus appear to be more deeply embedded in the local milieu than smaller subsidiaries. The home country models (Table 6.4) are less clear with respect to the relationship between the subsidiaries resources and its geographic orientation. When intra-firm citations are excluded from the models (Models 1-4), the results are as expected: larger subsidiaries are generally less likely to draw upon the home base (signs negative; coefficients significant in Models 1-3). However, the inclusion of intra-firm citations (Model 5) causes the sign on *Subsidiary Resources* to switch. In other words, when subsidiaries are allowed to cite the parent firm, the larger the subsidiary the more likely it is to cite the home base. This implies the somewhat surprising conclusion that it is the largest group of subsidiaries who draws heavily upon parent technology. I explore this result further in the next section in the context of investigation the anomalous results with respect to *Subsidiary Age*.

Hypothesis 8 predicted that a subsidiary's propensity to draw upon knowledge sources in the host country environment would be conditioned not only on its own structural attributes (age, resources) but also on the overall presence of the parent firm in the host country. Formally, the hypothesis was formulated as follows:

> *Innovations developed by subsidiaries that are part of a large host country organization will be (a) positively associated with external sources of knowledge located in the host country; and (b) negatively associated with external sources of knowledge located in the home country, including the parent firm.*

This hypothesis receives support at the host country level in all models (Table 6.5). However, at the state and host region levels, (Tables 6.6 and 6.7), *U.S. Presence* is generally insignificant. This raises the intriguing possibility that the benefit of a large host country organization is that it connects a subsidiary to a broader technical network – i.e., a *national* network -- than would otherwise be the case. Hypothesis 8 is, however, supported in the reverse direction in all home country models (Table 6.4). As *U.S. Presence* increases, U.S. subsidiaries draw less upon sources of innovation in the home base. This effect holds regardless of model specification and treatment of intra-firm citations.

4. Robustness Checks and Further Analysis

With several notable exceptions, the results presented so far generally support the hypotheses formulated in Chapter 2. As a check on the robustness of the main results, I conducted several additional tests. First, I aggregated the citations to the level of the patent, meaning that each subsidiary patent received an overall "geographic orientation" rating depending on whether it over or under cited each of the locations being modelled. Although this approach has the effect of reducing the sample size by a factor of about five (since each patent cites on average about five prior patents), the previous results proved quite robust. I also fit the models in cross-section using a single year of citing subsidiary patent to control for "fixed effects" (i.e., unobserved subsidiary effects that might be driving the results)[9]. Again, the results were quite robust, although not all variables were significant in all models – again due mostly to the dramatic drop in sample size and the inherent "noise" in patent citation data. None of the earlier results was directly contradicted.

The major exception to the generally strong support for my hypotheses is the result with respect to the age of the subsidiary. The age hypothesis was not only not supported, it also appears to be mis-specified judging from the signs on *Subsidiary Age* in home and host country models. There are several possible explanations, both methodological and substantive. Methodologically, the results could simply reflect problems stemming from multicollinearity. The correlation matrix reveals that *Subsidiary Age* is quite highly correlated with *Subsidiary Resources* ($r=.53$; $p<.01$). Although the large sample size generally pushes against such an explanation, it is possible that including both variables in the model could cause the sign on *Subsidiary Age* to switch – a classic symptom of multicollinearity. Yet another possible methodological explanation could arise from the inclusion of year dummies in the models, which might be mimicking – and thus controlling for -- the effects of *Subsidiary Age* to a significant degree. I checked both possibilities by refitting the models omitting each and then both of the possible confounding variables. The host country results did not change materially: *Subsidiary Age* still failed to reach significance at all geographic levels, although the sign was generally in the hypothesized direction, in contrast to the results presented earlier. Home country results were also largely unaffected by the alternative specification: *Subsidiary Age* remained positively associated with U.S. subsidiaries' propensity to cite the home base, meaning that older subsidiaries still appear to be drawing more upon home country sources of knowledge than younger subsidiaries – contrary to Hypothesis 6.

Another possible methodological explanation arises from the inclusion of different subsidiary "cohorts" in the pooled 1980 to 1990 results. For example, early entrants, say subsidiaries that filed their first patent before 1975, would have already accumulated considerable host country experience by the time of the 1980 start date of the citation analysis. Their inclusion in the models is likely to attenuate the effects of *Subsidiary Age* since they are, in a sense, already "old" and thus more likely to have reached an equilibrium position with respect to the geography of their external sources of innovation.

To observe more directly the dynamic effects of a subsidiary's tenure in the host country on its geographic sources of innovation, I conducted a subgroup analysis using a cohort approach. Taking the population of subsidiaries that filed their first patent application between 1979 and 1981, I refit the models using the 1980 to 1990 citation data[10]. For this cohort, the 1980 to 1990 period covers approximately their first decade in the U.S., where the evolutionary effects underpinning this hypothesis are likely to be more visible. In fact, the results of this analysis (not shown) indicated a *positive* relationship between *Subsidiary Age* and host country citing, as predicted by Hypothesis 6, although the results were significant mostly at lower geographic units of analysis – host state and BEA region. Interestingly, however, the results also showed a positive relationship between the age of the subsidiary and the propensity to cite the *home* country – consistent with the earlier results, but again contrary to Hypothesis 6.

In addition to these methodological possibilities, there are several substantive explanations for the anomalous results with respect to *Subsidiary Age*. First, the results could reflect an empirical phenomenon that I did not explicitly consider in formulating the hypotheses, namely the presence of a late period cohort of "technology seeking" subsidiaries. Such a phenomenon would manifest itself in the youngest subsidiaries being more oriented to the local environment and less oriented to the home country environment than was assumed in the original development of the hypothesis. This possibility, while it does cut against the embeddedness argument that underpins Hypothesis 6, does have some basis in the multinational literature (Dalton and Serapio 1993; Herbert 1989; Westney 1990, 1992).

To investigate this possibility, I examined the citation patterns of the most recent cohort of entering subsidiaries, those who filed their first patent application between 1988 and 1990. Table 6.8 presents the results of this analysis. The numbers in the tables are t-statistics derived from comparing the propensity of this cohort's patents to cite home and host country locations against a "baseline" expected propensity as defined by the geography of the matching control citations. Values over 1.96 (below -1.96) indicate a significant degree of over (under) citing by the subsidiary relative to the controls. As an additional point of comparison, I include the same figures for the oldest cohort of subsidiaries, defined as those established before 1975. The results show a perhaps surprising degree of host country citing by this youngest entering cohort. At each host country level, the 1988-1990 group of entering subsidiaries is significantly more likely to cite local sources than would be predicted from the underlying geography of patenting, as defined by the controls. In addition, the youngest cohort appears to be just as embedded in the host country technical environment as the oldest group of subsidiaries – contrary to Hypothesis 6, but consistent with both a technology seeking or "tapping" story and with the earlier anomalous results.

[Insert Table 6.8 Here]

The home country results shown in Table 6.8 are also somewhat surprising. Both oldest and youngest cohorts turn out to overcite the home base, although this results is due entirely to intra-firm citations, i.e., citations to the parent firm. When intra-firm citations are dropped from the calculations, the home country citation frequency of both cohorts declines to the point where it is almost exactly as would be predicted from a random citation process – neither higher nor lower than expected. Interestingly, the drop in significance is less pronounced for the youngest group, although it is still enough to shift the home country results into non-significance.

Figure 6.1 extends the findings for the youngest cohort by showing graphically the position of subsidiaries from the top ten home country domiciles in terms of their propensity to cite home and host (in this case, host state) sources of innovation[11]. The numbers on the horizontal and vertical axes again represent t-statistics of the test for significance between the actual citation frequency and the control citation frequency for the patents applied for by the youngest cohort of subsidiaries between 1988 and 1990. Thus scores to the right of 1.96 along the horizontal axis represent significant ($p < .05$) overciting of the host state. Similarly, scores above 1.96 along the vertical axis represent significant overciting of the home base, including the parent.

[Insert Figure 6.1 Here]

The analysis shows that the youngest group of subsidiaries from five of the ten home countries overcite the host state: Great Britain, Switzerland, Sweden, Germany, and Canada. France and the Netherlands are also very close in this regard (t-statistic 1.95). Of this group, only Swedish firms come close to overciting the home base, including the parent (t-statistic 1.91). Most simply cite the home base at approximately the level that one would predict from the control citations; none is significantly below the expected level.

Interestingly, the finding in Table 6.8 that the newest cohort of subsidiaries overcites the home base turns out to be driven largely by Japanese firms, who emerge as a clear outlier in terms of their reliance on home country sources of innovation. A further analysis reveals that the high level of home country citing by subsidiaries of

Japanese firms is not driven solely by citations to the parent firm. Even with intra-firm citations excluded, Japanese subsidiaries still overcite the home base ($p < .01$). Although this result is certainly exceptional when compared to the population of non-Japanese subsidiaries, it does accord with both the literature on overseas R&D units of Japanese firms (e.g., Florida and Kenney 1995; and Westney 1992a) and the broader literature on Japanese organizations. What is perhaps most surprising about the findings with respect to Japanese subsidiaries is not so much the home country results, but rather the host country results, which to reiterate, show a level of host state citing that is no greater than the level one would expect from a random citation process. One possible explanation is suggested by Teece (1992) who argues that acquisitions are the main mechanism through which Japanese firms have gained access to U.S. technology and technical networks. This is an interesting line of inquiry that will be pursued in future research.

To recap, the results presented in Table 6.8 go a long way to explaining the earlier puzzle with respect to the age of the subsidiary. In particular, the sub-group analysis shows that the anomalous results are driven by two main factors: (1) the youngest group of subsidiaries is more highly embedded in the host country technical environment than originally thought, in fact just as embedded as the oldest group of subsidiaries; and (2) the oldest group of subsidiaries remains highly connected to the home base, in particular to the parent firm.

Perhaps the most surprising aspect of the above analysis is the finding with respect to the oldest subsidiaries. At least two explanations appear plausible. First, it is possible that the oldest group of subsidiaries is actually composed of two distinct groups: a group that is deeply connected to the local environment, and a group that remains dependent on the parent organization. In other words, the hypothesis, which postulated a monotonic relationship between a subsidiary's tenure in the host country and the geographic orientation of its knowledge base, may be mis-specified: embeddedness in a local technical environment may not be a simple function of the subsidiary's age. Rather, it may have to do more with what the subsidiary actually does there, and, relatedly, whether it has the technical resources and absorptive capacity (Cohen and Levinthal 1990) to participate effectively in local knowledge sharing networks. Put the opposite way, it may be the case that there exists a group of older subsidiaries who remain disconnected from the local technical environment even after many years of physically being there.

The second, and not necessarily mutually exclusive explanation is that older subsidiaries may actually be building on *both* home and host country sources of innovation. That is, there may not be a trade-off in the orientation of innovating subsidiaries between home and host country sources of knowledge – which was implicit in the formulation of most of the hypotheses. In short, local knowledge may be additive rather than substitutive in terms of the subsidiary's knowledge base, a possibility that was in fact suggested by the analysis of the 1979-81 entering cohort, which showed that this group's citation patterns evolved toward both home and host country knowledge sources over time.

To test these possibilities, I again performed a subgroup analysis, this time focusing on the oldest group of subsidiaries, those established prior to 1975. I refit the original models using only citations on patents issued to this early cohort. The purpose of the analysis is to identify factors within this group that predict the geographic orientation of their external sources of innovation. Tables 6.9 through 6.12 present the results. As in Table 6.8, the results are shown for the pooled 1988-1990 time period (the three most recent years of data) in order to control for period effects as well as idiosyncratic "fixed effects" stemming from the behavior of particular subsidiaries. Perhaps the clearest finding is with respect to *Subsidiary Resources*. The positive and highly significant coefficient on this variable at all host country levels (Tables 6.10-6.12) demonstrates that as the number of patents issued to a subsidiary increases so do the odds that it will cite the host country, the host state, and the host region. The magnitude of the coefficient is quite large, implying an elasticity of between 1.05 and 1.32 with the higher values generally occurring at lower geographic levels.

[Insert Tables 6.9-6.12 Here]

This result is particularly interesting in that it supports the observation by Ronstadt (1977) that shifts in the orientation or mandate of overseas technical units tend to be intrinsically related to the growth of those units. Ronstadt observed that foreign units that evolve from a focus on transfering and adapting technology developed by the parent toward a more autonomous technical orientation tend to be the units that experience the highest levels of growth over time. Ronstadt's argument also works the other way: technical units that do not grow, also tend to be those that remain focused on adaptive kinds of technical activity[12]. The results in Table 6.9 support this latter observation: *Subsidiary Resources* is generally negative and significant in the home country models (Table 6.9), although its effect is attenuated by the inclusion of the home base dummies. Generally, then it appears that smaller subsidiaries remain more connected to the home base. Ronstadt's evolutionary story is also supported by the results with respect to the locational specialization variables, which show that older subsidiaries whose activities center around areas of host country (and state) technical specialization tend to build upon knowledge sources resident in these locations. Not surprisingly, subsidiaries that fail to establish distinctive technical areas within the firm also tend to be dependent on the parent firm (negative sign on *Subsidiary Specialization* in Table 6.9)[13].

A clearer picture of the relationship between the resources of the subsidiary and the geography of its external sources of innovation can be seen in Table 6.13, which shows the citation frequencies for the smallest and largest quartiles of pre-1975 entrants. The results confirm Ronstadt's basic argument and suggests an extension. The smallest quartile of pre-1975 subsidiaries is indeed much less oriented toward host country sources of technology than the largest quartile. Whereas the largest group of subsidiaries overcites host country sources at all geographic levels, the smallest group's host country citation frequencies are indistinguishable from the controls. Also, as Ronstadt's analysis would predict, the smallest group overcites the home base, although that turns out, again, to be largely due to intra-firm citations, i.e., citations to prior headquarters patents. Surprisingly, perhaps, Table 6.13 also shows that the largest group of pre-1975 subsidiaries overcites the home base to a significant degree as well, or, more accurately, overcites the parent firm, since the effect again disappears when intra-firm citations are excluded from the calculations.

[Insert Table 6.13 Here]

The results in Table 6.13 with respect to the oldest-largest group of subsidiaries point to, but still do not fully evidence, one of the explanations posited earlier, namely that the capacity to assimilate and utilize local knowledge may not substitute for home country knowledge sources but rather be complementary to them. Empirically, it is possible that the oldest-largest group of subsidiaries may contain members that have "multiple mandates" – mandates to both exploit and explore – that are underpinned by different knowledge bases, and thus by different geographic sources of innovation. It may also be the case that, even among the oldest-largest subsidiaries, there exist two groups of units, those that are highly local in their technical orientation and those that still depend heavily upon the parent organization as a source of technical know-how. Yet a third possibility is that these subsidiaries utilize home and host country knowledge simultaneously, i.e., in the context of working on a particular invention.

To untangle these explanations, I turn again to more descriptive forms of analysis, focusing in particular upon the oldest-largest group of subsidiaries: those established before 1975 and that ranked in the top quartile of this oldest group in terms of number of patents they generated between 1988 and 1990. Figure 6.2 shows the position of each of the thirty largest-oldest subsidiaries in terms of the home/host orientation of their citation trails. The numbers on the horizontal axis again represent t-statistics of the test for significant over- or underciting of the host state (compared to the control citations). The vertical axis provides the same figures for the home country: overciting of the home country is indicated by scores above 1.96 on the vertical dimension; scores below -1.96 indicate significant underciting.

[Insert Figure 6.2 Here]

The results illustrate that, in fact, there is no single explanation for the behavior of the oldest-largest group of subsidiaries; several different patterns are apparent. First, there appears to be a group of approximately six or seven units that are oriented toward the local environment, but not the home base. This is the group that is to the right of the 1.96 ($p < .01$) cutoff on the horizontal axis, but below 1.96 on the vertical axis. Another group of eight or so units is still oriented more toward the home base than the local environment: this is the group that is above the 1.96 point on the vertical axis but to the left of the 1.96 point on the horizontal (host state) axis. A much smaller group of about 4 units is in the "high-high" area, above 1.96 on both axes and is thus oriented towards both the home base and the local environment - a possible "multiple mandates" group of subsidiaries. The orientation of the remaining units, those clearly inside the rectangle or significantly negative on one dimension but not positive on another, remains unclear.

To summarize, the findings from the above tests indicate that the anomalous results with respect to the age of the subsidiary are due to unpredicted patterns of behavior among both the oldest and the youngest groups of subsidiaries. In particular, the youngest group of subsidiaries was shown to be much more oriented to the host country technical environment than initially hypothesized, perhaps due to an increase in recent years in the amount of "technology seeking" investment by foreign multinationals into the U.S. Further analysis (not shown) suggested that this result was especially pronounced for those subsidiaries that were already part of a well established parent firm network in the host country. In contrast, new entrants that represented the parent firm's first patenting subsidiary were much more likely to draw upon headquarters technology, and less likely to draw upon the local environment. This result is consistent with the theoretical argument underpinning the embeddedness hypotheses.

The behavior of the oldest group of subsidiaries was also shown to be at odds with the initial formulation of the age hypothesis. Overall, this group of subsidiaries was shown to be highly oriented to both home *and* host country environments, of which only the former was predicted by the initial formulation of Hypothesis 6. This result also turned out to be consistent with the findings from a "cohort analysis" that tracked the citing behavior of a group of entering U.S. subsidiaries from the point of their initial patent filing through their first decade in the host country.

Further analysis of the oldest subsidiary cohort revealed that it was possible to distinguish between two main groups. The first group were those subsidiaries that remained small and failed to develop distinctive areas of technical competence within the firm. This group was shown to remain oriented toward technology initially developed by the parent firm, and to be less connected to sources of innovation in the host country context. The second group of old subsidiaries, those that did grow and develop areas of distinctive technical competence was shown to have a much greater orientation to local sources of innovation. Interestingly, however, even among the largest-oldest subsidiaries there appeared to be multiple development paths. One group, in fact the group with largest number of units, were highly local in their technical orientation at the expense of home country (and parent firm) sources of innovation. A much smaller number of oldest-largest subsidiaries were in the "high-high" group, overciting both home and host country technology. One possible explanation for this group's citing behavior is the existence within these units of "multiple mandates" – mandates both to develop existing parent technology and to pursue commercial and technical opportunities based on local technical signals. Yet another group of oldest-largest subsidiaries appeared to continue to remain home focused, drawing disproportionately upon the parent firm at the expense of local technical sources.

5. Conclusion

This chapter has sought to extend the findings of the previous chapters by shifting the analysis from the population level to the level of the individual subsidiary and, further, to the level of the subsidiary innovation itself. The specific purpose of the chapter has been to shed light on the conditions under which innovations generated by foreign subsidiaries build upon sources of technical knowledge in the home and/or host country – the second research question. Empirically, the focus of the chapter was on testing the eight hypotheses related to this question that were formulated in Chapter 2.

Overall, the results presented in this chapter offer strong support for the basic argument underlying the thesis, namely that the characteristics of innovating subsidiaries, as well as the nature of the innovations themselves, influence the location of the knowledge sources underpinning these innovations, i.e., the geography of innovative search. At the level of the specific hypotheses underpinning this argument, the results were also strongly supportive. The notable exception was the role played by the tenure of the subsidiary in the host country environment, which was shown to have a quite different effect on the geographic sources of subsidiary innovations from that which was initially hypothesized. Subsequent investigation of this anomaly revealed some interesting, if unexpected, patterns in the geographic orientation of both the youngest and oldest groups of innovating subsidiaries.

Overall, the results suggest two distinct paths by which foreign subsidiaries come to draw upon sources of knowledge in the host country during the process of technological innovation. The first is the path that drove most of the hypotheses, namely through an evolutionary process in which foreign subsidiaries, most of which are initially established to transfer and adapt parent technology, may with time develop a set of differentiated technical capacities based on market and technological opportunities in the host country. However, as suggested originally by Ronstadt (1977), this path is not a deterministic function of the subsidiary's tenure in the host country. Many factors, internal and external, intervene as moderators. In addition, the results presented here also suggest that this evolutionary path does not produce a single coherent model of innovative search, even within the largest group of long established subsidiaries. Some subsidiaries appear to evolve away from home country (and parent) sources of innovation, becoming deeply embedded in the local technical milieu. For others, home and host country sources of innovation do not act as substitutes. Rather, home and host country sources are heavily utilized, perhaps in the same technical area, perhaps in different areas, as in situations where subsidiaries continue to adapt parent technology while developing their own, more autonomous technical capabilities - the so-called "multiple mandates" model

What is also evidenced in this chapter - and is also supported by Rondstadt's earlier work -- is that subsidiaries that do not evolve a distinctive set of technical capabilities tend to remain small and focused on technical activities that are strongly supported in the home base of the firm in general, and in the activities of the parent firm in particular.

The second path is the one that has received the lion's share of attention in recent years. This is the technology seeking path, in which strategically located R&D units consciously seek to "tap into" sources of knowledge and expertise in the host country. Subsidiaries established between 1988 and 1990 were shown to exhibit a high degree of local citing, a pattern that was evident in the activities of subsidiaries from five of the top ten home countries. Surprisingly, perhaps, subsidiaries of Japanese firms were not among this group. It appears, then, that newly established subsidiaries are generally able to overcome the "liability of newness" that was hypothesized to limit their degree of embeddedness in local technical communities.

At a more general level, the findings with respect to both the youngest and oldest subsidiaries are consistent with the notion of the multinational firm as an evolving institution, moving from organizational models based solely around the exploitation of knowledge developed in the home base to models based around the assimilation and, ultimately, generation of knowledge on a worldwide basis:

> The sequential expansion of a firm's activities after the first entry into a country is an expression of the evolutionary acquisition and recombination of knowledge. In its more advanced evolution, this process alters the global knowledge of the firm...(Kogut and Zander 1992: 640)

In the next chapter I turn to the question of whether and under what conditions foreign subsidiaries also contribute to the "global knowledge of the firm" (Kogut and Zander 1992: 640) by acting as conduits through which host country knowledge is diffused to other parts of the multinational network.

Endnotes

[1] Recall from Chapter 4 that patents issued to acquired U.S. firms account for less than 1/3 of all subsidiary patents even in the post 1986 period when acquisitions rose rapidly. Joint ventures account for a negligible proportion of U.S. subsidiary patents.

[2] As a check on the robustness of the results presented below, I refit the models using the complete sample of subsidiary patents, including a dummy variable to capture patents issued to acquisitions, i.e., U.S. firms that were acquired by foreign multinationals. For the age of the subsidiary I substituted the acquisition date. The age variable did not work well in these models (nor does it work well in the main regressions, for reasons I explore later in the chapter). Several other firm-oriented variables also did not work well in the combined regressions, such as whether or not the subsidiary patent cites a prior headquarters patent, the degree of technological differentiation between headquarters and subsidiary, and the size of the parent firm's U.S. operations. However, the locational specialization variables continued to work well (i.e., signs in the right direction, coefficient significantly different from zero). Future work will focus more explicitly on the nature of the differences between subsidiaries established through different entry modes.

[3] To clarify, aggregating from the citation to the patent means pooling all of the citations on a particular patent and developing an overall geographic "score" for that patent indicating the extent of its home or host country underpinnings. For reasons discussed in Chapter 3, I also did not aggregate to the level of the subsidiary. That is, I did not derive an overall subsidiary rating for the extent to which its technical activities are oriented toward the home or host country.

