Strategic Change and the Coevolution of Industry-University Relationships: Evidence from the Forest Products Industry

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Abstract

In this thesis we present an analysis of the dynamics of industry-university relationships tracing the origin of the relationship and its changes over time as the firm's strategies evolve. We analyze the strategic trajectories of nine European and North American forest products companies, distilling four generic strategies, and linking those strategies to each company's university relationships as judged by publications records, academic trajectories of the company's personnel, and interviews with company managers.

We found that firms are likely to form new university relationships when (1) integrating new positions in the value chain, (2) diversifying their industrial base, or (3) internationalizing the manufacturing base. When firms narrowed their business and geographical scope, however, they reduced university links.

We found that building an industry-university relationship was a gradual process. Periods of strategic stability and bidirectional people flows strengthened these relationships. Changes in the firm's CEO, however, signaled modifications in the firm's university relationships. These modifications were contingent on the strategy pursued by the firm and pre-existing industry-university systems. Based on those findings, we derive a framework to describe how industry-university relationships evolve with changes in firm strategy.

The thesis shows that changes in corporate strategy affect the formation and evolution of university relationships, an idea generalizable to other industries. The strategic change process of forest products firms, however, has features that may be applicable only to large, commodity-grade capital-intensive industries. In particular when confronted by change, forest products firms did not always evolve towards higher positions in the value chain, sometimes moving down this chain divesting internal technological capabilities. These "competency-destroying" cycles tended to coincide with periods of economic downturn. Because of the dissimilarities in the time scale for change, universities can act as "knowledge buffers" for of these cyclical industries, helping firms to regain lost capabilities and allowing corporate technologies time to mature despite changes in firm strategy.

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This thesis is dedicated to Constanza,

for her unconditional love and support throughout these years

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1. Introduction and Thesis Contributions

1.1. Goal and scope of the dissertation

There is broad consensus that industry-university relationships have positive effects on the innovative performance of companies [1, 2], and that these effects have increased in the last decades [3]. Universities are increasingly expected to contribute beyond teaching and research, to economic growth and social development [4]. Industries and universities are thus forging closer relationships [5-7] and governments are actively encouraging the formation of these links [8-11].

Different types of industry-university links have been mapped and described [12]. There is, however, little information on such relationships in terms of the strategy of participating firms [13]. Even though research alliances are embedded within a firm's strategic portfolio and thus evolve with firm strategy and competitive dynamics [14]. This thesis clarifies the role of firm strategy by analyzing industry-university relationships in a dynamic context, exploring both the origin of the university relationship and how it changes over time. The specific question we seek to answer is: *how do industry university relationships coevolve with firm strategy*?

To answer the question we conducted a systematic assessment of how changes in strategy affected the relationships between firms and universities or public research institutions. We undertook a longitudinal case study approach, analyzing nine forest products companies in three different regions: North America, Northern Europe, and Southern Europe. The forest products industry is selected as a mature industry that was in operation long before forestry or chemical engineering emerged as scientific fields. The industry provides an interesting research arena for determining the coevolution of industry-university relationships, because forest products firms have differed in their competitive strategies over time [15] and have forged different links with university partners.

The following sections describe the thesis structure and contents, give suggestions for how to read the thesis, and present a summary of the thesis contributions.

1.2. Thesis structure and chapter contents

The thesis is divided into six chapters and nine appendixes:

- Chapter 1 introduces the goals of this thesis and presents a summary of the contributions.
- Chapter 2 reviews the literature on industry-university relationships, with emphasis on the perspective of the firm. The positive effects of industry-university relationships and the different regional, industrial, academic, and technological factors that determine the formation and success of an industry-university relationship are described. The chapter argues that existing literature has become

fragmented and has overemphasized the structural characteristics of the collaborating partners (e.g. size, industrial sector, R&D intensity, geographic location, academic prestige), to the detriment of uncovering path-dependent processes that lead to the formation and evolution of industry-university links, the literature gap identified.