[4] As noted below, I experimented with several different years, all from the most recent period of citing subsidiary patents (i.e., 1988-1990).

[5] The coefficients in logistic regression analysis, *B*, represent the natural logs of the odds ratios, e^B. These are converted to likelihood ratios for presentation in the figures and text body.

[6] The variable *Geographic Controls* control for the underlying geographic patterns in the database.

[7] I also tried a different variable, *90th Percentile*, which captured whether the subsidiary patent was in the 90th percentile or greater in terms of the number of times it was cited. The results were identical.

[8] In addition to *Subsidiary Specialization*, I also ran the analysis using a dummy variable indicating whether the headquarters organization had *any* patenting presence in the relevant technical area in the same year that the subsidiary patent was filed. Results were essentially unchanged. This variable worked slightly better at the national level in the host country models. However, its effect was somewhat less robust at lower geographic levels.

[9] I experimented with several different years of data, all from the latest point in the series (1988, 1989, 1990), as well as pooled 1988-1990 results. The results were not particularly sensitive to the choice of year, although the models worked noticeably better for the three years of pooled data, confirming the sensitivity of citation data to sample size.

[10] I chose a three year period for the cohort analysis (i.e., 1979-1981) to mitigate idiosyncratic effects of individual subsidiaries and because the analysis tends to be highly sensitive to sample size given the noise in the data as well as the large number of controls entered into the models.

[11] Ideally it would have been possible to show the results for individual subsidiaries, as I do for later in the chapter for the largest quartile of subsidiaries established before 1975. However, the small number of patents typically issued to a subsidiary established in the 1988-1990 period is simply too small to permit a

meaningful subsidiary level analysis. I therefore choice to present the results for the youngest cohort aggregated to the home country level.

[12] In Ronstadt's formulation, the direction of the causality is ambiguous. That is, it is not clear whether growth generates a shift in mandate, or whether the decision to alter the subsidiary's mandate is prior to, and perhaps establishes the need for, an increase in resources.

[13] It should be pointed out that *Subsidiary Specialization* only reaches significance in Model 5. However, further investigation revealed that this is due primarily to the high correlation between this variable and *Subsidiary Resources*. When *Subsidiary Resources* was dropped from the models, *Subsidiary Specialization* emerged as a highly significant predictor of home country orientation, i.e., subsidiary innovations in technical areas that were not distinctive within the firm were more likely to draw upon home based sources of knowledge, especially the parent.

Table 6.1 Definition of Dependent Variables

Variable	Definition
Home Country Citation	Dichotomous variable which takes on the value of 1 if a cited patent originated in the home base of the subsidiary, and 0 otherwise.
Host Country Citation	Dichotomous variable which takes on the value of 1 if a cited patent originated in the host country, i.e., the U.S., and 0 otherwise.
Host State Citation	Dichotomous variable which takes on the value of 1 if a cited patent originated in the same state as the subsidiary's citing patent, and 0 otherwise.
Host BEA Region Citation	Dichotomous variable which takes on the value of 1 if a cited patent originated in the same BEA region as the subsidiary's citing patent, and 0 otherwise.

Table 6.2 Names and Definitions of Independent Variables

Variable	Definition
Adaptation of HQ Technology	Dichotomous variable: 1 if a subsidiary patent contains a citation to an earlier patent developed by the headquarters organization; 0 otherwise.
Home Country Specialization	Dichotomous variable: 1 if the subsidiary's patent is in a technical field in which the subsidiary's home country has a revealed technological advantage (RTA)* greater than one in the year of application of the subsidiary's patent; 0 otherwise.
Patent Importance	Percentile score, calculated by comparing the number of citations received by the subsidiary patent through 1992 compared to the distribution of citation counts for the population of U.S. patents issued in the same year as the subsidiary patent.
Subsidiary Specialization	Percentage of total company patents in a particular technical field accounted for by the subsidiary†. Based on 33 fields of technology.
Host Country Specialization	Dichotomous variable: 1 if the subsidiary's patent is in a technical field in which the U.S. has a revealed technological advantage (RTA) greater than one in the year of application of the citing subsidiary's patent; 0 otherwise.
Host State Specialization	Dichotomous variable: 1 if the subsidiary's patent is in a technical field in which the host state has an RTA greater than one in the year of application of the citing subsidiary patent; 0 otherwise.
Subsidiary Age	Application date of citing patent minus application date of first patent issued to the subsidiary.
Subsidiary Resources	Total number of patents issued to the subsidiary in the same year as the citing patent.
U.S. Presence	Number of parent company patents issued to <u>all</u> U.S.-based subsidiaries in the same year as the citing patent minus the number of patents issued to the focal subsidiary in that year.

*An RTA of greater than one indicates that the particular locational unit is disproportionately represented in that particular technical field relative to its position in other fields. See Cantwell (1989) for an extended discussion of the definition and interpretation of RTA.

†Measures of *Subsidiary Specialization* were calculated based on a concordance between patent classes and 33 fields of technology.

Table 6.3 Correlation Matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Home Country Citation	1.000															
2. Host Country Citation	-0.434	1.000														
3. Host State Citation	-0.114	0.261	1.000													
4. Host Region Citation	-0.086	0.199	0.671	1.000												
5. Adaptation of HQ Technology	0.372	-0.171	-0.039	-0.030	1.000											
6. Home Country Specialization	0.095	-0.064	-0.014	-0.013	0.117	1.000										
7. Host Country Specialization	-0.070	0.118	0.021	0.012	-0.080	-0.169	1.000									
8. Host State Specialization	-0.019	0.008	0.048	0.030	0.023	0.066	0.152	1.000								
9. Home Advantaged / U.S. Disadvantaged	0.103	-0.103	-0.023	-0.014	0.102	0.587	-0.719	-0.051	1.000							
10. Home Disadvantaged / U.S. Advantaged	-0.076	0.097	0.014	0.013	-0.114	-0.693	0.565	0.045	-0.406	1.000						
11. Home Advantaged / Host State Disadvantaged	0.057	-0.030	-0.034	-0.018	0.018	0.335	-0.164	-0.682	0.310	-0.232	1.000					
12. Home Disadvantaged / Host State Advantaged	-0.077	0.053	0.035	0.029	-0.091	-0.765	0.206	0.375	-0.449	0.619	-0.256	1.000				
13. Subsidiary Specialization	-0.080	0.035	0.030	0.029	-0.167	-0.117	0.098	0.041	-0.158	0.074	-0.105	0.086	1.000			
14. Patent Importance	-0.011	0.011	-0.002	0.004	0.005	-0.022	0.011	-0.010	-0.016	0.020	0.007	0.019	-0.001	1.000		
15. U.S. Presence	-0.063	0.036	0.001	-0.004	0.089	0.050	0.019	0.070	0.013	-0.021	-0.042	-0.019	-0.443	0.015	1.000	
16. Log (Citation Lag)	-0.054	0.046	-0.016	-0.008	-0.011	0.014	0.000	0.006	-0.008	-0.025	-0.007	-0.015	0.016	0.022	0.061	1.000

Table 6.4

Results of Logistic Regressions on Home Country Citations, 1980-1990 Citing Patents

Variable	1	2	3	4	5†
Geographic Controls	1.081*** (C.065)	1.061*** (0.066)	1.050*** (0.066)	0.509*** (0.068)	0.592*** (0.051)
Adaptation of HQ Technology	0.495*** (0.057)	0.485*** (0.057)	0.483*** (0.057)	0.315*** (0.059)	
Home Country Specialization	0.566*** (0.050)	0.524*** (0.051)			
Host Country Specialization		-0.213*** (0.0470			
Home Advantaged/U.S. Disadvantaged			0.506*** (0.052)	0.284*** (0.054)	0.226*** (0.038)
Home Disadvantaged/U.S. Advantaged			-0.156* (0.065)	-0.416*** (0.069)	-0.552*** (0.050)
Subsidiary Specialization	-0.617*** (0.079)	-0.573*** (0.080)	-0.555*** (0.080)	0.229** (0.082)	-0.413*** (0.067)
Patent Importance	-0.291** (0.114)	-0.271* (0.114)	-0.270* (0.114)	-0.385*** (0.117)	-0.153 (0.082)
Subsidiary Age	0.029*** (0.009)	0.029*** (0.009)	0.029*** (0.009)	0.027** (0.010)	0.040*** (0.008)
Log (Subsidiary Resources)	-0.136*** (0.021)	-0.140*** (0.021)	-0.136*** (0.021)	-0.014 (0.025)	0.058*** (0.016)
U.S. Presence	-0.291*** (0.015)	-0.285*** (0.015)	-0.282*** (0.015)	-0.067*** (0.019)	-0.041** (0.014)
Log (Citation Lag)	-0.226*** (0.028)	-0.225*** (0.028)	-0.225*** (0.028)	-0.224*** (0.029)	-0.183*** (0.021)
Technical Field Dummies	***	***	***	***	***
Year Dummies	***	***	***	***	***
Home Base Dummies				***	***
Constant	-0.813*** (0.234)	-0.716** (0.235)	-0.669** (0.234)	-3.224** (1.241)	-1.725*** (0.446)
Percent correctly predicted	94.38	94.38	94.38	94.37	89.33
Number of observations	40,159	40,159	40,159	40,159	43,214

†Intra-firm citations included $^{*}p<.05$ $^{**}p<.01$ $^{***}p<.001$

Table 6.5
Results of Logistic Regressions on Host Country Citations, 1980-1990 Citing Patents

Variable	1	2	3	4	5†
Geographic Controls	0.344*** (0.022)	0.343*** (0.022)	0.352*** (0.022)	0.340*** (0.[illegible])	0.340*** (0.020)
Adaptation of HQ Technology	-0.131*** (0.031)	-0.124*** (0.031)	-0.121*** (0.031)		
Host Country Specialization	0.434*** (0.022)	0.418*** (0.022)			
Home Country Specialization		-0.103*** (0.023)			
Home Advantaged/US. Disadvantaged			-0.249*** (0.025)	-0.224*** (0.024)	-0.224*** (0.024)
Home Disadvantaged/U.S. Advantaged			0.286*** (0.028)	0.346*** (0.027)	0.346*** (0.027)
Subsidiary Specialization	0.076* (0.038)	0.054 (0.039)	0.047 (0.039)	0.158 (0.039)	0.158*** (0.039)
Patent Importance	0.282*** (0.055)	0.274*** (0.055)	0.276*** (0.055)	0.245*** (0.052)	0.245*** (0.052)
Subsidiary Age	-0.015** (0.005)	-0.015** (0.005)	-0.015** (0.005)	-0.022** (0.005)	-0.022*** (0.005)
Log (Subsidiary Resources)	0.038*** (0.009)	0.043*** (0.009)	0.050*** (0.009)	0.025*** (0.009)	0.025** (0.009)
U.S. Presence	0.071*** (0.008)	0.069*** (0.008)	0.069*** (0.008)	0.042*** (0.008)	0.042*** (0.008)
Log (Citation Lag)	0.116*** (0.015)	0.116*** (0.015)	0.116*** (0.015)	0.132*** (0.014)	0.132*** (0.014)
Technical Field Dummies	***	***	**	**	***
Year Dummies	***	***	***	***	***
Home Base Dummies				***	***
Constant	-0.943*** (0.122)	-0.869*** (0.123)	-0.722*** (0.123)	-1.004*** (0.140)	-1.004*** (0.140)
Percent correctly predicted	65.60	65.58	65.70	65.70	62.20
Number of observations	40,159	40,159	40,159	40,159	43,214

†Intra-firm citations included $^{*}p<.05$ $^{**}p<.01$ $^{***}p<.001$

Table 6.6
Results of Logistic Regressions on Host State Citations, 1980-1990 Citing Patents

Variable	1	2	3	4	5†
Geographic Controls	1.193***	1.191***	1.198***	1.175***	1.182***
	(0.052)	(0.052)	(0.052)	(0.052)	(0.052)
Adaptation of HQ Technology	0.018	0.025	0.037	0.060	
	(0.048)	(0.048)	(0.048)	(0.049)	
State Specialization	0.357	0.360***			
	(0.042)	(0.042)			
Home Country Specialization		-0.077*			
		(0.035)			
Home Advantaged/Host State Disadvantaged			-0.272***	-0.275***	-0.276***
			(0.055)	(0.056)	(0.055)
Home Disadvantaged/Host State Advantaged			0.152***	0.133***	0.151***
			(0.037)	(0.038)	(0.037)
Subsidiary Specialization	0.208***	0.188**	0.165**	0.091	0.148*
	(0.059)	(0.059)	(0.059)	(0.062)	(0.062)
Patent Importance	-0.088	-0.094	-0.100	-0.102	-0.102
	(0.084)	(0.084)	(0.084)	(0.085)	(0.084)
Subsidiary Age	-0.006	-0.006	-0.005	-0.005	-0.008
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
Log (Subsidiary Resources)	0.040***	0.044***	0.052***	-0.005***	0.061***
	(0.014)	(0.014)	(0.014)	(0.008)	(0.016)
U.S. Presence	0.024*	0.022	0.020	0.022	0.022
	(0.012)	(0.012)	(0.012)	(0.014)	(0.014)
Log (Citation Lag)	-0.066**	-0.066**	-0.066**	-0.067**	-0.055**
	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)
Technical Field Dummies5	***	***	***	***	***
Year Dummies	***	***	***	***	***
Home Base Dummies				***	***
Constant	-2.230***	-2.181***	-1.966***	-2.483***	-2.777***
	(0.190)	(0.191)	(0.188)	(0.460)	(0.710)
Percent correctly predicted	89.61	89.61	89.61	89.62	90.29
Number of observations	40,159	40,159	40,159	43,214	40,159

†Intra-firm citations included   *p<.05 **p<.01 ***p<.001

Table 6.7
Results of Logistic Regressions on Host Area* Citations, 1980-1990 Citing Patents

Variable	1	2	3	4	5†
Geographic Controls	1.427***	1.424***	1.430***	1.427***	1.435***
	(0.074)	(0.074)	(0.074)	(0.075)	(0.074)
Adaptation of HQ Technology	0.033	0.042	0.051	0.087	
	(0.060)	(0.060)	(0.060)	(0.061)	
Host State Specialization	0.245***	0.251***			
	(0.052)	(0.052)			
Home Country Specialization		-0.104*			
		(0.043)			
Home Advantaged/Host State Disadvantaged			-0.097	-0.090	-0.087
			(0.068)	(0.068)	(0.068)
Home Disadvantaged/Host State Advantaged			0.201***	0.190***	0.206***
			(0.047)	(0.047)	(0.047)
Subsidiary Specialization	0.229**	0.203**	0.191**	0.074	0.121
	(0.074)	(0.074)	(0.074)	(0.078)	(0.078)
Patent Importance	-0.028	-0.036	-0.042	-0.023	-0.020
	(0.107)	(0.107)	(0.107)	(0.107)	(0.106)
Subsidiary Age	-0.005	-0.005	-0.004	-0.009	-0.012
	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
Log (Subsidiary Resources)	0.070***	0.075***	0.083***	0.109***	0.101***
	(0.017)	(0.017)	(0.017)	(0.020)	(0.020)
U.S. Presence	-0.016	-0.020	-0.021	-0.022	-0.022
	(0.015)	(0.015)	(0.015)	(0.018)	(0.018)
Log (Citation Lag)	-0.060*	-0.060*	-0.060*	-0.060*	-0.049
	(0.028)	(0.028)	(0.028)	(0.028)	(0.028)
Technical Field Dummies	***	***	***	***	***
Year Dummies	***	***	***	***	***
Home Base Dummies				***	***
Constant	-2.736***	-2.673***	-2.599***	-3.334***	-3.467***
	(0.237)	(0.239)	(0.236)	(0.741)	(0.740)
Percent correctly predicted	93.71	93.71	93.71	93.71	94.11
Number of observations	40,159	40,159	40,159	40,159	43,214

†Intra-firm citations included *p < .05 **p < .01 ***p < .001
*Host Area refers to the BEA region in which the subsidiary is located.

Table 6.8
Citing Behavior of Oldest and Youngest Subsidiary Cohorts, 1988-90 Citing Patents

	Home Country	Home† Country	Host Country	Host State	Host BEA Region
Youngest Cohort	4.33	1.71	3.41	7.16	7.82
Oldest Cohort	13.93	0.54	3.75	7.66	6.50

†Intra-firm citations excluded

Table 6.9
Results of Logistic Regressions on Home Country Citations, Patents of Pre-1975 Cohort

Variable	1	2	3	4	5
Geographic Controls	1.002***	1.004***	1.008***	0.579***	0.740***
	(0.149)	(0.149)	(0.149)	(0.151)	(0.087)
Adaptation of HQ Technology	0.499***	0.500***	0.503***	0.214*	
	(0.100)	(0.100)	(0.100)	(0.104)	
Home Country Specialization	0.471***	0.476***			
	(0.099)	(0.100)			
Host Country Specialization		0.028			
		(0.086)			
Home Advantaged/U.S. Disadvantaged			0.032	0.089	0.236***
			(0.096)	(0.101)	(0.057)
Home Disadvantaged/U.S. Advantaged			-0.437***	-0.443***	-0.628***
			(0.128)	(0.137)	(0.083)
Subsidiary Specialization	-0.281	-0.284	-0.317	0.358	-0.447***
	(0.199)	(0.200)	(0.199)	(0.207)	(0.138)
Patent Importance	-0.440*	-0.443*	-0.473*	-0.542**	-0.020
	(0.200)	(0.200)	(0.200)	(0.205)	(0.120)
Log (Subsidiary Resources)	-0.295***	-0.295***	-0.287***	-0.057	0.001
	(0.034)	(0.034)	(0.034)	(0.044)	(0.025)
U.S. Presence	-0.192***	-0.192***	-0.197***	-0.124**	-0.035
	(0.036)	(0.036)	(0.036)	(0.043)	(0.028)
Log (Citation Lag)	-0.169**	-0.169**	-0.167**	-0.149**	-0.029
	(0.056)	(0.056)	(0.056)	(0.057)	(0.035)
Technical Field Dummies	***	***	***	***	***
Year Dummies	**	**	**	**	***
Home Base Dummies				***	***
Constant	-0.930*	-0.940*	-0.530	-2.508	-2.463
	(0.466)	(0.467)	(0.464)	(3.798)	(1.418)
Percent correctly predicted	96.47	96.47	96.47	96.47	89.71
Number of observations	17,667	17,667	17,667	17,667	19,459

†Intra-firm citations included   *p<.05 **p<.01 ***p<.001

Table 6.10

Results of Logistic Regressions on Host Country Citations, Patents of Pre-1975 Cohort

Variable	1	2	3	4	5[†]
Geographic Controls	0.347***	0.346***	0.352***	0.346***	0.322***
	(0.033)	(0.033)	(0.033)	(0.033)	(0.031)
Adaptation of HQ Technology	-0.019	-0.014	-0.007	-0.033	
	(0.043)	(0.043)	(0.043)	(0.045)	
Host Country Specialization	0.434***	0.432***			
	(0.034)	(0.034)			
Home Country Specialization		-0.078*			
		(0.036)			
Home Advantaged/U.S. Disadvantaged			-0.236***	-0.191***	-0.222***
			(0.039)	(0.039)	(0.036)
Home Disadvantaged/U.S. Advantaged			0.306***	0.342***	0.409***
			(0.047)	(0.048)	(0.044)
Subsidiary Specialization	0.122	0.104	0.088	-0.109	0.013
	(0.077)	(0.077)	(0.077)	(0.081)	(0.076)
Patent Importance	0.340***	0.333***	0.336***	0.320***	0.200**
	(0.080)	(0.080)	(0.080)	(0.081)	(0.074)
Log (Subsidiary Resources)	0.053***	0.057***	0.065***	0.070***	0.052***
	(0.013)	(0.013)	(0.013)	(0.015)	(0.014)
U.S. Presence	0.079***	0.075***	0.072***	0.050**	0.028
	(0.016)	(0.016)	(0.016)	(0.019)	(0.018)
Log (Citation Lag)	0.021	0.021	0.025	0.027	0.026
	(0.024)	(0.024)	(0.024)	(0.024)	(0.022)
Technical Field Dummies	***	***	***	***	***
Year Dummies	**	**	***	**	**
Home Base Dummies				***	***
Constant	-0.480*	-0.423*	-0.279	-0.096	-0.198
	(0.197)	(0.199)	(0.199)	(0.247)	(0.2344)
Percent correctly predicted	67.73	67.68	67.72	67.70	62.88
Number of observations	17,667	17,667	17,667	17,667	19,459

[†]Intra-firm citations included   *p<.05 **p<.01 ***p<.001

Table 6.11
Results of Logistic Regressions on Host State Citations, Patents of Pre-1975 Cohort

	1	2	3	4	5†
Geographic Controls	1.119***	1.119***	1.120***	1.062***	1.084***
	(0.072)	(0.072)	(0.073)	(0.074)	(0.073)
Adaptation of HQ Technology	0.084	0.084	0.106	0.019	
	(0.064)	(0.064)	(0.064)	(0.066)	
Host State Specialization	0.348***	0.348***			
	(0.070)	(0.070)			
Home Country Specialization		-0.002			
		(0.053)			
Home Advantaged/Host State Disadvantaged			-0.078	-0.065	-0.086
			(0.088)	(0.090)	(0.090)
Home Disadvantaged/Host State Advantaged			0.149**	0.198***	0.219***
			(0.056)	(0.057)	(0.056)
Subsidiary Specialization	0.216*	0.216*	0.203	-0.015	0.050
	(0.107)	(0.108)	(0.107)	(0.117)	(0.116)
Patent Importance	0.182	0.182	0.187	0.089	0.083
	(0.120)	(0.120)	(0.120)	(0.121)	(0.120)
Log (Subsidiary Resources)	0.061**	0.061**	0.072***	0.154***	0.146***
	(0.020)	(0.020)	(0.020)	(0.026)	(0.025)
U.S. Presence	0.078**	0.078**	0.078**	0.061*	0.055
	(0.025)	(0.025)	(0.025)	(0.031)	(0.031)
Log (Citation Lag)	-0.049	-0.049	-0.051	-0.052	-0.054
	(0.034)	(0.034)	(0.034)	(0.035)	(0.034)
Technical Field Dummies	***	***	***	***	***
Year Dummies	*	*	*	*	*
Home Base Dummies				***	***
Constant	-2.804***	-2.802***	-2.585***	-2.602***	-2.785***
	(0.294)	(0.295)	(0.290)	(0.450)	(0.612)
Percent correctly predicted	88.76	88.76	88.76	88.96	89.85
Number of observations	17,667	17,667	17,667	17,667	19,459

†Intra-firm citations included *p<.05 **p<.01 ***p<.001

Table 6.12
Results of Logistic Regressions on Host Area Citations, Patents of Pre-1975 Cohort