- Chapter 3 defines the research question and summarizes the methodological approach. The latter consists of in-depth case studies with four embedded units of analysis: strategies, technologies, institutions, and people. The chapter also introduces the nine firms in our data set and describes the data collection and analysis protocol for analyzing the strategic trajectories and university relationships of these firms.
- Chapter 4 provides a theoretical framework, which draws from punctuated equilibrium theory [16, 17] to explain the strategic change process of firms. The framework also draws from systems theory to describe industry-university relationships as a coupled system. From the framework, a series of propositions are put forward to define the coevolution of industry-university relationships.
- Chapter 5 contains a cross-case analysis in which the validity of the propositions identified in Chapter 4 is assessed. Based on these findings, an improved framework was developed for illustrating how industry-university relationships coevolve with the firm's strategy.
- Chapter 6 presents a summary of the findings, and discusses their implications including avenues of future research.
- The appendixes give the nine case studies summarizing the strategic changes of the firms including the origins and evolution of the firm's university relationship. The case studies also assess how the firm's technological priorities have changed and how the firm's network of university partners evolved in response to these changes. Further, through analysis of the professional trajectories of the firm's R&D personnel, we can evaluate how bidirectional flows of people facilitated technology transfer between firms and universities.

Readers interested in the history of a particular firm should access the cases contained in the appendix. Note that most of the historic data was drawn from secondary sources, especially when archival data was hard to obtain or written in languages not accessible for this author (e.g. Finnish, Swedish).

1.3. Summary of Contributions

1.3.1. Theoretical and methodological contributions

- An extensive literature survey has been conducted, leading to an integrative framework for organizing research on industry-university relationships.

- Punctuated equilibrium theory and systems theory have been used to define a theoretical framework and eight propositions related to the question: how do industry-university relationships coevolve with firm strategy?
- A methodological approach has been designed consisting of in-depth longitudinal case studies with four embedded units of analysis: firm strategy, technological priorities, people flows, and university networks.
- Three methodological innovations have been developed:
    - Tracing of the process that led to the establishment and evolution of a firm's university relationships through the whole lifecycle of a firm.
    - Analysis of the content of the articles written by firm and university researchers to obtain fine-grained data on the evolution of the firm's research collaborations and technological priorities over time.
    - Tracking of the academic and professional trajectories of the company's R&D staff. This type of analysis has been done at the university level [18] but, to our knowledge, we are the first to use this analysis at the firm level.
- The eight propositions have been assessed and an enhanced theoretical framework derived for illustrating how industry-university relationships coevolved with the firm's strategy.

1.3.2. Literature contributions

- To our knowledge, no other study has analyzed industry-university relationships from the perspective of changes in the firm's strategy. The dissertation thus embodies an empirical contribution to the field of industry-university relationships.
- A mature industry was analyzed in contrast to much of the literature on industry-university relationships that has focused on newer high-tech sectors. The forest products industry has received little attention for well known reasons: firms are old, invest little in R&D, technologies are mature, and thus existing literature (as shown in Chapter 2) predicts low levels of university relationships. We show that beyond these structural characteristics, the firm's strategy plays an important role in explaining industry-university relationships.
- We found that strategic occurs at different timescales and magnitudes. In particular, we observed periods of strategic stability punctuated by changes in the CEO of the firms. Within periods of stability we observed a stable pattern of industry-university relationships. After CEO changes, however, we observed major changes in the firm's university relationships.
- We showed that the concept of organizational coupling [19, 20] is useful for characterizing industry-university relationships. An important dynamic is derived from this concept: not all university relationships are affected equally by a change in the firm's strategy.

- We show that firms were particularly likely to form new university relationships when (1) integrating new positions in the value chain, (2) diversifying their industrial base, or (3) internationalizing the manufacturing base. In contrast, when firms narrowed their business and geographical scope, they reduced university links. This differs from the literature on strategic alliance formation, which finds the rate of external alliance formation to be higher when firms were in difficult market situations [21].
- We found that when confronted by change, forest products firms did not always evolved towards higher positions in the value chain, but also moved down this chain divesting internal technological capabilities. These "competency-destroying" cycles tended to coincide with periods of economic downturn.
- We show that the firm's absorptive capacity not only depends on the firm's R&D intensity [22], but also on the firm's organizational form [23]. Firms with geographically distributed R&D infrastructure had a more diverse set of university partners. This contrasts with previous research findings that firms with centralized R&D labs spend more on university research [13].

1.3.3. Policy and Managerial Contributions

- We found an overlap between the universities attended by the firm's R&D personnel and the firm's university coauthors, which highlights the role of social capital and the firm's hiring routines in the formation of a university relationship.
- We show that reductions in the industrial capacity of a region (i.e., deindustrialization process) poses risks for universities and their research agendas with industry, and could potentially lead to a regional capability loss if firms relocate manufacturing operations.
- Because of the dissimilarities in the time scale for change, universities can act as "knowledge buffers" for of cyclical industries, helping firms to regain lost capabilities and allowing corporate technologies time to mature despite changes in firm strategy.

2. Literature Review

This chapter provides a review of the literature on industry-university relationships with emphasis on the perspective of the firm. The review is divided into six sections. Section 2.1 presents a framework for organizing the literature. Section 2.2 reviews literature on determinants of industry-university relationships, analyzing the regional, industrial, and academic attributes that affect the formation of an industry-university relationship. Section 2.3 shows different types of industry-university links with different properties that affect the outcomes of these relationships. Section 2.4 describes how technology characteristics affect industry-university relationships. Section 2.5 summarizes benefits for the participants of industry-university relationships. In Section 2.6 we explain the literature gap, specifically that no analysis has been conducted on the coevolution of industry-university relationships with changes in a firm's strategy.

2.1. Integrative Framework for Organizing Literature

Literature on industry-university relationships started to increase in the 1980s because of increased attention of policymakers on research commercialization as a means to stimulate the creation, diffusion, and utilization of knowledge [12]. The result is a growing body of literature that has become increasingly fragmented and that has emphasized the structural characteristics of the collaborating partners relative to uncovering path-dependent processes in industry-university links. The purpose of this section is thus to provide an integrative framework for organizing this literature.

Figure 1 serves as a map for navigating the different sections of the literature review. The main message of the figure is that industry-university relationships constitute a complex system characterized by nested, structural, technological and evaluative complexities.

The first column in Figure 1 shows the different units of analysis and the multiple institutional spheres in which these units are inserted, and whose properties affect the formation and evolution of industry-university links. For example, if a university is inserted within a specific regional innovation system, the regulatory context of the region will affect industry-university relationships. In Section 2.2 we expand on how the characteristics of regions, firms, and universities affect the formation and evolution of industry-university links.

The second column shows that industry-university relationships can take multiple forms. Bekkers and Bodas Freitas [24] distinguished more than 23 different types of industry-university links, from the publication of scientific articles, to the sharing of university facilities by firms. Each of these links can be grouped and combined forming multiple configurations [7, 24]. Research collaborations can involve funding for students, informal contacts, and infrastructure sharing all at the same time. These configurations differ in terms of the duration, intensity, and degree of formalization of the activities, and all of these factors affect the evolution and results of an industry-university relationship. We expand on the effects of these attributes in Section 2.3.