Variable	1	2	3	4	5†
Geographic Controls	1.237***	1.242***	1.240***	1.188***	1.203***
	(0.101)	(0.101)	(0.101)	(0.102)	(0.101)
Adaptation of HQ Technology	0.084	0.073	0.094	-0.016	
	(0.079)	(0.080)	(0.080)	(0.081)	
Host State Specialization	0.155	0.142			
	(0.084)	(0.085)			
Home Country Specialization		0.103			
		(0.067)			
Home Advantaged/Host State Disadvantaged			0.178	0.233*	0.211*
			(0.103)	(0.105)	(0.104)
Home Disadvantaged/Host State Advantaged			0.077	0.127	0.155*
			(0.071)	(0.072)	(0.071)
Subsidiary Specialization	0.077	0.099	0.096	-0.096	-0.031
	(0.142)	(0.143)	(0.142)	(0.152)	(0.151)
Patent Importance	0.089	0.093	0.095	0.018	0.020
	(0.152)	(0.152)	(0.152)	(0.152)	(0.151)
Log (Subsidiary Resources)	0.160***	0.156***	0.167***	0.289***	0.279***
	(0.027)	(0.027)	(0.027)	(0.035)	(0.035)
U.S. Presence	0.035	0.039	0.039	0.039	0.027
	(0.033)	(0.033)	(0.033)	(0.040)	(0.039)
Log (Citation Lag)	-0.129**	-0.130**	-0.131**	-0.132**	-0.130**
	(0.041)	(0.041)	(0.041)	(0.042)	(0.041)
Technical Field Dummies	***	***	***	***	***
Year Dummies	***	***	***	***	***
Home Base Dummies				***	***
Constant	-2.645***	-2.703***	-2.588***	-3.387*	-3.469*
	(0.355)	(0.357)	(0.351)	(1.433)	(1.432)
Percent correctly predicted	93.21	93.21	93.21	93.22	93.80
Number of observations	17,667	17,667	17,667	17,667	19,459

†Intra-firm citations included   *p<.05 **p<.01 ***p<.001

Table 6.13

Citing Behavior of Largest and Smallest Quartiles of pre-1975 Subsidiaries, 1988-90 Citing Patents (t-values)

	Home Country	Home† Country	Host Country	Host State	Host BEA Region
Smallest Quartile	3.01	0.98	1.97	0.79	1.61
Largest Quartile	12.90	-0.64	3.28	7.58	5.96

†Intra-firm citations excluded

Figure 6.1 Home / Host Citing by Home Country of 1988-1990 Entering Subsidiaries

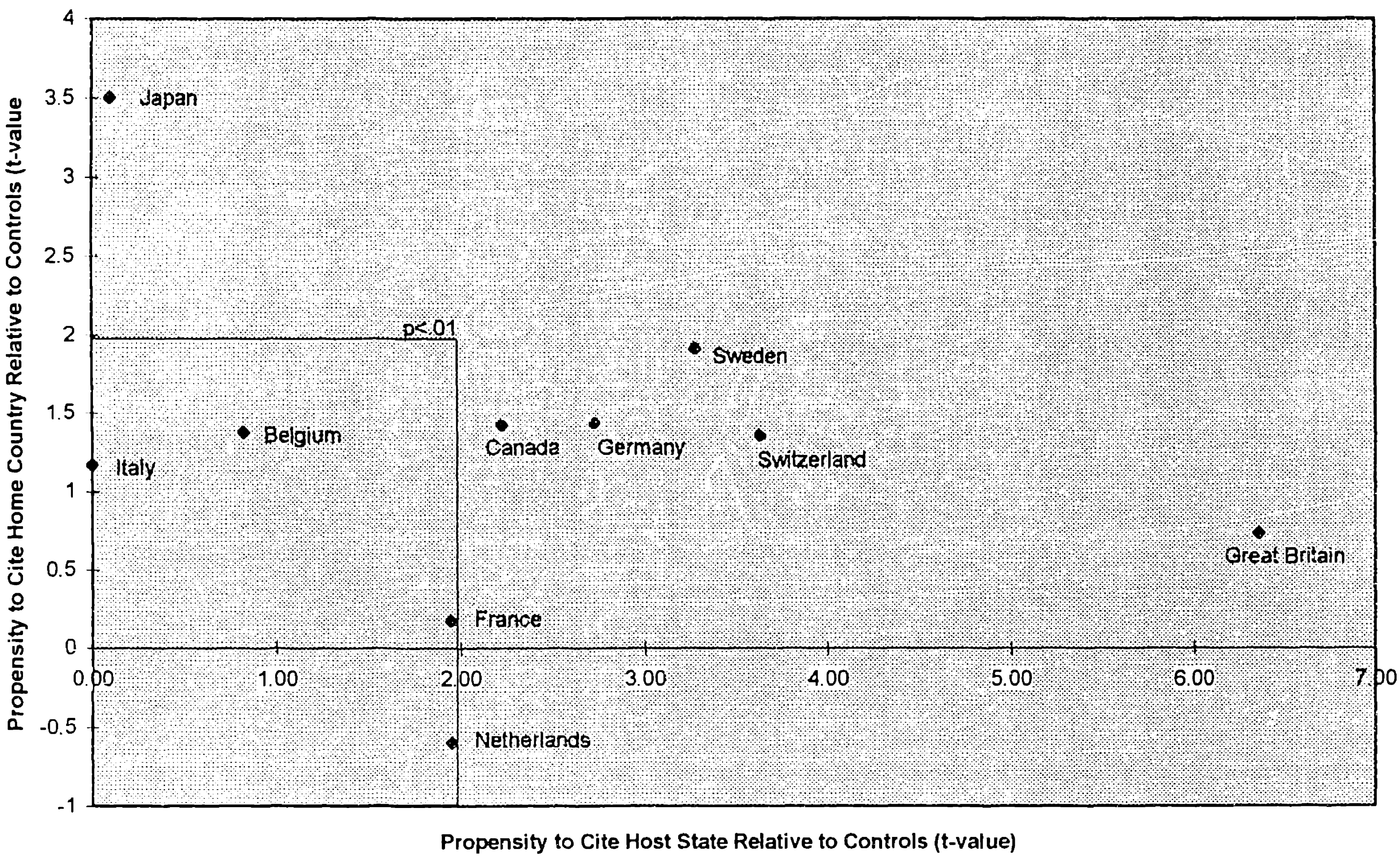
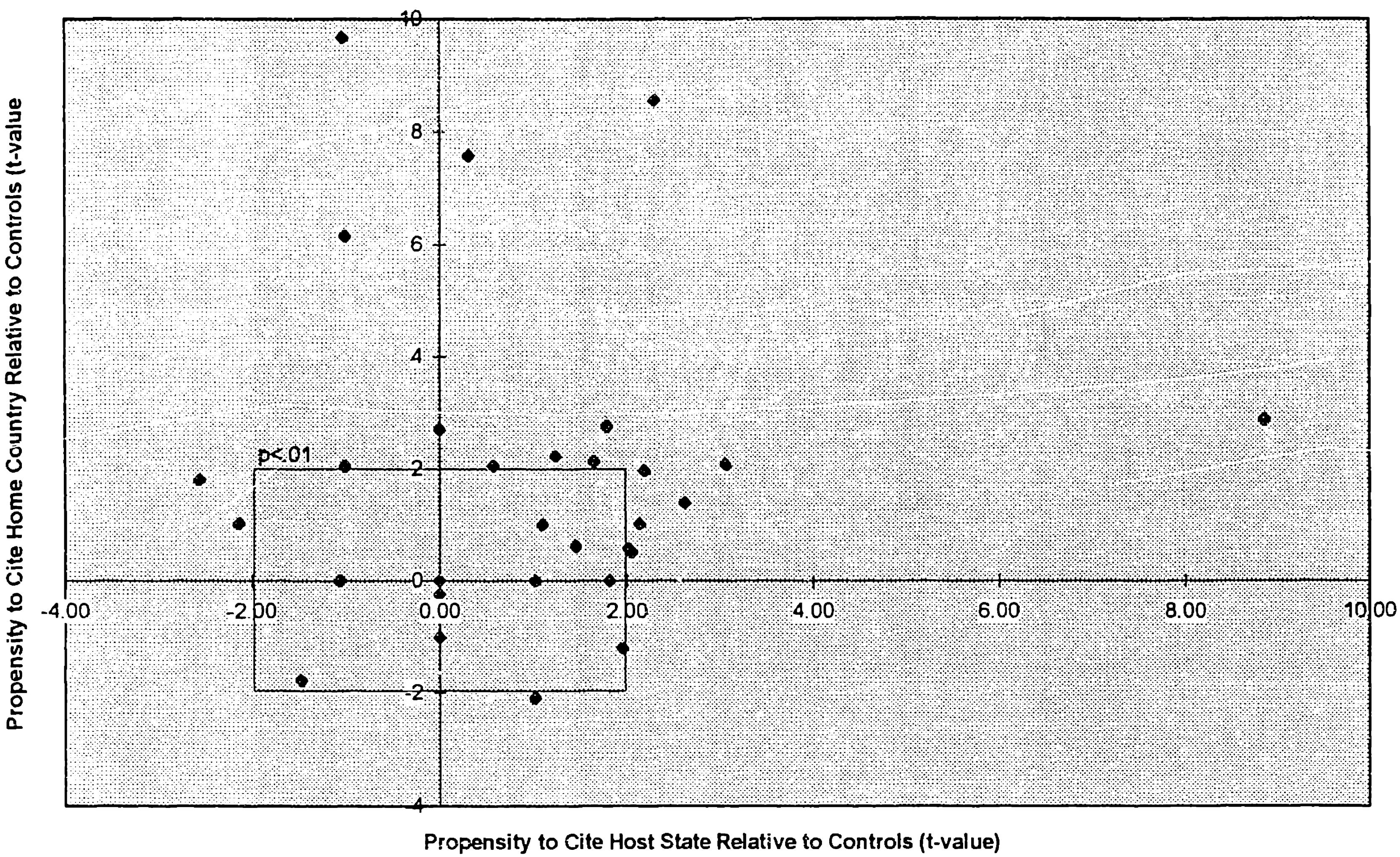


Figure 6.2 Home / Host Citing by Largest Quartile of Subsidiaries Established Before 1975



Chapter 7 Multinational Diffusion of Host Country Knowledge

1. Overview and Objectives

Chapters 5 and 6 analyzed the geography of the knowledge sources that underpin and inform U.S. subsidiaries' innovations. This chapter turns to the question of whether the assimilation of local knowledge by foreign subsidiaries that was evidenced in those chapters has an impact elsewhere in the multinational firm. This is the subject matter of the third and final research question addressed in this study: "To what extent and under what conditions do other parts of the multinational firm derive a learning benefit from a foreign subsidiary's capacity to assimilate knowledge in its local environment?"

Although this question plays a pivotal role in debates about the nature and evolution of the multinational firm, its complexity and the lack of suitable data have, to date, hamstrung systematic empirical investigation. The objective of this chapter, then, is to shed some empirical light on what might be termed the multinational diffusion hypothesis. The specific focus of the empirical analysis is on whether and under what conditions the *headquarters* organization (as opposed to other subsidiaries in the multinational network) derives a learning advantage from having a subsidiary that is geographically proximate to sources of knowledge within the host country (here, the U.S.). This is an important, perhaps even critical test: the multinational literature suggests that if we do not observe knowledge diffusion between the subsidiary and the parent, we are unlikely to see diffusion and learning within the broader multinational network (i.e., subsidiary - subsidiary diffusion). For example, research by Herbert (1989), Kim (1997), Westney (1992a) and Wortmann (1990) all point to the often extensive mechanisms employed by multinational firms to ensure that knowledge generated locally by foreign subsidiaries is also diffused back to the parent organization in the home base of the firm. Other studies (e.g., Bartlett and Ghoshal 1989) have noted the difficulties firms often have in developing distributed knowledge sharing networks, i.e., knowledge sharing between geographically dispersed subsidiaries.

As in Chapter 5, the answer to the research question addressed in this chapter is generated from the comparative analysis of patent citation paths. In the current chapter the comparison is structured around the following argument: If U.S. subsidiaries act as conduits through which knowledge originating in the host country (including knowledge subsidiaries generate themselves) is diffused back to the parent organization 'hen it follows that the parent organization should have a learning advantage over firms from the same home base and working in the same technical areas that do *not* have subsidiaries in the U.S. In other words, to the extent that the multinational diffusion hypothesis is correct, firms with foreign technical units should exhibit a systematically greater knowledge of technical developments occurring near to these units compared to firms with a geographically centralized technical organization -- "home based firms" in the terminology adopted here.

Following this logic, the research design developed for this chapter compares the citation paths of two groups of innovating organizations: (1) headquarters units, i.e., the home country organization of firms that have a patenting subsidiary in the U.S.; and (2) home-based firms, i.e., firms that do *not* have a patenting subsidiary in the U.S. Framed in terms of these comparison groups, the basic question asked in this chapter is: Are headquarters' units systematically more likely to utilize U.S. sources of science and technology during the innovation process than firms that do not have a U.S. technical presence (home-based firms)?

The remainder of the chapter is structured as follows. The next section discusses the research design and presents descriptive statistics on the sample of headquarters and home-based firms' patents analyzed in this chapter. Section 3 presents the main geographic results from the comparison of the two groups' citation paths. Section 4 explores the initial results further in order to shed light on some of the conditions under which foreign technical units are likely to increase the parent's firms knowledge of overseas science and technology. Section 5 summarizes and concludes.

2. Research Design

As in Chapter 5, the comparison between headquarters and home based firms is derived from a process of generating matched samples of patents issued to the two groups and then comparing the geography of the citations they list as references. Figure 7.1 illustrates the basic features of the research design.

[Insert Figure 7.1 Here]

The construction of the matched samples proceeded as follows. I once again began with the database of subsidiary patents, i.e., all 1980-1990 patents issued to U.S. subsidiaries of foreign multinationals. I then searched the full patent database for a matching headquarters patent. As in Chapter 5, this was accomplished by first identifying all of the patents issued to the headquarters organization[1] that (1) were applied for in the same year as the subsidiary patent; and (2) had the same 3-digit primary patent class as the subsidiary patent. From the set of "candidates" meeting these criteria, I selected the headquarters patent whose application date was closest to that of the subsidiary patent.

From the population of 16,210 U.S. subsidiary patents, I was able to identify unique headquarters matches for a total of 8,444. The sample of home-based firms' patents was then constructed in an analogous fashion. For each of the 8,444 headquarters patents, I selected a corresponding patent with the same technological and temporal characteristics that also (1) was issued to an inventor in the same country as the headquarters organization; and (2) was issued to an organization (the assignee) that had no patenting subsidiaries in the U.S. during the entire 1980-1990 period. When this matching process failed to turn up a same-technology, same-year analogue in a home-based firm, the headquarters patent was dropped from the sample. This process yielded 5,178 home-based firms patents. Thus the final sample is composed of two matched samples of citing patents, 5,178 issued to home-based firms and an equal number issued to headquarters units. The citations to prior patents listed by these two groups of citing patents were then extracted into a file for geographic analysis[2]. Descriptive statistics for these citations are presented in the next section.

Finally, as in the previous chapters, I also constructed a sample of control patents that are used to calculate an "expected" geographic citation frequency for the headquarters patents. That is, the controls establish the frequency with which a random drawing of patents with the same technological and temporal profile as the headquarters citations would be predicted to cite each of the geographic locations modeled in the analysis that follows. The construction of the control sample was accomplished using the same process adopted throughout this study. For each citation listed by a headquarters patent, I extracted from the database a corresponding control patent with the same primary patent class and the same application year as the citation, but which is itself not cited by the headquarters patent. The frequency with which these control patents originate in the focal geographic location establishes the "benchmark" against which the headquarters' citation frequency is compared. The purpose of the controls, as in the previous chapters, is to establish a conservative test of the diffusion hypothesis by ensuring that the observed pattern of headquarters citing is one that could not be predicted simply from the underlying geography of patenting activity. In other words, I am looking for a disproportionate pattern of overciting of U.S. sources by headquarters' patents before drawing any conclusions about cross-border learning benefits of foreign technical units.

2.1 Descriptive Statistics

Before turning to the geographic results, I first present descriptive statistics pertaining to the patents used in this chapter. As in Chapter 5 where a similar research design was used, the matching process utilized to construct comparable groups of headquarters' and home-based firms' patents results in a sample size that is much smaller than the potential population. This naturally raises the question of sample section bias. In fact, the potential for bias is arguably even greater in this chapter due to the problem of finding matching patents issued to *both* headquarters and home-based firms. Of the 16,210 subsidiary patents applied for between 1980 and 1990, I could only find headquarters *and* home-based matches for 5,619 patents, about 35 percent of the population. Table 7.1 shows the sample proportion for each of the eleven years of the study. The number is relatively stable at between 30 and 40 percent of the population of subsidiary patents, although it falls to a low of 27.8 percent in 1990.

[Insert Table 7.1 Here]

Table 7.2 shows the home country composition of the sample and illuminates a key reason for the large number of dropped patents: small countries such as Netherlands, Sweden, Switzerland, and Canada are under-represented in the sample simply because there are relatively few potential matches in these countries. In other words, the odds of finding a matching home-based firm patent bear a direct relationship to the amount of technical activity (patenting) in the various countries. Conversely, patents issued to headquarters and home-based firms of German and Japanese origin are over-represented in the sample. German patents, in particular, make up over 40 percent of the citing patents used in this chapter compared to a population percentage in the subsidiary database of only about 25 percent.

[Insert Table 7.2 Here]

The home country skewdness of the sample also manifests itself in the technical composition of the sample used in this chapter, as can be seen in Table 7.3. That is, because German and Japanese firms are particularly highly represented, the sample of citing patents tends to be over-represented in Electronics as well as Drugs and Medical Technology (the latter due largely to German firms). Mechanical Arts are under-represented, while chemical patents mimic the overall population[3].

[Insert Table 7.3 Here]

It is difficult to state *a priori* whether and how these deviations in the sample patents' technological and home country characteristics will bias the results. To the extent that Japanese and/or German firms have more or less highly developed mechanisms for diffusing knowledge from the subsidiary back to the parent firm, the results will be biased in one direction or another. In terms of the technological composition, any bias introduced into the results will depend on how the nature and geography of knowledge diffusion differs across sectors, an issue for which there is virtually no research to draw upon for guidance. In the regressions that follow, I attempt to minimize problems stemming from sample selection bias by introducing a set of technology and home country control variables. I return to these issues later in the chapter where I conduct several robustness checks on the initial set of results and explore for home base effects directly.

Finally, Table 7.4 presents a set of descriptive statistics on the citations referenced by the patents issued to the two comparison groups, headquarters and home-based firms. Since the patents themselves are matched by country, technical field and time period, I concentrate on the characteristics of their citations in order to check for any "uncontrolled" differences in the two groups' citing behavior that might bias the geographic results in one way or another. The data are presented for 1980, 1985, and 1990 citing patents – the beginning, middle, and end points in the series – as well as for the pooled 1980 to 1990 period. Overall, characteristics of the groups' citations do not appear to differ markedly from one another. The number of patents cited, the average time lag between citing and cited patents, and other characteristics of the groups' citations all are similar. Not surprisingly, the one exception is in the number of intra-firm citations (i.e., citations to prior patents generated by other parts of the same firm) across the two groups. Looking at columns D and E, the difference is quite dramatic. Nearly one-quarter of all headquarters citations are to prior patents belonging to the same firm (Column D). In 1980, the figure is 28.6 percent. Column E shows that most of these intra-firm citations are actually direct self-cites, i.e., citations by headquarters patents to prior headquarters patents. Overall, only 3.4 percent of total citations are to patents issued to *other* parts of the multinational firm, including U.S. subsidiaries. For home-based firms, the corresponding number barely deviates from zero, not surprising since by definition these patents belong to firms that have no patenting subsidiaries in the U.S[4].

[Insert Table 7.4 Here]

3. Main Geographic Results

Tables 7.5 and 7.6 present the initial set of geographic results. Table 7.5 contains the host country results for the 1980-1990 citing patents; Table 7.6 contains the host state results. Thus, the figures in Table 7.5 represent the proportion of each group's citations that originate anywhere in the U.S. In Table 7.6, the interpretation is analogous: the columns indicate the proportion of each group's citations that originate in the U.S. state where the subsidiary patent (with which the headquarters patent was matched) originated. The right hand side of each table shows t-statistics for tests of equality in the citation proportions shown. Columns A and B differ in their treatment of intra-firm citations, i.e., citations to prior patents developed by another unit of the same firm. In Column A, all intra-firm citations are excluded (thus citations by headquarters' patents to subsidiary patents are omitted). In Column B, headquarters' and home based firms' patents are allowed to cite patents originating in other units of their firm[5]. However, *direct* self citations (i.e., by headquarters' patents to its own prior patents) are in all cases excluded from the calculations. For headquarters' patents, then, the addition of intra-firm citations in Column B means that citations to patents issued to these firms' U.S.-based subsidiaries are included in the analysis[6]. Differences across the two columns will therefore provide an indication of the extent to which U.S. subsidiaries themselves act as an important mechanism through which knowledge originating in the U.S. is diffused to the parent firm.

[Insert Tables 7.5 and 7.6 Here]

To reiterate, the question being explored here is whether there is any evidence that having a technical subsidiary in the U.S. increases the capacity of the headquarters organization to assimilate and utilize knowledge originating in the particular location (the U.S. or a particular state) in which its patenting subsidiary is based. In terms of the tables, the basic question is whether the citing frequencies in Columns A and B (headquarters) are significantly higher than the citing frequencies in Column C (home-based firms).

Overall, the results show modest support for the multinational diffusion hypothesis. Looking first at the host country results, the figures in Table 7.5 indicate that the U.S. citation frequency of the headquarters patents is significantly higher than the patents issued to home based firms (Test of A=C), although the magnitude of the difference is small: 53.0 percent over the 1980-1990 time period versus 51.1 percent. The effect increases somewhat when intra-firm citations are included (Test of B=C). However, Table 7.5 also shows that the propensity of headquarters patents to cite U.S. sources is significantly *lower* than the controls, i.e., below the level that would be predicted from a random drawing of patents with a similar technological and temporal profile to the headquarters citations (Test of A=D and B=D). This result holds regardless of how intra-firm citations are treated. The conclusion, then, is that both groups of citing patents appear to undercite U.S. sources; headquarters' patents just undercite less than home-based firms' patents.

State level results (Table 7.6) are more supportive of the multinational diffusion hypothesis. It should be noted that the state level results are arguably the more important test of the hypothesis since the subsidiary's role as a conduit of host country knowledge transfer is likely to be more immediate for knowledge originating in the organization's immediate geographic locale. Over the 1980-1990 period, with intra-firm citations excluded (Column A), headquarters patents show a significantly greater propensity to cite the state in which they have a patenting subsidiary than either home-based firms' patents or the controls. The inclusion of intra-firm citations (Column B) increases the magnitude and significance of these results. Headquarters patents cite the host state significantly more than home-based firms' patents in ten of eleven years (Test of B=C). The lone exception is 1983. Across the eleven year period, 7.3% of the citations listed on headquarters' patents originated in the same state as the subsidiary patent they are matched with, versus only 4.6% for the home-based firms' patents. Comparing the headquarters' results to the controls at the host state level (Test of B=D) reveals that, overall, the headquarters citation frequency is greater than the baseline expected rate[7]. However, this effect holds in only about half of the years. Interestingly, the results appear to be stronger in the later years of the study. From 1985 on, the headquarters citation rate is greater than the control citation rate in every year expect 1990 regardless of how intra-firm citations are handled.

To summarize, the results presented so far provide some evidence for the proposition that innovating subsidiaries provide a learning advantage to other parts of the multinational firm. The national level results were contradictory. On the one hand, it was shown that headquarters' patents are significantly more likely to cite prior patents originating in the U.S. than are matched patents granted to home-based firms. On the other hand, further investigation revealed that the pattern of U.S. citing exhibited by headquarters' patents is not significantly different from the control citations, meaning that the headquarters pattern is consistent with a random citation model.

The state level results were more encouraging. Especially in the most recent period (post 1985), there is systematic evidence that having a patenting subsidiary in a particular U.S. state systematically increases the probability that the headquarters organization will cite technical sources originating in that state. The implication is that the subsidiary's presence in the state is providing a mechanism through which local knowledge is communicated back to the parent organization[8]. The magnitude of the difference between the headquarters and home-based firm's citation frequency is quite large: headquarters' patents range from 1.5 times to slightly over twice as likely as home based firms to cite sources in locations where they have a subsidiary[9]. Recall, too, that these differences cannot be accounted for by differences across the two groups' patents since they are matched for technology, as well as the time period of the invention. Moreover, the frequency of host state citing by headquarters' patents is generally not at a level that would be predicted by a random citation process: it is significantly greater in the last half of the series. Part of this effect is due to knowledge created by the subsidiary itself being utilized by the headquarters organization: including intra-firm citations in the analysis increases the host country and host state citation frequencies exhibited by headquarters' patents.

Before moving on, it is interesting to look more closely at the amount of intra-firm citing that actually occurs, since this is perhaps the most direct measure of multinational knowledge diffusion available through these data. Looking again at the two tables, the far right hand side column provides a test of whether the inclusion of intra-firm citations significantly alters the host country and state citation frequencies exhibited by headquarters patents (Test of A=B). Only for the pooled 1980-1990 results at the state level (Table 7.6) does the addition of intra-firm citations make a significant difference in the results. Moreover, the test of A=B fails to turn up a significant difference in each of the eleven years of the study, implying that the addition of intra-firm citations does not materially change the level of host country citing by headquarters patents. However, looked at another way, the numbers are a little more impressive: about 16 percent of all citations by headquarters' patents to the subsidiary's host state are to the subsidiary itself. This figure translates into a total of 197 citations over the combined eleven year period. Recall, however, from Chapter 5 that during the same period subsidiary patents cited prior headquarters patents over 2,000 times, a figure which caused the level of home country citing by U.S. subsidiaries to more than double! Clearly there is a manifest difference in the directionality of knowledge transfer in multinational firms – as would be predicted from the conventional theory of the multinational firm[10].

Figure 7.2 summarizes and extends the foregoing analysis by providing a home country breakdown of the results. Figure 7.2 juxtaposes U.S. and host state citing by headquarters' patents along the horizontal and vertical axes, respectively. Points outside of the $p<.01$ box indicate over- or under-citing of one or both locations. Clearly the aggregate results presented earlier mask important variation across firms from different home countries. Headquarters units of firms from three countries – France, Belgium, and Canada – actually show a significantly greater propensity to cite U.S. sources (all locations) than would be predicted from the control citations. However, headquarters units of Swiss, German, Japanese and Swedish emerge as clear outliers in the other direction: each undercites U.S. sources to a statistically significant degree. Figure 7.2 does, however, confirm the earlier finding that the state level results are more supportive of the multinational diffusion hypothesis. With intra-firm citations included (triangular data points), only Canadian and Italian headquarters' patents fail to overcite the state in which they have a patenting subsidiary. Japanese and Belgian firms are on the border of statistically significant overciting ($p<.01$). The distance between the two data points for each home country provides an indication of the importance of the U.S. subsidiaries' own work to the level of U.S. and host state citing by headquarters units. Dutch and German firms appear to have the highest level of intra-firm citing. The addition of intra-firm citations also matters importantly to Belgian, Japanese, and Swiss firms, as it moves each group into the significant overciting category at the state level.

[Insert Figure 7.2 Here]

4. Factors Affecting the Likelihood of Knowledge Diffusion

So far, the results provide some evidence that having an overseas technical facility provides a learning advantage to units of the multinational firm located in the home country. The results are clearest at the host state level, which is perhaps not surprising given that much of the literature on technological spillovers points to localized processes of knowledge assimilation and diffusion. Moreover, judging by the amount of intra-firm citing evidenced so far (i.e., citing by headquarters' patents of prior subsidiary patents), it also appears that at least some firms have been able to develop internal networks for learning and knowledge diffusion.

It is important to bear in mind that the results presented so far offer a generalized picture of the extent to which network diffusion occurs – or doesn't occur -- within multinational firms. The results do not illuminate the factors that may increase the probability of network diffusion occurring. For example, do subsidiaries established through acquisition provide more or less of a learning benefit than greenfield subsidiaries to other parts of the firm? How does the contribution of the subsidiary to the parent firm's knowledge base increase with the subsidiary's tenure in the local milieu? Are subsidiaries that themselves assimilate and utilize host country knowledge more likely to diffuse that knowledge abroad? The purpose of this section is to explore questions such as these in order to shed light on the conditions under which knowledge diffusion does or does not occur. For guidance in identifying potential predictive factors, I return to the main theoretical arguments advanced in Chapter 2 as well as the results from earlier empirical chapters.

In Chapter 2, it was argued that the assimilation of local knowledge by U.S. subsidiaries would be most pronounced for technical activities that were characterized as "exploration" oriented – i.e., activities that were not central to existing areas of parent company specialization. The argument is more ambiguous in the present context. On the one hand, activities geared toward the adaptation of existing products and processes to local market conditions are not likely to orient the subsidiary toward the assimilation of host country science and technology – an important precondition for diffusion of local knowledge back to the parent organization. On the other hand, subsidiary activities that are more closely aligned with the existing competence base of the parent firm (exploitation-oriented activities) are arguably more likely to be noticed and utilized. Put slightly differently, the parent firm is more likely to have the necessary absorptive capacity (Cohen and Levinthal 1990) to utilize ideas originating abroad that are closer to its technical core. The absence of a strong theoretical argument in one direction further motivates the need for empirical testing.

The embeddedness argument advanced in Chapter 2 also presents something of a puzzle in the context of the question addressed in this chapter. On the one hand, we can expect that subsidiaries that are not well integrated into the local technical milieu to be rather poor conduits for the diffusion of knowledge originating there since these subsidiaries are themselves unlikely to have assimilated that knowledge. On the other hand, the more the subsidiary is embedded in the local environment (and in touch with local technical developments), the more difficult it may be to ensure that local knowledge is diffused back through the multinational network. Indeed, this tension between local embeddedness and global integration/learning is one of the most widely researched – and still actively debated -- aspects of multinational behavior (e.g., Bartlett and Ghoshal 1989; Prahalad and Doz 1987). Ultimately, the question of whether such a tradeoff exists in the context of knowledge assimilation and diffusion is an empirical one.

To explore these issues, I again fit a series of logistic regression models taking a citation listed on a headquarters patent as the basic unit of analysis. I restrict the analysis to the host state level, which is where the earlier results indicated headquarters units seem to be gaining the greatest learning advantage. Thus the dependent variable in the models that follow takes on the value of unity for citations by headquarters' patents to prior art that originates in the state in which its subsidiary is located, and zero otherwise[11].

The independent variables are defined in Table 7.7. Not all of the variables utilized in Chapter 6 to operationalize my original hypotheses are included in the models. Rather, I concentrate on those variables that proved insightful in the earlier analysis: the age of the subsidiary, its technical resources, whether a subsidiary patent builds directly upon prior parent firm technology, and whether the patent is in an field of headquarters specialization.

[Insert Table 7.7 Here]

I also constructed several new variables. First, I developed a dummy variable indicating whether the headquarters patent is matched with a subsidiary patent that originated in an acquired U.S. firm (versus a greenfield subsidiary). This variable provides an interesting test of the embeddedness/integration tradeoff. As a prior, one would expect acquired firms to be more tightly linked into host country technical networks than they are into the multinational network. If this is correct, the expected sign on *Acquisition* would be negative. However, to the extent that multinationals acquire firms explicitly for the purpose of capturing localized knowledge, including knowledge generated by the target itself, acquisitions may indeed contribute to the broader knowledge base of the firm.

Second, I also developed a more direct measure of the extent to which a firm's U.S. subsidiary is embedded in the local technical environment. *Subsidiary Overcites Host State* takes on the value of one when the subsidiary patent with which the citing headquarters patent is matched cites the host state more than the control citations would predict, and zero otherwise. This variable is thus a direct measure of local knowledge assimilation by the U.S. subsidiary. Since knowledge assimilation is likely to be a necessary (if not sufficient) condition for its diffusion to other parts of the firm, I expect the sign on this variable to be positive, all else equal.

The usual set of controls for technology, home base, and year are again included in the models. As in Chapters 5 and 6, I also included the log of the time difference between the application dates on the headquarters patent and each citation. *Citation Lag* provides an indication of how the likelihood of a host state citation by a headquarters patent changes as a function of the age of the technology being cited, i.e., a measure of the space-time diffusion path of knowledge.

The main results are presented in Table 7.8. Models 1 and 2 on the left hand side of the table exclude all intra-firm citations. In models 3 and 4, citations by headquarters patents to prior subsidiary patents are included. Differences in the coefficients across the two groups of models thus provide an indication of the factors that influence *internal* technological building relationships – in this case where headquarters units are building upon subsidiary-developed technology.

The results are interesting and point to several factors that influence the likelihood that a headquarters patent will cite technology originating in the state where the firm has an innovating subsidiary. *Adaptation of HQ Technology* is positive and significant in all models, meaning that headquarters' patents that are matched with a subsidiary patent that itself builds upon prior headquarters technology are more likely to cite the subsidiary's host state. This is a perhaps surprising result since it implies that diffusion of host country knowledge is most likely to occur for technical activities previously characterized as "exploitation oriented" – i.e., activities that build upon the existing knowledge base of the firm. The result holds regardless of how intra-firm citations are handled; the positive sign on *Adaptation of HQ Technology* is evidently not just picking up the diffusion of internally generated knowledge. Perhaps the most likely explanation for this result is that *Adaptation of HQ Technology* is capturing the knowledge sharing activities of firms that have developed relatively effective cross-border technical networks: subsidiaries that draw upon headquarters technology are also, it turns out, likely to contribute back to the knowledge base of the parent firm, both through their own work and through increasing the awareness of the parent in host country technical developments[12].

[Insert Table 7.8 Here]

The positive sign on *Headquarters Specialization* indicates that the probability of a headquarters patent citing a prior U.S. subsidiary patent is higher for technical areas that are important to the headquarters unit – not a particularly surprising result. However, the coefficient on this variable reaches significance only in Models 3 and 4 (where intra-firm citations are included), implying that the diffusion of internally generated knowledge between headquarters and subsidiary units is most likely to occur in technical areas that are well represented in the headquarters unit. Another expected result is the positive sign on *Host State Specialization*, which indicates that when the headquarters patent is in a technical area of host state specialization, the probability of it citing the host state rises. This result certainly supports the findings of the previous chapters, which consistently highlighted the importance of the focal location's relative technological advantage in increasing the likelihood that a subsidiary will utilize knowledge from that location.

The remaining variables capture various structural characteristics of the subsidiary whose patent the headquarters patent is matched with. These variables thus provide an indication of the attributes of subsidiaries that are most conducive to the diffusion of host country knowledge to other parts of the multinational firm. Interestingly, the sign on *Subsidiary Age* is positive and highly significant in all models. None of the ambiguity that surrounded the age of the subsidiary in the previous chapter is present here: the likelihood of a headquarters patent citing the host state rises with the tenure of the subsidiary in that state. Part of the explanation is that more recently established subsidiaries are much less likely to have their own innovations cited as references by headquarters' units simply because of the shorter period of time that their innovations will have been "at risk" of receiving a citation. This can be seen by looking at how the coefficient on *Subsidiary Age* increases when intra-firm citations are added to the models (Models 3 and 4). However, the positive, significant effect of this variable is robust to the elimination of intra-firm citations (Models 1 and 2), meaning that this result is not driven solely by internally generated knowledge.

Subsidiary Resources is similarly positive and significant implying that the larger the subsidiary the more likely it is to contribute to the headquarter's knowledge base. As with *Subsidiary Age*, the subsidiary's own technical activities again play an important role in producing this effect. When intra-firm citations are added to the models (Models 3 and 4), the effect size on *Subsidiary Resources* nearly doubles. However, even with intra-firm citations excluded (Models 1 and 2), the positive significant effect remains.

The significant, negative sign on *Acquisition* implies that acquired U.S. firms are less likely than greenfield subsidiaries to facilitate the diffusion of host country knowledge across organizational units within multinational firms. The sign and significance of *Acquisition* remains regardless of how intra-firm citations are handled. This is an interesting, if somewhat expected result.

Further analysis revealed some additional insights about the difference between acquisitions and greenfield subsidiaries in this regard. First, patents generated by acquired units are significantly less likely to be cited by headquarters units than are patents generated by greenfield subsidiaries, implying that there is greater technical overlap and greater amounts of joint development between headquarters and greenfield subsidiaries than there is between headquarters and acquisitions. Second, as with greenfield subsidiaries, there is a positive and significant relationship between the age of the acquired unit (defined as the date of acquisition) and the degree to which the headquarters unit cites technology originating in the same state as that unit. In other words, it appears that older acquisitions are more integrated into the multinational network than are relatively new acquisitions. This interpretation is also supported by a third result, which is that those acquisitions that themselves build upon parent technology (implying a more integrated multinational innovation network) are also the most likely to contribute positively to the parent firm's ability to assimilate host country knowledge. Together, these results point to the importance of strong *internal* networks as a precondition for the diffusion of host country knowledge to the parent firm.

The inclusion of a direct measure of the extent to which the subsidiary is capturing local knowledge adds to the explanatory power of the models (Models 2 and 4). *Subsidiary Overcites Host State* is positive and significant regardless of how intra-firm citations are handled. The interpretation of this result is as follows: when the subsidiary patent with which the headquarters patent is matched overcites the host state, the likelihood that a citation on a headquarters patent will originate in the host state also increases. The coefficient on *Subsidiary Overcites Host State* implies that as this variable moves from zero to one, the odds of a host state citation by the headquarters patent increase by between 50 and about 70 percent.

Finally, the positive sign on *Citation Lag*, and its significance in Models 1 and 2, requires some explanation. The positive sign indicates that the level of host state citing by headquarters' patents actually rises with the age of the technology being cited. On reflection, this result runs counter to the multinational diffusion hypothesis. After all, any learning advantage created by the presence of a foreign technical subsidiary ought to manifest itself in greater awareness by the headquarters unit of *new* technological developments occurring in the subsidiary's immediate geographic locale. However, further investigation revealed the explanation for this result: the most recent technology being cited by headquarters' patents originates disproportionately from the headquarters' own geographic locale, i.e., the home country. As originally suggested in Chapter 5, the headquarters unit itself appears to be highly embedded in its local technical milieu. Interestingly, when intra-firm citations are included in the analysis of headquarters' citations (Models 3 and 4), *Citation Lag* fails to reach significance. This implies that headquarters units are citing recent innovations developed by their U.S. subsidiaries – recent enough to cancel out the effect of the bias toward new home country technology that is driving the results for *Citation Lag* in Models 1 and 2. This result can be seen more directly by looking at the average time differential between the application dates of citing headquarters patents and three groups of citations: citations to the firm's U.S. subsidiary's innovations; citations to the host state that are not innovations of the firm's subsidiary; and citations to the home country. Table 7.9 contains the results, presented in terms of mean and median time lags between citing and cited patents. The shortest time lag is clearly for intra-firm innovations: the average time differential between the application date of a headquarters patent and the application date of a subsidiary patent cited as a reference is just under 4 years. Citations to home country innovations have an average lag of about four and a half years, while citations to prior patents originating in the subsidiary's host state (but not in subsidiary itself) average a full year older at five and a half years.

[Insert Table 7.9 Here]

Overall, the analysis presented above suggest that structural attributes of U.S. subsidiaries influence to an important degree the extent to which knowledge of host country technical developments is diffused across borders to the parent firm. In particular, the results consistently indicate that the more integrated the subsidiary is in the local technical environment, whether measured directly through the pattern of citations indicated on subsidiary patents or indirectly through subsidiary attributes such as age

5. Conclusion

The basic purpose of this chapter has been to search for evidence that foreign subsidiaries engaged in the process of technological innovation contribute positively to the knowledge base of other units of the firm, either directly through their own work or indirectly through greater awareness of technical developments occurring in the host country environment. Whether and to what extent foreign technical subsidiaries provide such learning benefits to the broader firm is a central issue in current debates about multinational firms. Looking at the specific question of whether a foreign technical subsidiary provides the headquarters organization with an improved capacity to assimilate technology originating in the host country, the results presented in this chapter were somewhat mixed. Headquarters units did exhibit a greater likelihood of utilizing U.S. technology than firms from the same country that do not have a U.S. technical facility. However, further analysis revealed that both headquarters and home-based firms tend to undercite U.S. sources to a significant degree.

Support for the "multinational diffusion hypothesis" was much stronger when the analysis shifted to more finely grained geographic units of analysis – U.S. state in the analysis conducted here. In particular, headquarters units were shown to be much more likely to draw upon technology originating in the U.S. state where their foreign subsidiary is located than were firms lacking such a subsidiary. Moreover, the extent of host state citing exhibited by headquarters' patents was significantly greater than could be predicted from the nature of the technology and time period in question.

Further analysis revealed several factors that appeared to increase the awareness by the headquarters organization of host country (U.S.) technical developments. Overall, the pattern that emerges is one in which the greater embeddedness of the subsidiary in the local environment, the greater the odds that the headquarters organization will derive a learning benefit, i.e., the greater the odds that headquarters will utilize technology originating in locations near to the subsidiary. The notable exception to this result is the finding that subsidiaries established through acquisition, who can be expected to be tightly integrated into the local technical environment, were shown to provide less learning benefit than subsidiaries established through greenfield investment. One possible interpretation is that effective knowledge diffusion actually requires "dual embeddedness" on the part of the subsidiary, i.e., embeddedness in both external and internal networks.

The results appear to indicate that acquisitions are lacking the latter, a result that was also suggested by the results of Chapter 5, which clearly showed that acquisitions rely less on technology developed by the headquarters organization than do greenfield subsidiaries.

Several caveats are in order with respect to the results presented here. First, the results cannot prove in any meaningful sense that foreign subsidiaries *cause* the greater awareness and utilization of foreign technology by headquarters units that is apparent in the above analysis. Rather, the "proof" is based upon the elimination of alternative explanations through the extensive set of controls built into the research design. At the very least, causality would necessitate the establishment of proper time-order, something that cannot be accomplished with these data. Did headquarters always have an awareness of and interest in technology originating in the host state? Or does having a subsidiary in a particular location systematically improve that awareness? The implicit argument of this chapter is the latter. However, a plausible alternative explanation is simply that the firm was always interested in a particular technology-location, indeed so interested that it established a technical subsidiary there. Thus the presence of a technical subsidiary and the awareness by the headquarters organization of technology originating in that location may be endogenous: untangling these effects would require more and better data than the kind used here. Particularly needed are data that could illuminate some of the mechanisms through which the diffusion of knowledge occurs across borders within firms.

A related caveat stems from the data and methods used in this chapter, which can be expected to understate the amount of knowledge diffusion that actually occurs within multinational firms, and to mask considerable variation across firms in this regard. Anecdotally, we know that diffusion and learning across units of multinational firms does occur, and that some firms have been able to develop well functioning international technical networks. To the extent that such processes manifest themselves in citation patterns on patents – and it will clearly be a limited extent – the amount of diffusion was not always enough to register a significant effect. Moreover, the factors that affect the capacity of firms to build these networks are likely to reside in the kinds of phenomenon -- organizational strategies, practices, and routines – that are impossible to measure with the data used in this study. Thus the results presented here must be interpreted with caution; they are exploratory and tentative. More and different kinds of empirical research is clearly required on these issues before more definitive conclusions can be drawn about the extent and conditions under which subsidiaries act as conduits for the diffusion of local knowledge.

Endnotes

[1] Recall that the definition of a "headquarters" patent is any patent issued to the parent firm that lists the first inventor's address as being in the home country of the firm. Thus any patents issued to Siemens on which a German address was listed for the first inventor would be described as a headquarters patent. Technically, such a patent may not originate in the "official" headquarters unit, since a firm may have several patenting units in its home base. To take a well known American example, Xerox has patenting units in several locations within the U.S., e.g., Rochester, Palo Alto, Stamford. All of these units would be classified as headquarters because they originate in the home country of the firm.

[2] The following example, which builds on the Ciba-Geigy discussion in Chapter 5, is intended to clarify further the procedure used in this chapter to construct the samples. The process begins with a Ciba-Geigy patent issued to an inventor in the company's Ardsley, New York facility. Assume the patent is in patent class 8, "Bleaching and Dyeing of Textiles and Fibers" and was applied for in 1986. A matching patent (also class 8 and also applied for in 1986) issued to a Basel, Switzerland based unit of Ciba-Geigy is then identified. If more than one headquarters patent meets the matching criteria, the headquarters patent that is closest to the subsidiary patent in terms of its application date is chosen. To generate the matching home-based firm patent, the database is then searched for a matching (same primary patent class, same application year) patent that originated in Switzerland and which is assigned to an organization that does not have a patenting facility in the U.S. Patents issued to Roche and Sandoz, for example, would be excluded from consideration because both firms had patenting units in the U.S. during the 1980-1990 time period. The procedure eventually identifies a patent issued to a Swiss firm, Herberlein Textildruck AG, as a match. This patent meets all of the criteria: it was issued to a Swiss inventor, its primary patent class is 8, it was applied for in 1986, and the firm has no patenting units in the U.S. during the 1980-1990 period. The citations listed on the Ciba-Geigy headquarters patent and the Herberlein patent are then extracted into the main citation file for analysis.

[3] The fact that chemical patents are about the same as the overall population stems from the aggregate effects of over-representation of German firms (high in chemicals) and Japanese firms (low in chemicals).

[4] The reason that the number of cross-border, intra-firm citations is not zero is that these firms were not restricted to having no international patenting subsidiaries. Thus the slightly greater than zero number is picking up citations to patents issued to non-U.S, but still foreign, subsidiaries.

[5] Clearly there is likely to be a very a small number of intra-firm citations for home-based firms, since by definition they have no patenting facilities in the U.S. Note that this does not preclude these firms from having patenting facilities in other countries outside the U.S. Citations to any such units' patents would be included in the bottom sections of both tables.

[6] Citations to patents developed by other foreign units of the firm are also included in these calculations, of course.

[7] Compared to the controls, home-based firms systematically undercite U.S. sources at both the national and state levels. To simplify the presentation, I do not present this comparison.

[8] Obviously the data used here cannot illuminate the actual organizational mechanisms through which that knowledge is diffused. This will be an interesting subject for future research. It should also be pointed out that an alternative explanation for these results is that the headquarters organization was always interested in the host country technology it is citing, as manifested in its decision to locate a technical facility in that location. In other words, the subsidiary's presence in that location may be an artifact or result of an a priori headquarters orientation to that location. This is a question of the direction of causality: is the subsidiary's presence increasing headquarters' orientation to local technology (as I am

arguing)? Or is the headquarters' orientation driving the decision to locate a subsidiary in particular geographic setting?. It should be pointed out that these arguments are not necessarily mutually exclusive: the subsidiary might be assisting the headquarters unit assimilate sources of technology that it was already interested in and aware of. Untangling the two explanation would require data stretching back to a much longer period than I have here.