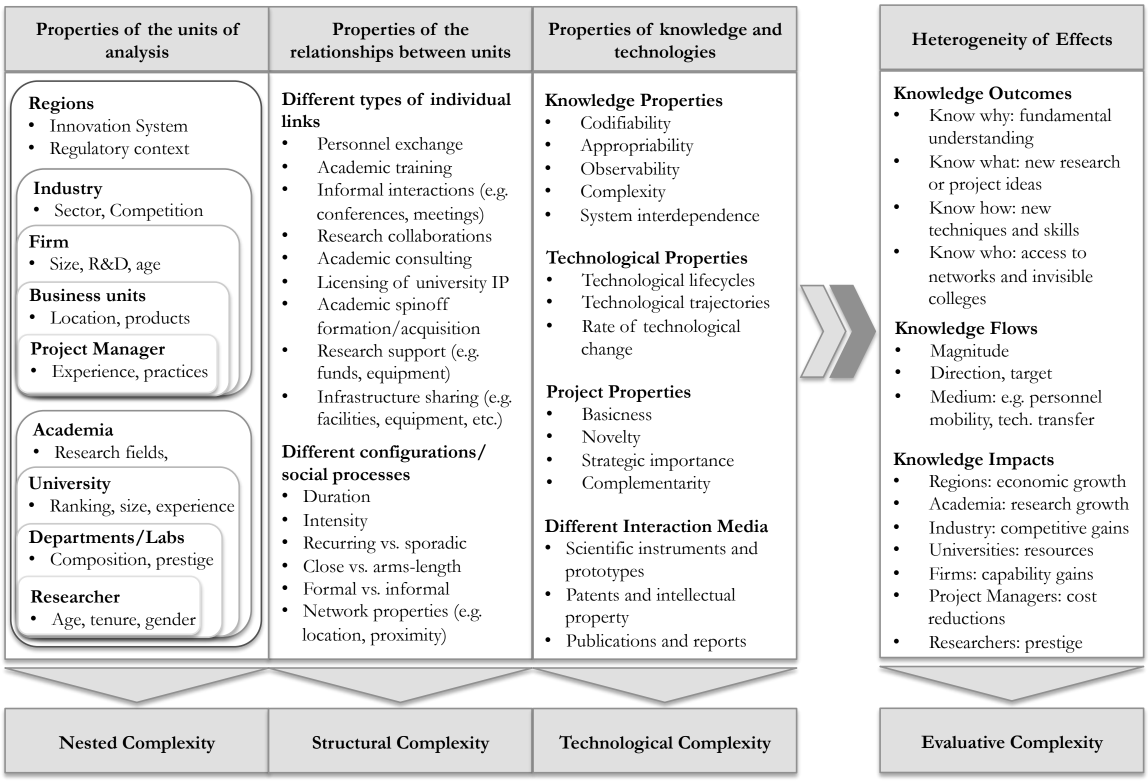

FIGURE 1: INTEGRATIVE FRAMEWORK FOR ORGANIZING RESEARCH ON INDUSTRY-UNIVERSITY LINKS

The third column shows properties of knowledge and technologies that affect industry-university relationships. Most of the existing literature has concentrated on tacit knowledge, arguing that frequent personal interactions are needed for transferring this type of knowledge [25, 26]. However, this is only one dimension of knowledge that affects industry-university relationships. In Section 2.4 we expand on the different technological and project attributes that influence the formation and management of an industry-university relationship.

The fourth column shows that industry-university relationships have different effects on the various stakeholders in the first column who value different aspects of the relationships and measure success in different ways. In Section 2.5 we describe how regions, firms and universities evaluate the impacts of industry-university relationships

2.2. REGIONAL, INDUSTRIAL AND ACADEMIC DETERMINANTS OF INDUSTRY-UNIVERSITY RELATIONSHIPS

Figure 2 summarizes the most relevant attributes that determine the formation and evolution of industry-university relationships. The specific importance of these attributes depends on the vantage point of the players. We thus distinguished between regional, industrial and academic attributes, and organized them according to three levels of analysis. The purpose of this figure is to illustrate the increased fragmentation of the literature.