[9] This figure was calculated through a separate logistic regression analysis, which is not shown.

[10] Earlier in the chapter, I raised the issue of sample selection bias, which could result from the large number of subsidiary patents that did not generate a matching headquarters or home-based firm patent. Although the directionality of any bias is difficult to assess ex ante, it is possible to mitigate the problem to some extent by modifying the original research design. Specifically, by restricting the analysis to headquarters' patent citations only (i.e., comparing their geography to that of the control citations) a much larger sample proportion can be utilized. This is because of the larger number of headquarters patents that were not able to be matched with a unique home-based firm patent. So instead of the 5,169 citing headquarters patents used in the above analysis, the modified design allowed the citations from 8,444 headquarters patents to be compared with the control citations.

Using the modified research design, the results presented earlier did not change materially. State-level results were again much more encouraging of the multinational diffusion hypothesis; this was again especially true for later periods (post 1985). Interestingly, the number of intra-firm citations (i.e., citations by headquarters patents to their U.S. subsidiaries' prior work) turned out to be quite a bit higher for the larger sample. Whereas in the earlier analysis, 16.1 percent of all host state citations by headquarters patents were citations to the subsidiary, the corresponding figure rose to 20.2 percent for the larger sample. This represents an increase from 197 intra-firm citations to a total of 464 – still far below the two thousand plus citations by subsidiaries to prior headquarters innovations during the same 1980-1990 period.

[11] This dependent variable in the state level models may require some additional clarification. Recall, that each headquarters patent is matched with a U.S. subsidiary patent. Thus a value of unity for this variable is given to a citation that originates in the same state as the subsidiary patent (with which the headquarters patent is matched) originated.

[12] An alternative explanation is the same one identified earlier in footnote 7, namely that the presence of a subsidiary in a particular location merely reflects a pre-existing interest by the parent firm in technology originating in that location.

Table 7.1 Sample Size by Year

Year	Headquarters Patents* (Sample)	Subsidiary Patents (Population)	Sample Percentage
1980	412	1035	39.8%
1981	411	1049	39.2%
1982	407	1131	36.0%
1983	406	1164	34.9%
1984	440	1153	38.2%
1985	468	1219	38.4%
1986	475	1313	36.2%
1987	580	1761	32.9%
1988	683	2118	32.2%
1989	771	2232	34.5%
1990	566	2035	27.8%
Pooled	5619	16210	34.7%

*The sample used in this chapter is also composed of an equal number of home-based firms' patents

Table 7.2 Home Country Composition of Sample Compared to Population*

Home Country	Headquarters Patents (Sample %)	Subsidiary Patents (Population %)	Ratio: Sample to Population %
Belgium	0.1	0.9	0.11
Canada	2.5	2.9	0.86
Switzerland	5.7	11.6	0.49
Germany	42.1	25.6	1.64
France	8.7	10.5	0.83
Great Britain	13.1	17.9	0.73
Italy	1.2	1.0	1.20
Japan	15.0	8.2	1.83
Netherlands	8.0	17.8	0.45
Sweden	2.3	3.7	0.62

Table 7.3 Technical Composition of Sample Compared to Population*

Year	Chemicals (Ex. Drugs)			Drugs & Medical			Electronic Arts			Mechanical Arts			Other		
	A Sample (%)	B Full (%)	C A÷B	A Sample (%)	B Full (%)	C A÷B	A Sample (%)	B Full (%)	C A÷B	A Sample (%)	B Full (%)	C A÷B	A Sample (%)	B Full (%)	C A÷B
1980	44.7	38.7	1.16	11.0	11.0	1.00	27.4	25.1	1.09	11.2	16.9	0.66	5.6	8.3	0.67
1981	39.8	41.3	0.96	15.9	10.4	1.53	30.7	25.9	1.19	8.3	14.1	0.59	5.4	8.3	0.65
1982	36.6	34.1	1.07	14.3	11.8	1.21	30.7	27.9	1.10	12.3	16.3	0.75	6.1	10.0	0.61
1983	33.5	34.5	0.97	14.5	9.2	1.58	32.0	28.7	1.11	14.0	19.6	0.71	5.9	8.0	0.74
1984	32.7	31.3	1.04	15.9	11.2	1.42	32.7	29.2	1.12	12.0	19.0	0.63	6.6	9.4	0.70
1985	33.8	32.2	1.05	18.4	16.2	1.14	28.4	29.3	0.97	12.4	14.6	0.85	7.1	7.8	0.91
1986	35.2	32.1	1.10	14.5	14.2	1.02	28.2	26.5	1.06	12.4	17.4	0.71	9.7	9.7	1.00
1987	31.9	33.9	0.94	16.6	14.0	1.19	30.2	28.0	1.08	11.0	14.4	0.76	10.3	9.7	1.06
1988	30.2	34.1	0.89	13.5	12.4	1.09	33.0	27.0	1.22	13.5	17.5	0.77	9.8	9.0	1.09
1989	30.5	31.5	0.97	16.5	14.6	1.13	32.9	29.4	1.12	12.2	15.7	0.78	7.9	8.8	0.90
1990	31.1	34.0	0.91	15.9	14.5	1.10	32.9	26.7	1.23	12.7	17.1	0.74	7.4	7.7	0.96
Average	34.5	34.3	1.01	15.2	12.7	1.20	30.8	27.6	1.12	12.0	16.6	0.72	7.4	8.8	0.84

*Population refers to population of 1980-1990 subsidiary patents

Table 7.4

Descriptive Statistics on Citations Referenced by Matched Patents Issued to Headquarters and Home-Based Firms[*]

	Number of Patents Cited	Average Number of Citations	Average Citation Lag (Years)	% Intra-firm Citations	% Cross-Border, Intra-firm Citations	% Citations Same Primary Class[†]	Average "Importance" of Cited Patents[§]
1980 Citing Patents							
Headquarters	681	2.80	3.94	28.6	4.1	67.5	0.80
Home-Based Firms	579	2.59	4.04	4.1	0.0	69.4	0.78
1985 Citing Patents							
Headquarters	1309	4.01	5.96	21.8	3.3	59.6	0.82
Home-Based Firms	1234	3.57	5.99	1.7	0.0	56.5	0.79
1990 Citing Patents							
Headquarters	1881	4.75	7.23	21.9	2.7	65.1	0.80
Home-Based Firms	1947	4.58	7.35	2.0	0.2	55.9	0.82
All Years							
Headquarters	15687	4.14	6.04	23.6	3.4	66.8	0.82
Home-Based Firms	15732	3.93	6.24	2.0	0.1	57.4	0.80

[*]Based on 5,178 citing patents issued to each of the two comparison groups. All intra-firm citations excluded except where noted
[†]Percent of total citations that have the same 3-digit primary class as the citing patent.
[§]Based on the total number of citations received by the cited patents. Number shown is a percentile score, which shows how each group's cited patents compare to all U.S patents issued in the same year.

Table 7.5 Host Country Results

	Host Country Citation Frequency (%)				Tests for Significance				
	A	B	C	D	A=C	A=D	B=C	B=D	A=B
Year	Headquarters	Headquarters*	Home Based Firms	Controls	*t*	*t*	*t*	*t*	*t*
1980	57.6	58.3	49.2	59.3	2.97	-0.66	3.54	-0.40	0.28
1981	56.0	56.6	50.8	61.6	2.09	-2.23	3.07	-2.01	0.25
1982	51.2	51.4	50.6	58.7	0.26	-3.27	1.09	-3.21	0.09
1983	53.0	53.6	47.8	57.8	2.33	-2.21	3.15	-1.99	0.28
1984	57.6	57.3	51.7	55.7	2.79	0.86	3.36	0.65	-0.11
1985	51.9	52.6	52.2	57.0	-0.12	-2.59	0.84	-2.25	0.35
1986	56.8	56.7	52.6	56.9	2.20	-0.09	2.75	-0.14	-0.04
1987	53.0	53.1	52.2	56.4	0.49	-2.07	1.28	-2.11	0.01
1988	49.9	50.4	48.8	56.1	0.70	-4.15	1.91	-3.81	0.36
1989	51.5	51.9	52.8	55.6	-0.95	-2.98	0.00	-2.77	0.29
1990	51.9	52.0	50.5	53.9	0.83	-1.25	1.23	-1.15	0.05
Pooled	53.0	53.3	51.1	56.6	3.33	-6.45	5.93	-5.16	0.55

* $p<.05$ ** $p<.01$ *** $p<.001$

Table 7.6 Host State Results

	Host State Citation Frequency (%)				Tests for Significance				
	A	B	C	D	A=C	A=D	B=C	B=D	A=B
Year	Headquarters	Headquarters*	Home Based Firms	Controls	*t*	*t*	*t*	*t*	*t*
1980	7.2	8.8	5.4	6.4	1.35	0.57	2.50	1.48	1.09
1981	6.0	7.7	5.3	6.0	0.61	-0.02	2.13	1.23	1.46
1982	6.3	7.6	4.7	5.0	1.48	1.23	2.79	1.95	1.71
1983	5.1	6.6	6.2	5.5	-1.05	-0.45	0.60	0.64	1.58
1984	6.1	6.6	4.1	4.9	2.18	1.26	2.84	1.62	0.78
1985	7.9	8.8	4.0	5.7	4.20	2.19	5.24	2.98	0.90
1986	5.5	6.7	3.6	3.5	2.37	2.51	3.86	3.70	1.34
1987	7.6	8.2	4.8	4.4	3.59	4.13	4.45	4.68	0.67
1988	5.8	6.8	3.7	4.1	3.29	2.57	4.84	3.89	1.35
1989	6.4	7.3	5.3	4.6	1.78	2.80	3.26	4.06	1.32
1990	6.4	6.6	4.5	5.4	2.60	1.33	2.88	1.47	0.19
Pooled	6.4	7.3	4.6	4.9	7.10	5.96	10.91	8.77	3.56

$^{*}p<.05$ $^{**}p<.01$ $^{***}p<.001$

Table 7.7 Names and Definitions of Independent Variables

Variable	Definition
Adaptation of HQ Technology	Dichotomous variable: 1 if the headquarters patent is matched with a subsidiary patent that contains a citation to an earlier headquarters patent; 0 otherwise.
Headquarters Specialization	Total headquarters patents in the technical field listed on the citing patent divided by total headquarters patents, all fields. Calculated for each year. Classification of technical field is based on a concordance between patent classes and 33 fields of technology (see Appendix 3).
Host State Specialization	Dichotomous variable: 1 if the headquarters patent is in a technical field in which the host state has an RTA* greater than one in the year of application of the citing subsidiary patent; 0 otherwise.
Subsidiary Age	Calculated based on the subsidiary patent with which the headquarters patent is matched. Application date of subsidiary patent minus application date of first patent issued to the subsidiary.
Subsidiary Resources	Total number of patents issued to the subsidiary in the same year as the citing patent.

*An RTA of greater than one indicates that the particular locational unit is disproportionately represented in that particular technical field relative to its position in other fields. See Cantwell (1989) for an extended discussion of the definition and interpretation of RTA.

Table 7.8 Results of Logistic Regressions on Host State Citations

	Intra-firm Citations Excluded		Intra-firm Citations Included	
Variable	1	2	3	4
Geographic Controls	0.930***	0.922***	0.897***	0.894***
	(0.088)	(0.088)	(0.079)	(0.079)
Adaptation of HQ Technology	0.243***	0.224**	0.247***	0.234***
	(0.073)	(0.073)	(0.065)	(0.065)
Headquarters Specialization	0.028	0.043	0.158**	0.166**
	(0.089)	(0.084)	(0.060)	(0.060)
Host State Specialization	0.664***	0.621***	0.595***	0.564***
	(0.073)	(0.074)	(0.065)	(0.065)
Log (Subsidiary Age)	0.082***	0.086***	0.107***	0.111***
	(0.017)	(0.017)	(0.017)	(0.017)
Log (Subsidiary Resources)	0.089***	0.083***	0.159***	0.153***
	(0.025)	(0.025)	(0.022)	(0.023)
Acquisition	-0.213**	-0.246***	-0.227***	-0.251***
	(0.068)	(0.069)	(0.062)	(0.062)
Subsidiary Overcites Host State		0.539***		0.422***
		(0.062)		(0.057)
Log (Citation Lag)	0.196***	0.198***	0.049	0.051
	(0.040)	(0.040)	(0.034)	(0.034)
Technical Field Dummies	***	***	***	***
Year Dummies	***	***	***	***
Home Base Dummies	***	***	***	***
Constant	-5.965***	-6.060***	-4.847***	-4.921***
	(1.279)	(1.279)	(1.265)	(1.265)
Percent correctly predicted	93.61	93.61	92.21	92.21
Chi-Square (Model)	437.50	508.57	596.24	648.12
Number of observations	23,399	23,399	24,522	24,522

$^{*}p<.05$ $^{**}p<.01$ $^{***}p<.001$

Table 7.9 Time Lag Between Headquarters Patents and their Citations

	Mean Citation Lag* (Years)	Median Citation Lag* (Years)
Citations to Subsidiary Patents	3.94	3.98
Citations to Home Country Patents	4.49	4.92
Citations to Host State (excluding subsidiary)	5.51	6.34

*Application Date of Citing Patent - Application Date of Cited Patent

Figure 7.1 Schematic Overview of Research Design

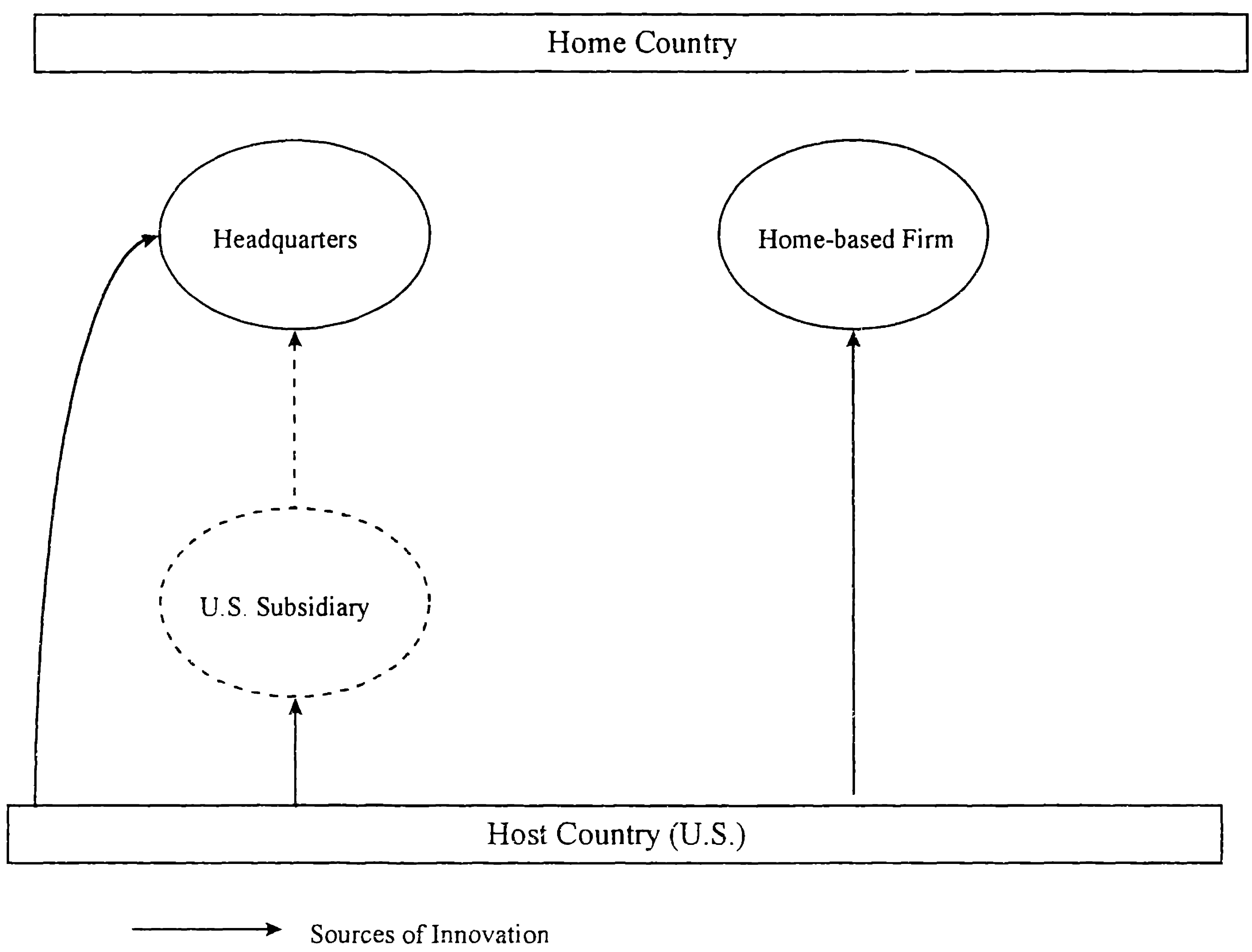
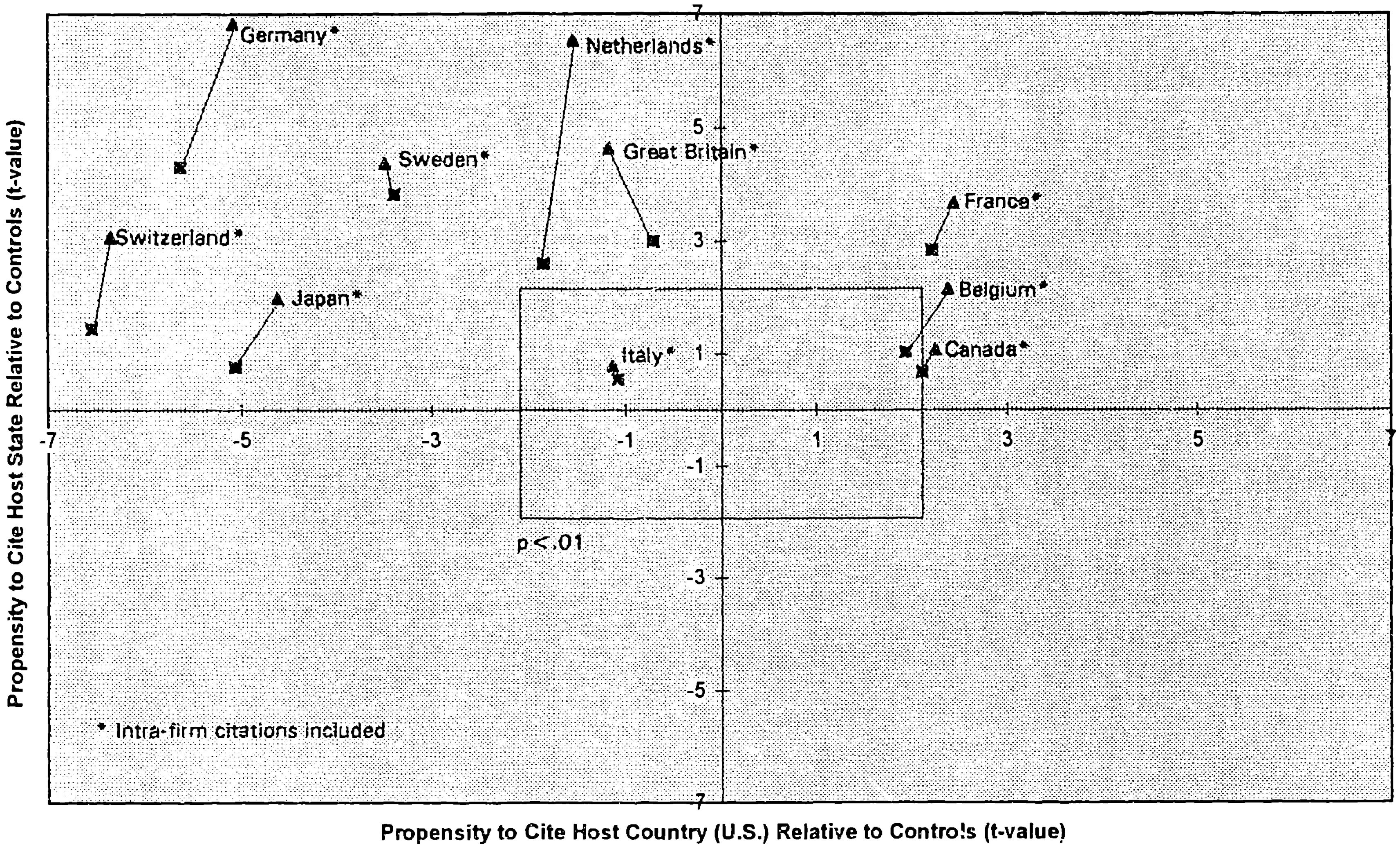


Figure 7.2 U.S. and Host State Citing by Headquarters Units, Pooled 1980-90 Citing Patents



Chapter 8 Summary and Conclusions

1. Overview and Objectives

The purpose of this concluding chapter is to summarize the main results of the study and discuss the implications of my findings for theory and practice. In addition, I discuss the limitations of the current study and lay out several avenues for future research.

2. Summary of Research Findings

This section summarizes the main findings of the study in the context of the three research questions addressed in the thesis.

2.1 Research Question 1

> Where, geographically, do foreign subsidiaries derive their scientific and technical ideas from during the process of technological innovation?

Chapter 5 sought to answer the first research question through a geographic analysis of the citations listed on patents issued to U.S.-based subsidiaries of foreign multinationals. Important findings from the analysis include the following:

2.1.1 <u>U.S. subsidiaries' innovations build to a significant degree upon localized sources of knowledge in the host country</u>

The results of the analysis contained in Chapter 5 showed that U.S. subsidiaries were significantly more likely to build upon U.S. technology during the innovation process than were headquarters organizations (units of the same firm located in the home country), implying, as has often been conjectured in the multinational literature, that one of the advantages of having a multinational network of foreign subsidiaries is the ability to assimilate knowledge resident in host country locations. Even after controlling for several important explanatory factors (e.g., technology, time period), U.S. subsidiaries were between half again and twice as likely to draw upon U.S. sources of innovation compared to headquarters organizations.

The claim that U.S. subsidiaries are capturing *localized* knowledge (i.e., knowledge that does not diffuse seamlessly across spatial boundaries) during the innovation process was further supported by three additional findings:

1. The magnitude and significance of the main geographic results generally increased as the analysis moved down to the sub-national level. U.S.-based subsidiaries were especially likely to draw upon knowledge originating in their host state, implying that the sources of knowledge that inform their innovations are local in nature.

2. Further analysis revealed that the overall pattern of host country and host state citing exhibited by U.S. subsidiaries' patents resembled quite closely that of U.S. firms'. In fact, both organizational groups were shown to overcite U.S. sources of innovation to a significant degree, especially sources that are highly proximate (originating in the same state as the citing organization). Stated formally, the observed pattern of host country and host state citing exhibited by U.S. subsidiaries' patents is not consistent with a random citation process; rather, it is significantly more localized.

3. Finally, support for this claim was also provided by regression results, which showed that the degree of localization of subsidiary knowledge sources fades over time, meaning that U.S. subsidiaries are more likely to utilize nearby innovations when those innovations are relatively new. This result implies that one of the

benefits of "being there" is that resident units are able to pick up on recently developed innovations before knowledge of them is disseminated through various institutional channels.

2.1.2 Greenfield subsidiaries and acquisitions both build upon localized host country knowledge during the innovation process

The finding that U.S.-based subsidiaries are highly oriented toward local sources of innovation was not attributable simply to the presence of acquired U.S. firms in the subsidiary sample. Separate analysis of subsidiaries established through greenfield investment revealed that they, too, consistently overcite both the host country (i.e., the U.S.) and their host state to a statistically significant degree. Where acquisitions and greenfield subsidiaries were shown to differ was in their propensity to draw upon innovations originating from within the parent firm itself (see 2.1.3. below)

2.1.3 Headquarters units of multinational firms continue to be an important source of knowledge for innovating subsidiaries, especially those established through greenfield investment.

The citation analysis conducted in Chapter 5 also revealed another pattern, one that fits into a more conventional view of the multinational firm than is implied by the first result discussed above, namely that innovations developed by the headquarters organization are often important underpinnings of later innovations developed by U.S.-based subsidiaries of these firms. This finding emerged from the analysis of citations by U.S. subsidiaries' patents to prior *home* country patents. Interestingly, the results indicated that U.S. subsidiaries' patents cite non-internal sources located in the home base (i.e., patents issued to assignees other than the parent firm) at about the level that would be predicted from a random citation process. However, when citations to prior headquarters patents were included in the calculations, the rate of home country citing by

U.S. subsidiaries nearly doubled. In fact, the observed pattern of citations to headquarters' patents was far greater than either the level exhibited by U.S. firms' patents or than could be explained by chance. Further analysis revealed that the citing of headquarters' patents was especially pronounced for subsidiaries established through greenfield investment as opposed to acquisitions. In fact, greenfield subsidiaries accounted for nearly 85 percent of the more than two thousand citations by U.S. subsidiary patents to prior headquarters patents over the 1980 to 1990 time period, a figure which is considerably higher than the 66 percent of total citations accounted for by greenfield subsidiaries' patents.

The finding in Chapter 5 that U.S. subsidiaries' patents overcite both their local, host country environment *and* their parent firm's earlier work emerged as a potentially contradictory set of outcomes. Three plausible explanations, not necessarily mutually exclusive, were put forward and investigated further in later empirical chapters. First, there may exist two different kinds of foreign subsidiary: those engaged in adaptive, or in the terminology adopted throughout this study "exploitation-oriented" kinds of technical activity, in which the parent firm plays a large role as a source of innovation; and those engaged in more autonomous forms of technical activity in which actors and institutions in the local environment may play a more important role as sources of stimulation and know-how ("exploration-oriented" activity). Second, particular foreign subsidiaries may have "multiple mandates", meaning that within a single unit there may be activities that build upon local technical knowledge and a different set of activities that build upon technical signals originating from within the parent firm itself. And third, foreign subsidiaries may draw upon both parent and local technology simultaneously, i.e., in the context of developing a particular invention.

2.1.4 Headquarters units are deeply embedded in the technical environment of the home country

Although the first research question concerns the geographic sources of *subsidiaries'* innovations, an unintended but interesting discovery that emerged from the analysis was that headquarters organizations also appear to be highly oriented toward local sources of innovation, in their case to sources resident in the home base of the firm. This result supports the basic finding from the analysis of subsidiaries' patent citations in the sense that it provides yet another indication that knowledge does not travel seamlessly across geographic boundaries. However, this result, together with the finding that U.S. subsidiaries draw upon parent technology to an important degree, also provides additional evidence for the longstanding proposition in the multinational literature that foreign subsidiaries act as mechanisms through which knowledge embedded in the home country institutional context and utilized by the parent firm to develop firm-specific resources is subsequently transferred to foreign markets. I develop this line of reasoning further in Section 3 in the context of discussing the theoretical contributions of the study.

2.2 Research Question 2

> Under what conditions do innovations generated by foreign subsidiaries build upon sources of science and technology in the home and/or host country?

This question advanced the study by moving toward a more finely-grained investigation of the variance within and across subsidiaries in the geographic underpinnings of their technological innovations. Important findings from Chapter 6 include the following:

2.2.1 The characteristics of foreign subsidiaries' innovations influence the geography of the knowledge sources that underpin them

Supporting one of the main theoretical arguments of the thesis, the results from Chapter 6 showed that subsidiary innovations that had characteristics associated with "exploration-oriented" R&D were more likely to draw upon sources of innovation in the host country environment, and less likely to draw upon sources of innovation in the home country. Similarly, home country sources were associated with innovations that exhibited characteristics associated with "exploitation-oriented" R&D. Most of the specific hypotheses underpinning the argument were supported by the empirical tests. Generally, host country sourcing by U.S. subsidiaries was associated with innovations that represent areas of U.S. subsidiary technical specialization within the multinational firm, particularly when the technical field was also one in which the local environment (host country, host state) was comparatively advantaged. Home country sources of knowledge were associated with subsidiary innovations that were in technical fields in which the headquarters organization had a strong technical presence; that built directly upon earlier headquarters innovations; and that represented technical fields of home country comparative advantage.

2.2.2 Structural characteristics of foreign subsidiaries also influence the geography of the knowledge sources that underpin their innovations

Subsidiary attributes were also found to influence the geography of their sources of innovation, although not always in ways that supported the "embeddedness" perspective underpinning the hypotheses. In particular, the results suggested that older, larger subsidiaries – those that were hypothesized to be most likely to have a strong local (host country) orientation in their citing behavior – were composed of a diverse group of subsidiaries, some of which were locally oriented, some of which drew disproportionately on home *and* host country innovation sources, and some of which remained focused on home country (mostly headquarters) technology. Surprisingly, the results also suggested that young subsidiaries – those with less than three years tenure in the host country -- do not appear to experience a "liability of newness" in terms of their access to sources of innovation in the host country. Although this result directly contradicted the original hypothesized relationship between the age of the subsidiary and its geographic orientation (which predicted that newly established subsidiaries would be more oriented toward home base / headquarters sources of innovation), further analysis suggested that it was young subsidiaries that were already part of a well established network of subsidiaries in the U.S. that were driving this result. In contrast, subsidiaries that represented the parent company's first innovating unit in the U.S. were less likely to cite U.S. sources and more likely to draw upon home country sources, especially the parent firm.

2.3 Research Question 3

> To what extent and under what conditions do other parts of the multinational firm derive a learning benefit from a foreign subsidiary's capacity to assimilate knowledge in its local environment?

The third and final research question shifted the focus of the study toward an assessment of the *systemic* (i.e., firm wide) impact of distributed innovation and local knowledge assimilation by foreign subsidiaries. The analysis, contained in Chapter 7, was structured around the specific question of whether headquarters organizations (as opposed to other foreign subsidiaries in the multinational network) benefited from having innovating subsidiaries in the U.S. in terms of an enhanced awareness and utilization of U.S. technology.

2.3.1 Overall, headquarters organizations appear to derive a modest, but detectable learning benefit from their U.S.-based technical facilities

Compared to firms that do *not* have U.S. technical facilities ("home-based" firms), headquarters organizations were shown to be significantly more likely to build upon U.S. sources of innovation. The results were especially strong at the level of the host state: headquarters' patents ranged from 1.5 times to slightly over twice as likely as matched patents issued to home-based firms to cite sources originating in locations where they have a patenting subsidiary. Moreover, the frequency of host state citing by headquarters' patents was generally higher than the level that would be predicted by a random citation process. In other words, headquarters' patents were shown to significantly overcite sources of innovation in U.S. states where they have technical facilities.

2.3.2 Headquarters organizations also build directly upon their U.S. subsidiaries' innovations, but not nearly at the level at which U.S. subsidiaries build upon headquarters' innovations

Over the 1980-1990 period of the study, headquarters' patents cited prior work by their U.S.-based subsidiaries a total of 197 times, a figure which represents about 1 percent of all citations listed on headquarters' patents. The corresponding figure for subsidiaries, i.e., references by subsidiary patents to prior headquarters patents, was over 2,000 citations, or more than 5 percent of the total. Obviously these results suggest a manifest difference in the direction of internal knowledge flows within multinational firms. Moreover, these results are quite consistent with the conventional view of knowledge creation and diffusion within multinationals, namely that it is the headquarters organization that acts as the lead unit in terms of generating new and valuable knowledge. I return to this point below in discussing the implications of my findings for the theory of the multinational firm.

2.3.3 Subsidiaries differ in the learning benefit they provide to headquarters organizations: greenfield subsidiaries provide more of a learning benefit, especially those that are themselves oriented toward host country technology

Analysis of the factors that influence the awareness by the headquarters organization of host country (U.S.) technical developments suggested that not all subsidiaries provide an equal learning benefit. The overall (and somewhat surprising) pattern that emerged from the analysis was that the greater orientation of the subsidiary to the local environment, the greater the likelihood that the headquarters organization would also utilize host country technology. However, this pattern turned out to be true only for subsidiaries established through greenfield investment. For acquisitions (which, overall, were shown to provide a significantly lower learning benefit), the level of integration with the local technical environment did not materially affect the propensity of the headquarters organization to draw upon sources from that environment. Interestingly, however, what turned out to matter for acquisitions was their orientation toward headquarters technology: acquired subsidiaries that were more oriented toward headquarters' technology were also more likely to contribute to headquarter's capacity to utilize U.S. sources of innovation.

The interpretation of these results, advanced in Chapter 7, was that for subsidiaries to facilitate the diffusion of host country knowledge to other parts of the multinational firm, they may need to be "insiders in two systems" (Westney 1992b). That is, the assimilation of local knowledge by the subsidiary appears to be a necessary but not sufficient condition for it to also contribute to the knowledge base of the rest of the firm.

Rather, subsidiaries need to be embedded in both external and internal innovation networks. Acquired firms, it would appear, tend to be less well integrated into the internal technology development network, a perhaps not particularly surprising result. Indeed, the earlier results from Chapter 5 showed that acquisitions are much less likely to build upon headquarter's technology than are greenfield subsidiaries. The results in Chapter 7 extend this finding by showing that those acquisitions that are better integrated into the internal, multinational network (as evidenced by their citing of headquarters' innovations) are also more likely to provide a learning benefit to that network.

3. Contributions to Theory and Practice

3.1 Contributions to the Theory of the Multinational Firm

3.1.1 Distributed innovation and the subsidiary-host country interface

As discussed in the introductory chapter, the questions addressed in this study grow out of a set of important debates in the international management field about the nature and evolution of the multinational firm. Perhaps the most basic issue in the debate concerns the locus of innovation in multinational firms, the conventional view being that innovation is concentrated in the headquarters organization and tends to respond to commercial and technical signals originating in the home base. In equally stylized terms, the alternative, (i.e, non-conventional) view of the multinational firm is one in which subsidiaries take on a much more important role in generating innovations, and, it is frequently hypothesized, in response to resources and stimuli in their local environment, i.e., the host country. Unlike much of the previous empirical work on this issue, this study did not focus on the *quantity* of R&D or number of innovations generated by foreign subsidiaries per se, although Chapter 4 did provide a fair amount of descriptive information about U.S. subsidiaries' patenting activities that is relevant to these mapping questions. Rather, the contribution of this study to the multinational debate is derived from focusing empirical attention on the subsidiary-environment interface in the context of technological innovation: whether and under what conditions innovating subsidiaries build upon host country sources of science and technology.

The most important contribution of this study to the multinational debate is empirical. In particular, the large amount of evidence showing that foreign subsidiaries systematically assimilate and utilize knowledge that originates in, and is localized to, the host country is, I believe, a critical, even fundamental finding for this debate – especially given the current limited state of knowledge about the phenomena. However, it should be clear that the results of this study do not in any sense "prove" that the non-conventional view of the multinational firm outlined above is correct. Indeed, many of the results (e.g., the large number of citations by subsidiary patents to prior headquarters patents), can be argued to support the conventional view.

Perhaps this study's most far reaching implication, then, is the realization, now supported by empirical research, that the various conceptions or "models" of the multinational firm are not in any sense mutually exclusive alternatives. The notion that there is a single model, or even that firms are converging toward a particular model, is undermined by the results of this study which show important and sustained variation across, and even within, particular subsidiaries in the geographic underpinnings of their technological innovations. In practical terms, an implication of this study is that scholars of multinational firms need to begin framing their research questions in terms of the conditions under which a particular phenomenon is likely to be observed rather than simply whether or not the phenomenon exists in a quantitatively important way. This is especially true for the normative literature on multinational strategy and organization, which has tended to advance relatively unqualified declarations that a particular multinational model is "the wave of the future" (Perrino and Tipping 1989).

3.1.2 The geographic sources of innovation in the multinational enterprise

Another, related contribution to the multinational literature is the confirmation provided by the study's results of the importance of "location" – the "L" in Dunning's OLI theory of foreign direct investment and the multinational firm (Dunning 1977; 1988). Although the main focus of the study was on foreign subsidiaries' technical activities, an interesting and important finding from the perspective of the OLI theory is that location clearly matters to both home and foreign units. Once again, the contribution to theory comes from the empirics. Although scholars dating back to Vernon (1966) have held that the home country plays a critical role in providing the stimulus and know-how that underpins firms' technological innovations, there have been no empirical tests of this proposition that I am aware of, no doubt due to limitations in the available data. Thus, the results presented in Chapter 5, where it was shown that headquarters' patents significantly overcite innovations originating in the home base is an extremely important result, notwithstanding its peripheral status with respect to the immediate goals of this study. In effect, this result transforms an intellectual pillar of the theory of FDI from an untested assumption to an empirically validated observation.

3.1.3 Diffusion and learning within the multinational innovation network

This study contributes to another important aspect of the debate about the nature of the multinational firm, namely the question of whether and under what conditions multinationals that have a network of innovating subsidiaries derive a *systemic* learning benefit from that network. Although the nature and direction of knowledge flows within multinational firms has long been central to the various models of multinational strategy and organization (e.g., Bartlett and Ghoshal 1989; Gupta and Govindarajan 1991; Hedlund 1986), to the best of my knowledge there are no empirical studies that have looked systematically at "bottom up" knowledge flows, i.e., flows of knowledge from foreign subsidiaries to either the headquarters organization or to other subsidiaries in the multinational network. This study provides a starting point by looking at the subsidiary to headquarters dyad.

The analysis of headquarters' citation patterns revealed a modest amount of evidence in support of the claim that foreign technical units provide a learning benefit to other parts of the multinational firm. Certainly such a result fits with most researchers' beliefs about the capacity of multinational firms to create effectively functioning organizations based around shared or "multi-point" learning. More interestingly, further analysis revealed that there is a significant amount of variation across firms from different home countries in this regard, and even variation across different kinds of subsidiaries in terms of the systemic learning benefit they provide.

Clearly the research presented here is a starting point to further investigation into the factors that influence the effective development of such networks and the conditions under which we are likely to observe them.

3.1.4 Foreign subsidiaries as conduits of locally embedded knowledge

Taken together, the citation patterns evidenced in the empirical chapters of the thesis suggest a rather more complex interplay between location, knowledge and the multinational firm than is commonly seen in the literature. One interpretation of the collective results is to view multinational firms as mechanisms through which locationally embedded knowledge travels across borders. This interpretation is consistent with the evolutionary view of the multinational firm, which has been articulated most clearly by Kogut (1991; 1992a). Overall, the results of this study strongly support several important propositions that underpin this perspective: that knowledge is location-bound to a significant degree; that firms draw upon localized innovatory resources in their home base in the context of developing proprietary knowledge that is later exploited in foreign markets; that foreign subsidiaries depend extensively upon the parent firm for intangible resources (e.g., knowledge). Where the results extend this theory is by evidencing the fact that the more advanced forms of international expansion (e.g., international R&D) may also "alter the global knowledge of the firm" (Kogut and Zander 1993: 640) through exposure to the diverse sources of knowledge resident in the various host country environments of the multinational enterprise.

3.1.5 Subsidiary development, sequential foreign investment, and period effects: Untangling the evolutionary theory of the multinational firm

On a more speculative level, the results of this study suggest a further articulation of the emerging evolutionary theory of the multinational firm. In particular, the results of this study can be interpreted in terms of three evolutionary patterns that, to date, have been frequently conflated in the academic literature. The first is subsidiary evolution, probably the best understood and most solidly researched aspect of this emerging evolutionary view of the multinational firm. The notion here is that particular subsidiaries tend to develop (subject to many contingencies) toward more autonomous and advanced organizational forms, as in situations where subsidiaries have been able to develop world mandates for particular product and/or technical areas (Rondstadt 1977; Birkinshaw 1996). The results of this study provide support for this component of the theory by showing that some subsidiaries - but by no means all - shift their orientation over time from the parent firm as a key source of innovation to sources of innovation resident in their immediate host country environment.

However, the results presented in this study also suggest two other "evolutionary" patterns that are less well integrated into the theory in its current state. First, is the notion that the parent firm's pattern of investments within a particular country may also evolve over time, an idea that is central to Kogut's (1983) original notion of "sequential foreign investment" as well as later work by Kogut (1990; 1992b) and Chang (1996). The results of this study provide at least some support for this notion by showing that newly established subsidiaries that are part of an already large host country network (i.e., a network of other subsidiaries belonging to the particular parent firm) are more likely to draw upon local sources of innovation and less likely to draw upon the parent firm than are subsidiaries that represent initial forays by the parent firm into a particular host country, in this case, into the U.S..

A final aspect of a more complete evolutionary theory of the multinational firm, and one that is also suggested to some extent by the results of this study, is the notion that the nature of competition, markets, and technology - i.e., the business environment within which multinationals operate - is also evolving over time, thus creating differences over time in the incentives and costs of particular kinds of international expansion. For example, the establishment by Samsung of an advanced VLSI laboratory in Silicon Valley as part of its initial entry strategy into the U.S. DRAM market reflects more of this kind of an effect (which I refer to as a "period effect") than either the subsidiary- or firm- level evolutionary effects highlighted above. Although the Samsung story may be an extreme one, the findings from Chapter 6 suggested that subsidiaries who applied for their first patent between 1988 and 1990 - the most recent period for which data were available - were actually quite likely to build upon local knowledge sources. What is missing from the analysis was an explicit comparison of earlier "cohorts" of entering subsidiary, hence the results must be viewed as tentative.

This study has by no means produced a fully worked out evolutionary theory of the multinational firm. Further theoretical articulation as well as more and different forms of empirical testing are still required. In future research I plan to develop these ideas further, and to explore them empirically using the data at hand.

3.2 Contributions to Management Practice and Public Policy

3.2.1 Management Implications

Although not specifically directed at a managerial audience, results from this study none-the-less have several important implications for managers. First, the results add yet another data point to the recurrent theme in the literature on global competition that "location matters". Paradoxically, even as the world economy becomes ever more integrated, it is becoming increasingly apparent that firms draw to an important degree upon their local institutional context for tangible and intangible resources that allow them to meet the challenges of global competition. This fundamental fact is perhaps most obvious and salient when discussing innovation, that is, a firm's capacity to generate, on an on-going basis, a stream of new, commercially valuable knowledge.

The results of this study both support and extend this claim. They support the claim via the large amount of empirical evidence that organizations - and not just foreign subsidiaries - draw upon local knowledge sources during the process of technological innovation. They extend the claim by also showing that firms are able, in some sense, to transcend their original or "home" institutional context and capture knowledge originating in foreign contexts. In this sense the results of this study can be said to support Michael Porter's (1990) argument that firms need to:

> be aware of, and ideally have some access to, *all* the important scientific work going on in the world that is related to its industry....Today, a firm seeking competitive advantage should question its strategy if it does not have at least one foreign technology monitoring or research site. (1990: 609-610)

For firms that do not have the resources to establish foreign subsidiaries with technical and/or monitoring capabilities, the results of this study point to the challenges they face in terms of assimilating the new and diverse sources of knowledge that now originate in far flung regions of the world. This is especially true in an environment in which "products" are increasingly disassociated from "technologies". Although this has always been true to some extent, the growing number of product areas that now integrate or "fuse" knowledge from different scientific and technical disciplines suggests that firms are going to find it increasingly difficult to keep track of "*all* the important scientific work going on in the world that is related to its industry" (Porter 1990: 609). Recent conversations I have had with R&D managers in the automobile, telecommunications, aerospace, pharmaceutical and chemical industries suggest that the pressures to locate and utilize the various sources of knowledge originating in a diverse set of locations around the world is growing ever more intense.

On a perhaps more optimistic note for managers, the results of this study suggest that there do not appear to be any significant barriers to entry in terms of an organization's ability to participate in the local technical community, even if that community is outside of the firm's home domicile. Chapter 6 showed that even the most recently established subsidiaries assimilate and utilize knowledge originating in their immediate geographic locale, although this pattern was strongest for those firms with fairly well developed technical organizations in the host country. Even though the basic results cuts against the thrust of the "embeddedness" argument contained in Chapter 2, a growing body of research suggests that this results may not be exceptional: in the last several years many researchers have reported on newly established subsidiaries with missions geared toward capturing know-how resident in the local technological infrastructure (e.g., Dalton and Scerapio 1993; Florida and

Kenney 1995; Herbert 1989; Westney 1992; Wortmann 1990). Interestingly, most of these examples are of foreign subsidiaries in the U.S.. Whether and to what extent other national innovation systems are as permeable and accommodating is an important and as yet unanswered empirical question.

If the most basic implication of this study for managers is the growing need to be aware of and gain access to geographically distributed, contextually embedded knowledge, a more complicated and yet also potentially important implication is the need to focus more managerial attention on building cross-border, *internal* innovation networks, i.e., multinational networks. The results from Chapter 7 provide yet another indication that multinationals may struggle with this aspect of the "global challenge" more than they do with the process of becoming embedded in local technical communities. Of course, the assumption here is that multinationals are actually trying to construct global innovation network. The results of this study cannot speak in any meaningful way whether or not this is in fact true. Nor can they speak to the organizational structures and processes that are most effective in this regard. Such issues clearly require future research, a topic I turn to in the final section of the chapter.

3.2.2 Public Policy Implications

Many scholars have pointed out the public policy controversy surrounding the host country impact of R&D activities performed by foreign subsidiaries (Reich 1991; Vernon 1992; Teece 1992; Tyson 1991). Vernon (1992: 14-15) eloquently captures a key aspect of the debate in reference to the U.S. case:

> Some of the principal arguments against foreign direct investment are about its effects on research and development activities in the United States...Some cases seem to fit the mould of a rapacious foreign investor, buying up the crown jewels of US science and engineering, and carrying them off to distant locations....

This study did not directly address the main policy questions surrounding foreign R&D: whether the R&D activities of foreign subsidiaries "displace" domestic R&D or stimulates domestic firms to greater levels of R&D; whether, from a general equilibrium perspective, the bidding up of prices for scare factors (e.g., scientists) offsets any benefits that may accrue in terms of spillovers or competitive effects; and whether and under what conditions foreign R&D units generate knowledge spillovers that are assimilated by local organizations.

Having said that, this study does inform the policy debate in at least one important respect, namely via the basic and fundamental finding that subsidiaries in the U.S. are capturing local spillovers during the process of technological innovation. Policymakers (especially in the U.S.) have repeatedly raised concerns about foreign multinationals' access to the cutting edge scientific developments of premier (and often partially publicly funded) research institutions. The results of this study bear this concern out to some degree. However, it must be quickly added that they key question in this debate - whether these foreign firms also *contribute* to the local spillover pool - is not addressed in this study, although it is a question I intend to pursue in the not too distant future.

3.3 Methodological Contributions

A third and final category of contribution made by this thesis is in terms of the data and research methods utilized. I believe there are insights here for researchers operating both inside and outside of the international management field. For IM researchers, perhaps the most basic but important methodological lesson is that we should continuously be on the lookout for novel sources of data, approaches to research design, and data analysis techniques that originate outside of our field, but which might be used to answer questions within it. Another way of saying this is to broaden Dunning's (1990) "plea for a more eclectic approach" to international business research to include not just substantive ideas and theories from related disciplines, but also the data and methods used by scholars in these areas. The data and methods used in this study derive directly from the economics literature. No doubt there are many more similar opportunities to borrow methodological ideas and sources of data from the disciplines.

For readers interested in the methodology of patent citation analysis, this study contains many minor alterations of the pioneering Jaffe, Tratjenberg and Henderson (1993) technique that may prove useful in subsequent research. A partial list of innovations on the basic JTH methodology include: the inclusion of comparison groups located outside of the U.S. (e.g., headquarters); a tighter set of controls for matching patents across comparison groups within the U.S. (e.g., matching for state of origin, as in Chapter 5); and the development of a more finely grained (9-digit level) measure of technological proximity between matched patents (Chapter 5).

Fortunately, the most important of these innovations turns out also to be the simplest to explain. Whereas JTH (1993) started with a sample of originating patents and then examined the geography of the subsequent citations to these patents in order to draw inferences about spillovers, the approach used in Chapters 5 and 6 of this study is, in some sense, the mirror image. That is, I begin with a sample of patents (issued to foreign subsidiaries, reflecting my research questions) and then look backwards in time at the geography of the *prior* patents that are cited as references by this sample. Although this is not a major innovation by any stretch of the imagination, it does provide the first example of how the JTH methodology can be adapted to explore a different set of research questions. Moreover, the approach adopted here is likely to be more useful for researchers interested in studying firm behavior since there is an notion of agency built explicitly into the questions that are facilitated by this approach: i.e., less "Where does technical knowledge travel" and more "Where do firms get their technical ideas from?" In fact, this approach shows considerable promise as a research methodology in the emerging stream of literature on firms' "knowledge strategies".

4. Limitations of the Study

As outlined in Chapter 1, the most basic goal of this study has been to break the current logjam in the debate about the role of the host country as a source of stimulus and know-how for foreign subsidiaries engaged in R&D. The means for accomplishing this objective was a unique source of subsidiary-level innovation data derived from U.S. patent records. These data, along with the patent citation methodology utilized throughout this study, allowed, for the first time, a systematic, large sample examination of the geographic sources' of foreign subsidiaries' innovations. As is often the case in social science research, the very features of the data, methods, and research design that facilitated the study's principle contributions are also the sources of its key limitations. In this section, I discuss four limitations of the current study, all of which in one way or another derive from the nature of the data and methods utilized.

4.1 Analytical Rigor versus Contextual Detail

The most fundamental limitation of the current study stems from the lack of relevant contextual information inherent in U.S. patent data. Another way of saying this is that this study is limited by the classic trade-off between rigor and grain. Although the data facilitated the construction of large samples and controlled research designs, many of the variables that one would like to have used as explanatory factors (especially strategy and organizational process variables) are simply not present in the data, or for that matter in most secondary source data. The choice to use these data derives from the main objectives of the study, which themselves derive from the current state of knowledge within the field regarding the phenomenon and questions under study. Numerous case studies, one might even say anecdotes, exist in the empirical literature. What is largely absent from the literature is the complementary empirical approach: rigorous testing of specific hypotheses using large sample, systematically collected data. In this sense, the data used in this study are appropriate for advancing the current debate, but, like all data, they can only be used to reach a specific and limited set of conclusions.

4.2 Patent Citations versus Mechanisms of Knowledge Diffusion

A second limitation of the study, again directly related to the data used, derives from the use of patent citations to draw inferences about an organization's sources of innovation. As discussed at length in Chapter 3, a citation listed as a reference on a patent is, at best, several steps removed from a measure of an actual flow of knowledge from one organization to another. Numerous individuals other than the inventor(s) may intervene during the process of applying for and ultimately receiving a U.S. patent. Patent examiners, patent lawyers, and corporate staff can and do influence the final list of references to prior art that appears on a patent document. However, the key point to realize is that citations are being used in this study as a proxy for technological building relationships not as a direct measure of knowledge flows. In this sense, patent citations are no different than other indirect measures of theoretical constructs: R&D intensity as a measure of asset specificity; Tobin's Q as a measure of intangible assets; or number of alliances as a measure of network centrality. Through careful research design it is possible to show that different organizational groups (e.g., U.S. subsidiaries, headquarters, U.S. firms) exhibit significantly different citation patterns and that these patterns are consistent with the assimilation of localized knowledge by one or more of these groups. But it should always be borne in mind that the data used in this study provide only indirect measures of the actual phenomenon, and, therefore, that it is necessary to draw *inferences* from the results of the analysis of these data.

A related limitation of this study concerns the lack of information about the mechanisms through which knowledge travels between technical personnel within and across organizations. Ironically, patent documents may indeed be one such mechanism, but it is unlikely that they are the most important one. Other mechanisms that have appeared in the literature include journal articles, conference presentations, reverse engineering, knowledge trading between technical personnel in rival firms, inter-firm mobility of scientists and engineers, even industrial espionage. Undoubtedly there are many and varied institutional channels of knowledge diffusion.

4.3 Generalizability from the U.S. case

A third limitation of this study concerns the generalizability of the results. As discussed in the introductory chapter, several difficult tradeoffs in terms of the scope of the study were made early on in the research process, tradeoffs that by their very nature affect the conclusions that can be drawn from the study. The most difficult design decision was whether to focus the study around one (or a small number) of industries/technical fields while looking at a broad set of host countries; or whether to focus the study around a single host country and look across industries/technical fields. For reasons discussed in Chapter 1, I chose the latter route. This inevitably raises the question of whether the results obtained from the analysis of the U.S. case (i.e., the U.S. as the host country) are likely to be similar to results that would be obtained by looking at other host country cases, say, Germany or Japan, for example.

For several reasons, I shall argue that the particular results obtained in this study are *not* likely to be generalizable to other host countries. First, the U.S. is widely acknowledged to possess one of the most open and permeable innovation systems of any country in the world. Labor markets are very fluid. Access to university researchers is excellent. The well-functioning market for corporate control in the U.S. also makes acquisitions of high technology firms a much more feasible alternative than in countries such as Japan and Germany where many institutional structures limit or outright negate the possibilities for such acquisitions. In addition, the overall excellence of U.S. science and technology has often been cited as a major magnet for foreign firms. In short, of all host countries, we should be perhaps least surprised at observing in the U.S. case the main result found in this study, namely that foreign subsidiaries draw to an important degree upon localized knowledge during the process of technological innovation.

This is not to say that the U.S. case is unimportant. Indeed, the very features that make the U.S. unique were also the features that make it an important test case. First, the U.S. is by far the largest and most important location for foreign R&D in the world. This fact is certainly borne out by the anecdotal evidence on foreign R&D, and can be easily seen statistically through patent and other secondary sources of innovation data (e.g., Zander 1994). Second, and critical to the original goals of the study, if foreign subsidiaries had *not* shown a marked tendency to draw upon knowledge in the U.S., then it could be argued that such a result was a conservative one, in the sense that it was likely to be robust to other host countries. In other words, while the U.S. case would have been generalizable for a "negative" set of results, the results happened to turn out "positive". Although the lack of generalizability of the results beyond the U.S. case is a clear limitation of the current study, it is also equally clearly an opportunity for future research, a point I discuss in the next section.

5. Directions for Future Research

In this final section I discuss opportunities for future research in terms of their relationship to the questions – and findings – of the current study. The discussion is organized around three areas of research: research that represents further investigation of the specific questions addressed in this study, which I refer to as "deepening" of my current focus; research that represents more or less direct extensions of the current work; and research that builds on the current work but in an indirect way.

5.1 Deepening of Current Focus

The answers to the questions posed in this study are necessarily tentative ones, given the nature of the data utilized to address them and the lack of a well developed body of empirical research with which to benchmark most of the results. Hence, one obvious area of future research is simply to focus on the same set of questions but to use alternative sources of data and methods.

One approach, arguably the opposite approach to the one adopted here, would be to push toward a very finely grained kind of research methodology based on case studies of particular subsidiaries and/or particular subsidiary innovations. The key issue in such a study would be how to integrate the research design with the structure and findings of the current study, i.e., in a way that builds upon the present results. After all, what is probably needed *least* in the literature on subsidiary innovation is simply another set of case studies based upon convenience samples. Rather, the goal of such a study should be to structure a set of comparative case studies that would be designed to illuminate further the nature of the subsidiary-environment interface in the context of technological innovation, and more specifically, to illuminate the conditions under which local knowledge and/or parent firm knowledge is utilized during the innovation process. One possibility would be to utilize the findings from Chapter 6 to classify individual subsidiaries in terms of their geographic sources of innovation (as in Figure 6.2 for example) and then to focus the case studies around "outlier" cases, i.e., cases that represent extreme points in terms of a local and/or parent firm orientation. This approach would be consistent with Yin's (1993) "principle of maximum variation", which is especially appropriate for exploratory kinds of research.

This would be an especially useful approach if a such a set of cases could be found in the same industry.

Another possibility would be to focus the case studies on those units that indicate a simultaneous orientation toward local sources of innovation *and* parent firm sources. Such an approach would tilt the study toward an investigation of how foreign subsidiaries integrate different kinds of technical knowledge, e.g., firm-specific knowledge and external knowledge emanating from local market and technical signals.

Yet another possibility would be to identify a set of firms with multiple subsidiaries in the U.S. that exhibit considerable variation in terms of the geographic orientation of their sources of innovation (again, as indicated by their patent citations). This approach would allow for a tighter set of controls (e.g., for firm characteristics) and would be more likely to illuminate the strategy and organizational factors that likely underpin a subsidiary's geographic orientation.

The limitations of a case study methodology are well known, especially in the context of a stream of research that is already heavily tilted toward inductive and hypothesis generating kinds of studies. One way to push toward a more finely grained kind of study and yet still advance the hypothesis testing agenda that is relatively underdeveloped in this line of inquiry would be to utilize a survey methodology. Again, the key issue that arises is how to ensure that such a study would be tightly integrated with the current one so that the follow on study is part of a clearly defined, cumulative research program. The approach that appears, at first consideration, to offer the most potential would be to survey patent holders (inventors) working for U.S. subsidiaries of foreign multinationals. Questions that focus on the various sources of stimulus and know-how these individuals drew upon in the course of developing the patented invention would be particularly interesting and well integrated with the current study. One part of the survey, which would also directly complement the current study, could specifically ask the patent holder which of the citations listed on the patent document represent actual sources utilized, and how they obtained knowledge of the cited work. This would enable the study to make a methodological contribution ("Do patent citations measure actual knowledge flows?") as well as a substantive one.

Both of the approaches described above would also contribute to the investigation of the various mechanisms through which knowledge diffuses across organizations. The survey approach, in particular, would hold the promise of moving the spillover literature beyond its current state, which to date has tended to generate a laundry list of institutional mechanisms through which knowledge diffuses across organizations. Particularly interesting would be a study that illuminated the conditions under which researchers (and firms) utilize various channels of knowledge diffusion, and whether by accident or whether through a committed strategy of innovative search. Such a study could also facilitate a more direct link between the literature on innovation in multinational firms and the emerging strategy research on the subject of "generic knowledge strategies" (Bierly and Chakrabarti 1996) by obtaining data on the extent, importance - and location - of "external learning", a key component of such strategies.

5.2 Direct Extensions

In addition to the "deepening" trajectory, another set of projects represents work that would be more or less of a direct extension of the research conducted here. One obvious possibility would be to expand the scope of the study beyond the U.S. case.

Whether, to what extent, and under what conditions foreign subsidiaries in other countries draw upon localized knowledge during the innovation process are questions that are clearly motivated by the results of this study. In addition, since U.S. patent data cover the activities of inventors in every advanced industrial country in the world, it would be possible to use the same basic source of data to investigate these questions, which has obvious advantages in terms of both comparability and feasibility. Countries that have an adequate level of foreign activity to warrant investigation include the U.K., Germany, France, Japan, and Switzerland. Unfortunately, it is difficult, a priori, to argue for one country being a better complement to the U.S. case than another. One possibility, of course, is to vary host country explicitly in the study, and perhaps focus the analysis around a particular industry or technical field (or perhaps a small number of industries). An interesting design would be to vary the host country and compare the results for a technical field such as pharmaceuticals which is generally considered to be quite close to basic science and another field such as medical instruments that is thought to be more closely associated with customer-driven innovation.

A second research agenda, in fact, one that I have already begun, is to look at the contribution of U.S.-based subsidiaries to the host country spillover pool. That is, whereas the current study focused on whether U.S. subsidiaries are able to extract knowledge from their local environment, the follow-on study focuses on the question of whether these units also generate knowledge that is assimilated by local organizations. Although the same basic data and research methodology can be used to conduct the analysis, the framing is much more in terms of the public policy questions concerning foreign technical activity than it is in terms of the theory of the multinational firm.

Finally, another obvious and direct extension of the current study would be to expand the analysis of the multinational diffusion of knowledge (i.e., internal, cross-border diffusion) that was begun in this study. Whereas Chapter 7 looked at whether there is any evidence that foreign subsidiaries provide a learning benefit to the headquarters organization, an important and largely unexplored question in the multinational literature is whether and under what conditions multinational firms are characterized by distributed (subsidiary-subsidiary) learning and knowledge diffusion.

5.3 Indirect Extensions

In addition to research projects that follow clearly along the same basic trajectory as the current study, there are several interesting projects suggested by this study that would represent a branching out into somewhat different lines of inquiry. For example, the renewed interest in locational aspects of economic activity, of which this study is part, offers several intriguing possibilities for indirect extensions of the current work. One such project would examine R&D location choices by multinational firms. Focusing on R&D site selection by foreign multinationals would be a potentially valuable contribution to the location choice literature, which has to date focused primarily on the location of foreign manufacturing investment. For several reasons, one relating to the importance of technological spillovers, it is highly likely that there are important differences in the factors that influence the location of R&D versus other pieces of the value chain. An added incentive to pursue this project is the ability to leverage some of the data from the current project. Since patent data can be used to model the location of patenting subsidiaries down to finely-grained (i.e., sub-national) geographic units of analysis, it appears quite feasible to use these data to investigate the factors that determine where, within a country, foreign multinationals choose to locate their technical facilities. Such a study would be particularly interesting and well integrated with the current work if a meaningful variable could be constructed to assess the impact of the nature and size of the local "spillover pool" on foreign multinationals' R&D locational decisions.

A more ambitious project that I believe holds very exciting theoretical possibilities would be to explore further the apparently complex relationship that was suggested in Chapter 5 between knowledge flows, geography, and organization. This project, which I have termed "the location of innovative search", would seek to develop a more generalizable theory of where firms - not just multinational firms - derive their scientific, technical, and commercial ideas from during the process of technological innovation. Although there is a body of research that has looked at the "functional sources of innovation", i.e., whether and under what conditions different actors (e.g., suppliers, manufacturers) are responsible for technical progress in an industry, to the best of my knowledge there is no body of work that has explicitly sought to integrate into that work a locational dimension. Where and how firms engaged in technological innovation search for ideas and solutions to technical problems are, I believe, interesting and largely unexplored questions. Another way of asking this question is to ask what the nature and boundaries of firms' innovation networks are. How do firms alter their external innovation networks, for example when confronted by radical shifts in technology, as in the emergence of biotechnology for pharmaceutical firms? Or when previously tangential technical fields begin to have a bearing on a particular product or technical area, as in the application of digital information technology to photography?

Interestingly, even though the topic of this research may not explicitly involve multinational firms, it can be argued that multinationals are likely to be a very interesting, if special, case to study this phenomenon. That is, precisely because these firms, especially recently established subsidiaries of these firms, are often outsiders to particular technical communities, studying their entry strategies may be particularly revealing, both as to how these firms do gain access to technical communities, as well as to the ways in which these communities monitor and control the diffusion of knowledge which is often highly valuable in a commercial sense.

Finally, a rather different study, in fact one that I have been working on for some time with Eleanor Westney at MIT, looks at the strategies and organizational systems (structures, processes) conducive to the effective international management of R&D. An applied study, this work is based around a questionnaire (and follow-up interviews) that has been completed by over 100 R&D managers in 18 different countries. This work complements the current study in that it focuses a considerable amount of attention on foreign technical units, albeit from a managerial perspective. It also extends the current study's focus beyond just those multinational firms that have a distributed innovation capability. Included in the sample, for example, are firms that perform all of their R&D at home, in some cases at a single geographic location. Thus, a particularly interesting question, given the results of this thesis, is whether and how these firms ensure that they are aware of and have access to knowledge that originates outside of their home base.

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Appendix 1 The Main U.S. Subsidiary Patent Database

PATENT NUMBER	U.S. Patent Number
FILED DATE	Date of patent application
GRANTED DATE	Date of issuance of patent by USPTO
CITY	City of residence listed by first inventor on patent application
STATE	State of residence listed by first inventor on patent application
COUNTY*	U.S. county in which CITY is located
BEA	BEA region in which COUNTY is located
ASSIGNEE	Name of assignee listed on patent
PARENT FIRM	Parent company of ASSIGNEE
HOME BASE	Country in which parent firm is domiciled
ACQUISITION	1 if assignee is an acquisition; 2 if joint venture; 0 otherwise
CL1	Primary patent class
CL2	Secondary patent class
CL3	Secondary patent class
TECHNICAL FIELD	Technical field of the invention, based on 33 technical areas
PRIOR CITATIONS	Patent number of each prior patent listed as a reference
LATER CITATIONS	Patent number of each subsequent patent that lists current patent as a reference

*Items in bold indicate that information to construct this field was obtained from sources other than the USPTO database. Data sources and manipulations are described in Chapter 3.

Appendix 2 Aggregation of U.S. Patent Classes into 5 Broad Technical Areas *

1. Chemicals (Excluding Drugs)

8	Beaching and dyeing of textiles and fibers
23	Chemistry
47	Plant husbandry
51	Abrading
55	Gas separation
62	Refrigeration
71	Chemistry, fertilizers
86	Ammunition and explosive-charge making
89	Ordnance
102	Ammunition and explosive devices
106	Compositions, coating or plastic
127	Sugar, starch and carbohydrates
134	Cleaning and liquid contact with solids
149	Explosive and thermic compositions or charges
156	Adhesive bonding and miscellaneous chemical manufacture
201	Distillation: processes, thermolytic
203	Distillation: processes, separatory
204	Chemistry, electrical and wave energy
210	Liquid purification or separation
252	Compositions
260	Chemistry carbon compounds
422	Process disinfecting, deodorizing, preserving or sterilizing, chemical apparatus
423	Chemistry, inorganic
426	Food or edible material: processes, compositions and products
427	Coating processes
430	Radiation imagery chemistry-process, composition or product
432	Heating
512	Perfume compositions
518	Chemistry - processes which include a Fischer-Tropsch reaction
520	Synthetic resins
521	Part of the class 520 series-synthetic resins or natural rubbers
522	Part of the class 520 series-synthetic resins or natural rubbers
523	Part of the class 520 series-synthetic resins or natural rubbers
524	Part of the class 520 series-synthetic resins or natural rubbers

* Based on Jaffe (1986; 1989)

525 Part of the class 520 series-synthetic resins
526 Part of the class 520 series-synthetic resins or natural rubbers
527 Part of the class 520 series-synthetic resins or natural rubbers
528 Part of the class 520 series-synthetic resins
530 Chemistry, peptides or proteins, lignins or reaction products thereof
534 Part of the class 532-570 series-organic compounds
536 Part of the class 532-570 series-organic compounds
540 Part of the class 532-570 series-organic compounds
544 Part of the class 532-570 series-organic compounds
546 Part of the class 532-570 series-organic compounds
548 Part of the class 532-570 series-organic compounds
549 Part of the class 532-570 series-organic compounds
552 Part of the class 532-570 series-organic compounds
556 Part of the class 532-570 series-organic compounds
560 Part of the class 532-570 series-organic compounds
562 Part of the class 532-570 series-organic compounds
564 Part of the class 532-570 series-organic compounds
568 Part of the class 532-570 series-organic compounds
570 Part of the class 532-570 series-organic compounds
585 Chemistry, hydrocarbons
930 Part of the class 532-570 series-organic compounds

2. Drugs and Medical Technology

3 Artificial body members
128 Surgery
424 Drug, bio-affecting and body treating compositions
435 Chemistry: molecular biology and microbiology
436 Chemistry: analytical and immunological testing
514 Drug, bio-affecting and body treating compositions
600 Surgery
604 Surgery
606 Surgery
623 Prosthesis (artificial body members), parts thereof or aids and accessories thereof
800 Multicellular living organisms and unmodified part thereof
935 Genetic engineering: recombinant DNA technology, hybrid or fused cell technology and related manipulations of nucleic acids

3. Electronic Arts

33 Geometrical instruments
52 Photographic Equipment
73 Measuring and testing
74 Machine elements and mechanisms
84 Music
136 Batteries, thermoelectric and photoelectric

174 Electricity, conductors and insulators
177 Weighing scales
178 Telegraph
179 Telephony
181 Acoustics
200 Electricity, circuit maker and breakers
219 Electric heating
235 Registers
236 Automatic temperature and humidity regulation
244 Aeronautics
250 Radiant energy
290 Prime mover dynamo plants
307 Electrical transmission or interconnection systems
310 Electrical generator or motor structure
313 Electric lamp and discharge devices
314 Electric lamp and discharge devices, consumable electrodes
315 Electric lamp and discharge devices, systems
318 Electricity, motive power systems
320 Electricity, battery and condenser charging and discharging
322 Electricity, single generator systems
323 Electricity, voltage magnitude and phase control systems
324 Electricity, measuring and testing
328 Miscellaneous electron space discharge device
329 Demodulators and detectors
330 Amplifiers
331 Oscillators
332 Modulators
333 Wave transmission lines and networks
334 Tuners
335 Electricity, magnetically operated switches, magnets and electromagnets
336 Inductor devices
337 Electricity, electrothermally or thermally actuated switches
338 Electrical resistors
339 Electrical connectors
340 Communications, electrical
341 Coded data generation or conversion
342 Communications, directive radio wave systems and devices
343 Communications, radio wave antennas
346 Recorders
350 Optics, systems and elements
351 Optics, eye examining vision testing and correcting
352 Optics, motion pictures
353 Optics, image projectors
354 Photography
355 Photocopying

356 Optics, measuring and testing
357 Active solid state devices, e.g. transistors, solid state diodes
358 Pictorial communication, television
360 Dynamic magnetic information storage and retrieval
361 Electricity, electrical systems and devices
362 Illumination
363 Electric power conversion systems
364 Electrical computers and data processing systems
365 Static information storage and retrieval
367 Communication, electrical: acoustic wave systems and devices
368 Horology-time measuring systems and devices
369 Dynamic information storage and retrieval
370 Mutiplex communications
371 Error detection/correction and fault detection/recovery
372 Coherent light generators
373 Industrial electric heating furnaces
374 Thermal measuring and testing
375 Pulse or digital communications
377 Electrical pulse counters, pulse dividers or shift registers
378 X-ray or gamma systems or devices
379 Telephonic communications
381 Electrical audio signal processing
382 Image analysis
388 Electricity, motor control systems
392 Electric resistant heating devices
400 Typewriting machines
429 Chemistry, electrical current producing apparatus, product and process
433 Dentistry
437 Semiconductors device manufacturing: process
439 Electrical connectors
455 Telecommunications
475 Planetary gear transmission systems and components
505 Superconductor technology - apparatus, material, process
902 Electronic funds transfer

4. Mechanical Arts

3 Artificial body members
4 Baths, closets, sinks and spittoons
7 Compound tools
10 Bolts, nail, nut, rivet and screw making
12 Boot and shoe making
15 Brushing, scrubbing and general cleaning (apparatus)
15 Brushing, scrubbing and general cleaning (apparatus)
16 Miscellaneous hardware
19 Textiles, fibers preparation

19	Textiles, fibers preparation
24	Buckles, buttons, clasps, etc.
26	Textiles, cloth finishing
27	Undertaking
28	Textiles, manufacturing
29	Metal-working
34	Drying and gas or vapor contact with solids
37	Excavating
38	Textiles, ironing or smoothing
42	Firearms
48	Gas, heating and illuminating
49	Moveable or removable closures
53	Package making
56	Harvesters
57	Textiles, spinning, twisting and twining
59	Chain, staple and horseshoe making
60	Power plants
63	Jewellery
65	Glass manufacturing
66	Textiles, knitting
68	Textiles, fluid treating apparatus
69	Leather manufactures
70	Locks
72	Metal deforming
75	Metallurgy
76	Metal tools and implements, making
79	Button making
81	Tools
83	Cutting
87	Textiles, braiding, netting and lacemaking
91	Motors, expansible chamber type
92	Expansible chamber devices
98	Ventilation
99	Foods and beverages: apparatus
100	Presses
101	Printing
104	Railways
105	Railway rolling stock
108	Horizontally supported planar surfaces
109	Safes, bank protection and related devices
110	Furnaces
111	Planting
112	Sewing
114	Ships
116	Signals and indicators

118 Coating apparatus
122 Liquid heaters and vaporizers
123 Internal combustion engines
124 Mechanical guns and projectors
126 Stores and furnaces
130 Threshing
132 Toilet
133 Coin handling
135 Tents, canopies, umbrellas and canes
137 Fluid handling
138 Pipes and tubular conduits
139 Textiles, weaving
140 Wireworking
141 Fluent material handling, with receiver or receiver coating means
142 Wood turning
144 Wood working
145 Woodworking tools
147 Coopering
148 Metal treatment
150 Cloth, leather and rubber receptacles
152 Resilient tires and wheels
157 Wheelwright machines
159 Concentrating evaporators
160 Closures, partitions and panels, flexible and portable
162 Paper making and fiber preparation
163 Needle and pin making
164 Metal founding
165 Heat exchange
166 Wells
169 Fire-extinguishers
171 Unearthing plants or buried objects
172 Earth working
173 Tool driving or impacting
175 Boring or penetrating the earth
180 Motor vehicles
182 Fire escapes, ladders, scaffolds
184 Lubrication
185 Motors, spring, weight and animal powered
186 Store service
187 Elevators
188 Brakes
190 Baggage
191 Electricity, transmission to vehicles
192 Clutches and power stop control
193 Conveyors, chutes, skids, guides and ways

194 Check-controlled apparatus
196 Mineral oils apparatus
198 Conveyors, power driven
199 Type casting
202 Distillation: apparatus
206 Special receptacle or package
209 Classifying, separating and assorting solids
211 Supports, racks
212 Traversing hoists
213 Railway draft appliances
220 Metallic receptacles
221 Article dispensing
222 Dispensing
223 Apparel apparatus
224 Package and article carriers
225 Severing by tearing or breaking
226 Advancing material of indeterminate length
227 Elongated member driving apparatus
228 Metal fusion bonding
229 Paper receptacles
232 Deposit and collection receptacles
234 Selective cutting (e.g. punching)
237 Heating systems
238 Railways, surface track
239 Fluid sprinkling, spraying and diffusing
241 Solid material comminution or disintegration
242 Winding and reeling
246 Railway switches and signals
248 Supports
249 Static moulds
251 Valve and valve actuation
254 Pushing and pulling implements
256 Fences
258 Railway mail delivery
261 Gas and liquid contact apparatus
266 Metallurgical apparatus
267 Spring devices
269 Work holders
270 Sheet material associating or folding
271 Sheet feeding or delivery
272 Amusement and exercising devices
276 Type setting
277 Joint packing
278 Land vehicles, animal draft appliances
279 Chucks or sockets

280 Land vehicles
281 Books, strips and leaves
282 Manifolding
283 Printed matter
285 Pipe joints or couplings
291 Track sanders
292 Closure fasteners
293 Vehicle fenders
294 Handling, hand and hoist-line implements
295 Railway wheels and axles
296 Land vehicles, bodies and tops
298 Land vehicles, dumping
299 Mining or in situ disintegration of hard material
300 Brush, broom and mop making
301 Land vehicles, wheels and axles
303 Fluid pressure brake and analogous systems
305 Wheel substitutes for land vehicles
308 Machine elements, bearings and guides
312 Supports, cabinet structures
366 Agitating
376 Induced nuclear reaction, systems and elements
383 Flexible bags
384 Bearings or guides
401 Coating, implements with material supply
402 Binder device releasably engaging aperture or notch of sheet
403 Joints and connections
404 Road structure, process and apparatus
404 Road structure, process and apparatus
405 Hydraulic and earth engineering
406 Conveyors, fluid current
407 Cutters for shaping
408 Cutting by use of rotating axially moving tool
409 Gear cutting, milling or planing
410 Freight accommodation on freight carrier
411 Expanded, threaded, headed, and driven fasteners-locked or coupled bolts
412 Bookbinding, process and apparatus
413 Sheet metal container making
414 Material or article handling
415 Rotary kinetic fluid motors or pumps
416 Fluid reaction surfaces (impellers)
417 Pumps
418 Rotary expansible chamber devices
419 Powder metallurgy-processes
420 Nonferrous alloys or metallic compositions
425 Plastic article or earthenware shaping or treating: apparatus

431 Combustion
440 Marine propulsion
441 Buoys, rafts, and aquatic devices
445 Electric lamp or space discharge component or device manufacturing
453 Coin handling
460 Crop threshing or separating
462 Books, strips and leaves for manifolding
464 Rotary shafts, gudgeons, housing and flexible couplings for rotary shafts
474 Endless container making
474 Endless belt power transmission and components
493 Manufacturing container or tube from paper
494 Imperforate bowl, centrifugal separators
502 Catalyst, solid solvent, or support thereof, product or process
503 Record receiver having plural leaves or a colorless color former, method of use or developer thereof
901 Robots
976 Nuclear technology

5. Other

2 Apparel
4 Baths, closets, sinks and spittoons
5 Beds
7 Compound tools
10 Bolts, nail, nut, rivet and screw making
14 Bridges
16 Miscellaneous hardware
17 Butchering
30 Cutlery
36 Boots, shoes and leggings
40 Card, picture and sign exhibiting
43 Fishing, trapping and vermin destroying
44 Fuel and ignition devices
52 Static structures, e.g. buildings
54 Harness
119 Animal husbandry
125 Stone working
131 Tobacco
168 Farriery
208 Mineral oils
215 Bottles and jars
217 Wooden receptacles
231 Whips and whip apparatus
245 Wire fabrics and structure
264 Plastic and nonmetallic article shaping or treating process
273 Amusement devices, games

289 Knots and knot tying
297 Chairs and seats
380 Cryptography (ciphering and coding apparatus)
428 Stock material or miscellaneous articles
434 Education and demonstration
446 Amusement devices, toys
449 Bee culture
450 Foundation garments
501 Compositions: ceramic

Appendix 3 Aggregation of U.S. Patent Classes into 33 Fields of Technology*

1. Food and Tobacco Products

127 Sugar, starch and carbohydrates sub class 29-71
131 Tobacco sub class 1-226, 291-999
426 Food or edible material: processes, compositions and products

2. Inorganic Chemicals

423 Chemistry, inorganic

3. Agricultural Chemicals

71 Chemistry, fertilizers

4. Chemical Processes

23 Chemistry
51 Abrading sub class 293-328
55 Gas separation sub class 1-99
62 Refrigeration sub class 1-122
106 Compositions, coating or plastic
134 Cleaning and liquid contact with solids sub class 1-42
156 Adhesive bonding and miscellaneous chemical manufacture sub class 1-479, 600-688
201 Distillation: processes, thermolytic
203 Distillation: processes, separatory
204 Chemistry, electrical and wave energy sub class
210 Liquid purification or separation sub class 501-982
252 Compositions
260 Chemistry carbon compounds sub class 95, 684-708
432 Heating sub class 1-53
427 Coating processes
430 Radiation imagery chemistry-process, composition or product
512 Perfume compositions
518 Chemistry - processes which include a Fischer-Tropsch reaction

* Based on Zander (1994)

5. Beaching and Dyeing

8 Beaching and dyeing of textiles and fibers
422 Process disinfecting, deodorizing, preserving or sterilizing, chemical apparatus sub class 1-43

6. Other Organic Chemicals

260 Chemistry carbon compounds
520 Synthetic resins
521 Part of the class 520 series-synthetic resins or natural rubbers
522 Part of the class 520 series-synthetic resins or natural rubbers
523 Part of the class 520 series-synthetic resins or natural rubbers
524 Part of the class 520 series-synthetic resins or natural rubbers
525 Part of the class 520 series-synthetic resins
526 Part of the class 520 series-synthetic resins or natural rubbers
527 Part of the class 520 series-synthetic resins or natural rubbers
528 Part of the class 520 series-synthetic resins
530 Chemistry, peptides or proteins, lignins or reaction products thereof
534 Part of the class 532-570 series-organic compounds
536 Part of the class 532-570 series-organic compounds
540 Part of the class 532-570 series-organic compounds
544 Part of the class 532-570 series-organic compounds
546 Part of the class 532-570 series-organic compounds
548 Part of the class 532-570 series-organic compounds
549 Part of the class 532-570 series-organic compounds
552 Part of the class 532-570 series-organic compounds
556 Part of the class 532-570 series-organic compounds
560 Part of the class 532-570 series-organic compounds
562 Part of the class 532-570 series-organic compounds
564 Part of the class 532-570 series-organic compounds
568 Part of the class 532-570 series-organic compounds
570 Part of the class 532-570 series-organic compounds
930 Part of the class 532-570 series-organic compounds

7. Pharmaceuticals

424 Drug, bio-affecting and body treating compositions
435 Chemistry: molecular biology and microbiology
436 Chemistry: analytical and immunological testing
514 Drug, bio-affecting and body treating compositions
800 Multicellular living organisms and unmodified part thereof
935 Genetic engineering: recombinant DNA technology, hybrid or fused cell technology and related manipulations of nucleic acids

8. Metallurgical Processes

29 Metal-working
75 Metallurgy
148 Metal treatment
164 Metal founding sub class 1-148
228 Metal fusion bonding sub class 101-265
419 Powder metallurgy-processes
420 Nonferrous alloys or metallic compositions

9. Other Metal Products

3 Artificial body members
4 Baths, closets, sinks and spittoons
7 Compound tools
10 Bolts, nail, nut, rivet and screw making
16 Miscellaneous hardware
24 Buckles, buttons, clasps, etc.
27 Undertaking
30 Cutlery sub class 1-165, 167, 395-499, 501-999
49 Moveable or removable closures
63 Jewellery
70 Locks
108 Horizontally supported planar surfaces
109 Safes, bank protection and related devices
124 Mechanical guns and projectors
132 Toilet
135 Tents, canopies, umbrellas and canes
138 Pipes and tubular conduits
150 Cloth, leather and rubber receptacles
160 Closures, partitions and panels, flexible and portable
182 Fire escapes, ladders, scaffolds
190 Baggage
206 Special receptacle or package
211 Supports, racks
215 Bottles and jars sub class 100-367
220 Metallic receptacles
232 Deposit and collection receptacles
248 Supports
256 Fences
267 Spring devices
272 Amusement and exercising devices
279 Chucks or sockets
285 Pipe joints or couplings
292 Closure fasteners
312 Supports, cabinet structures
383 Flexible bags
403 Joints and connections

411 Expanded, threaded, headed, and driven fasteners-locked or coupled bolts
464 Rotary shafts, gudgeons, housing and flexible couplings for rotary shafts
623 Prosthesis (artificial body members), parts thereof or aids and accessories thereof

10. Chemical and Allied Equipment

34 Drying and gas or vapor contact with solids
51 Abrading sub class 1-292, 329-999
55 Gas separation sub class 100-999
53 Package making
68 Textiles, fluid treating apparatus
65 Glass manufacturing sub class 138-999
99 Foods and beverages: apparatus
134 Cleaning and liquid contact with solids sub class 43-999
131 Tobacco sub class 227-290
127 Sugar, starch and carbohydrates sub class 1-28
118 Coating apparatus
156 Adhesive bonding and miscellaneous chemical manufacture sub class 480-599, 669-999
159 Concentrating evaporators
162 Paper making and fiber preparation
196 Mineral oils apparatus
202 Distillation: apparatus
209 Classifying, separating and assorting solids
210 Liquid purification or separation sub class 1-500
229 Paper receptacles
249 Static moulds
241 Solid material comminution or disintegration sub class 132-999
261 Gas and liquid contact apparatus
366 Agitating
422 Process disinfecting, deodorizing, preserving or sterilizing, chemical apparatus sub class 44-999
493 Manufacturing container or tube from paper
494 Imperforate bowl, centrifugal separators
502 Catalyst, solid solvent, or support thereof, product or process
503 Record receiver having plural leaves or a colorless color former, method of use or developer thereof

11. Metal-Working Equipment

59 Chain, staple and horseshoe making
72 Metal deforming
76 Metal tools and implements, making
81 Tools
83 Cutting
163 Needle and pin making

164 Metal founding sub class 149-999
173 Tool driving or impacting
225 Severing by tearing or breaking
228 Metal fusion bonding sub class 1-100
234 Selective cutting (e.g. punching)
266 Metallurgical apparatus
269 Work holders
308 Machine elements, bearings and guides sub class 1-9, 11-245
384 Bearings or guides
407 Cutters for shaping
408 Cutting by use of rotating axially moving tool
409 Gear cutting, milling or planing
413 Sheet metal container making
474 Endless container making
474 Endless belt power transmission and components

12. Assembly Equipment

186 Store service
187 Elevators sub class 1-28, 30-999
193 Conveyors, chutes, skids, guides and ways
198 Conveyors, power driven
212 Traversing hoists
224 Package and article carriers
226 Advancing material of indeterminate length
242 Winding and reeling
254 Pushing and pulling implements sub class 134-999
258 Railway mail delivery
271 Sheet feeding or delivery
294 Handling, hand and hoist-line implements
402 Binder device releasably engaging aperture or notch of sheet
406 Conveyors, fluid current
410 Freight accommodation on freight carrier
414 Material or article handling
901 Robots

13. Mining Equipment

166 Wells
175 Boring or penetrating the earth
299 Mining or in situ disintegration of hard material

14. Specialized Industrial Equipment

12 Boot and shoe making
15 Brushing, scrubbing and general cleaning (apparatus)

19 Textiles, fibers preparation
26 Textiles, cloth finishing
28 Textiles, manufacturing
30 Cutlery sub class 166, 168-394, 500
37 Excavating
38 Textiles, ironing or smoothing
56 Harvesters
57 Textiles, spinning, twisting and twining
66 Textiles, knitting
69 Leather manufactures
79 Button making
87 Textiles, braiding, netting and lacemaking
98 Ventilation
100 Presses
101 Printing
111 Planting
112 Sewing
116 Signals and indicators
130 Threshing
133 Coin handling
139 Textiles, weaving
140 Wireworking
141 Fluent material handling, with receiver or receiver coating means
142 Wood turning
144 Wood working
145 Woodworking tools
147 Coopering
157 Wheelwright machines
169 Fire-extinguishers
171 Unearthing plants or buried objects
172 Earth working
194 Check-controlled apparatus
199 Type casting
221 Article dispensing
222 Dispensing
223 Apparel apparatus
227 Elongated member driving apparatus
254 Pushing and pulling implements sub class 1-133
270 Sheet material associating or folding
276 Type setting
277 Joint packing
278 Land vehicles, animal draft appliances
281 Books, strips and leaves
282 Manifolding
283 Printed matter

291 Track sanders
300 Brush, broom and mop making
401 Coating, implements with material supply
404 Road structure, process and apparatus sub class 83-133
412 Bookbinding, process and apparatus
425 Plastic article or earthenware shaping or treating: apparatus
445 Electric lamp or space discharge component or device manufacturing
453 Coin handling
460 Crop threshing or separating
462 Books, strips and leaves for manifolding

15. General Industrial Equipment

48 Gas, heating and illuminating
91 Motors, expansible chamber type
92 Expansible chamber devices
110 Furnaces
122 Liquid heaters and vaporizers
126 Stores and furnaces
137 Fluid handling
165 Heat exchange
184 Lubrication
185 Motors, spring, weight and animal powered
188 Brakes
192 Clutches and power stop control
237 Heating systems
239 Fluid sprinkling, spraying and diffusing
251 Valve and valve actuation
303 Fluid pressure brake and analogous systems
415 Rotary kinetic fluid motors or pumps
416 Fluid reaction surfaces (impellers)
417 Pumps
418 Rotary expansible chamber devices
431 Combustion
432 Heating sub class 54-999

16. Power Plants

60 Power plants

17. Nuclear Reactors

376 Induced nuclear reaction, systems and elements
976 Nuclear technology

18. Telecommunications

178 Telegraph
179 Telephony
329 Demodulators and detectors
332 Modulators
340 Communications, electrical
341 Coded data generation or conversion
342 Communications, directive radio wave systems and devices
343 Communications, radio wave antennas
367 Communication, electrical: acoustic wave systems and devices
370 Mutiplex communications
375 Pulse or digital communications
379 Telephonic communications
382 Image analysis
455 Telecommunications

19. Image and Sound Equipment

84 Music
181 Acoustics
358 Pictorial communication, television
381 Electrical audio signal processing

20. Electrical Systems

174 Electricity, conductors and insulators
200 Electricity, circuit maker and breakers
307 Electrical transmission or interconnection systems sub class 1-199, 586-999
313 Electric lamp and discharge devices
314 Electric lamp and discharge devices, consumable electrodes
315 Electric lamp and discharge devices, systems
308 Machine elements, bearings and guides sub class 10
323 Electricity, voltage magnitude and phase control systems
328 Miscellaneous electron space discharge device
330 Amplifiers
331 Oscillators
333 Wave transmission lines and networks
334 Tuners
335 Electricity, magnetically operated switches, magnets and electromagnets
336 Inductor devices
337 Electricity, electrothermally or thermally actuated switches
338 Electrical resistors
339 Electrical connectors
361 Electricity, electrical systems and devices sub class 1-432, 437-999
362 Illumination
363 Electric power conversion systems
372 Coherent light generators

439 Electrical connectors
505 Superconductor technology - apparatus, material, process

21. General Electrical Equipment

62 Refrigeration sub class 123-999
136 Batteries, thermoelectric and photoelectric
204 Chemistry, electrical and wave energy sub class 193-499
219 Electric heating
236 Automatic temperature and humidity regulation
290 Prime mover dynamo plants
310 Electrical generator or motor structure
318 Electricity, motive power systems
320 Electricity, battery and condenser charging and discharging
322 Electricity, single generator systems
361 Electricity, electrical systems and devices sub class 433-436
373 Industrial electric heating furnaces
388 Electricity, motor control systems
392 Electric resistant heating devices
429 Chemistry, electrical current producing apparatus, product and process
437 Semiconductors device manufacturing: process

22. Semiconductors

307 Electrical transmission or interconnection systems sub class 200-585
357 Active solid state devices, e.g. transistors, solid state diodes

23. Office Equipment

235 Registers
360 Dynamic magnetic information storage and retrieval
364 Electrical computers and data processing systems
365 Static information storage and retrieval
369 Dynamic information storage and retrieval
371 Error detection/correction and fault detection/recovery
377 Electrical pulse counters, pulse dividers or shift registers
400 Typewriting machines
902 Electronic funds transfer

24. Motor Vehicles

123 Internal combustion engines
180 Motor vehicles
296 Land vehicles, bodies and tops

25. Aircraft

244 Aeronautics sub class 1-13, 15-999

26. Other Transport Equipment

104 Railways
105 Railway rolling stock
114 Ships sub class 1-19, 26-999
191 Electricity, transmission to vehicles
213 Railway draft appliances
238 Railways, surface track
246 Railway switches and signals
280 Land vehicles
293 Vehicle fenders
295 Railway wheels and axles
298 Land vehicles, dumping
301 Land vehicles, wheels and axles
305 Wheel substitutes for land vehicles
440 Marine propulsion
441 Buoys, rafts, and aquatic devices

27. Textiles and Wood Products

2 Apparel
5 Beds
36 Boots, shoes and leggings
217 Wooden receptacles
245 Wire fabrics and structure
289 Knots and knot tying
297 Chairs and seats
450 Foundation garments

28. Rubber Products

152 Resilient tires and wheels
264 Plastic and nonmetallic article shaping or treating process

29. Non-Metallic Mineral Products

52 Static structures, e.g. buildings
65 Glass manufacturing sub class 1-137
125 Stone working
215 Bottles and jars sub class 1-99
241 Solid material comminution or disintegration sub class 1-131
428 Stock material or miscellaneous articles
501 Compositions: ceramic

30. Coal and Petroleum Products

44	Fuel and ignition devices
208	Mineral oils
585	Chemistry, hydrocarbons

31. Photographic Instruments

52	Photographic Equipment
354	Photography
355	Photocopying

32. Other Instruments

33	Geometrical instruments
73	Measuring and testing
74	Machine elements and mechanisms
128	Surgery
177	Weighing scales
187	Elevators sub class 29
235	Registers sub class 1-60, 90-374, 387-399, 458-999
250	Radiant energy
324	Electricity, measuring and testing
346	Recorders
350	Optics, systems and elements
351	Optics, eye examining vision testing and correcting
352	Optics, motion pictures
353	Optics, image projectors
356	Optics, measuring and testing
368	Horology-time measuring systems and devices
374	Thermal measuring and testing
378	X-ray or gamma systems or devices
433	Dentistry
475	Planetary gear transmission systems and components
600	Surgery
604	Surgery
606	Surgery

33. Other Manufacturing and Non-Industrial

6	Bee culture
14	Bridges
17	Butchering
40	Card, picture and sign exhibiting
42	Firearms
43	Fishing, trapping and vermin destroying
47	Plant husbandry

54 Harness
86 Ammunition and explosive-charge making
89 Ordnance
102 Ammunition and explosive devices
114 Ships sub class 20-25
119 Animal husbandry
149 Explosive and thermic compositions or charges
168 Farriery
231 Whips and whip apparatus
244 Aeronautics sub class 14
273 Amusement devices, games
380 Cryptography (ciphering and coding apparatus)
404 Road structure, process and apparatus
405 Hydraulic and earth engineering
434 Education and demonstration
446 Amusement devices, toys
449 Bee culture