	Macro attributes	Meso attributes	Micro attributes
Regional	**Development Stage** • Knowledge stocks • Social and cultural norms • Innovation infrastructure (e.g. R&D labs, licensing offices, science parks)	**Regulatory Context** • Legal framework (e.g. IP regime) • Public research support • Diversity of funding agencies	**Innovation System** • Economic context • Industrial clusters • University networks • Regional R&D expenditures
Industrial	**Industrial Structure** • Industrial sector • Industry lifecycle • Level of competition • Technological opportunities	**Firm Structure** • Firm age • Firm size • Absorptive capacity • Ownership structure • Geographic location • Organizational form • Social capital	**Organizational Behavior** • Technological openness • Search routines • Hiring routines • Experience • Strategy • Managerial practices • Rewards structure
Academic	**University Characteristics** • University Mission • Research orientation • Internal policies • Size • Supporting organizations • Prestige (e.g. ranking) • Research resources	**Academic Department** • Prestige (e.g. ranking) • Research resources • Academic field • Diversity of research teams	**Academic Researcher** • Age • Gender • Academic Status • Experience • Social capital • Research field • Teaching obligations

FIGURE 2: DETERMINANTS OF INDUTRY-UNIVERSITY LINKS

REGIONAL DETERMINANTS

At the macro-level, a region's development stage has been described in the literature as an important factor affecting the formation of industry-university links [27, 28]. Mueller, for example, found that accumulated research investments of firms and universities were important antecedents for industry-university relationships [27]. This is why industry-university relationships have traditionally been limited in regions with low levels of research investments, as in developing nations [28].

Industry-university relationships have been shaped over time by cultural norms and social trends. Hatakenaka described how the student unrest of the late 1960s negatively affected the formation of industry-university collaborations in Japan because students protested against the perceived corporate control of universities [29]. Owen-Smith et al., found that industry-university linkages in the European biotechnology sector have lagged when compared to their US counterparts because of legal restrictions that prevented faculty involvement with commercial organizations and because of cultural resistance from academics against involvement with industry in response to alleged privatization of public science [30].

Other studies have analyzed the regional network of innovation-supporting institutions to facilitate industry-university interactions. Etzkowitz, et al., found that incubators helped in the diffusion of knowledge between industry and university in the early stages of the regional innovation system of Linköping, Sweden [31]. Owen-Smith et al., found that the heterogeneity of public research organizations in the US, including universities, research hospitals, government laboratories, and NGOs, was instrumental for the growth of the biotechnology industry [30]. In contrast, the European innovation system was composed of a narrower set of research organizations that were less interconnected than their US counterparts [30], hindering the development of the European biotechnology sector. The diversity of innovation-supporting organizations and the network structure they adopt are therefore two important elements for explaining the formation of industry-university links.

Industry-university relationships are also affected by the regulatory context of the region. Lynskey found that growth of the biotechnology sector in Japan coincided with several institutional and legal changes during the mid 1990s, including the passing of different pieces of legislation to promote industry-university relationships and to facilitate technology transfer through the creation of technology licensing organizations (TLOs) [32]. In the US, more than eight pieces of legislation were passed between 1980 and 1993 to promote industry-university relationship [8]. The most important piece is perhaps the Bayh-Dole Act, which allowed universities to own the intellectual property generated from federally funded research. As a result, there has been a steady increase in the number of patents generated by universities in the US [33].

Availability of public research funds has been shown to positively affect industry-university relationships. Segarra-Blasco and Arauzo-Carod found that access to regional, national, and European funds enhanced the cooperation between firms and universities in Spain [34]. De Fuentes and Dutrenit found a positive relationship between fiscal incentives for corporate R&D and the interaction between firms and public research organizations in Mexico [28]. Busom and Fernandez-Ribas found that the availability of R&D subsidies and public support increased a firm's probability of forming an R&D partnership with a university [35].

In addition to availability of funds, Owen-Smith et al., found that diversity of funding sources is important for fostering industry-university links [30]. An advantage of the US system was that funds provided by NIH were complemented by multiple other funding sources such as NGOs and private firms, which utilized different evaluation mechanisms for allocating research grants [30]. In Europe, funding mechanisms were centralized at a national level, which negatively affected the formation of a critical research mass, especially in smaller countries.

At the micro level, it is found that differences in a region's innovation system also affect the formation and evolution of industry-university links [36]. Within such systems, firms and universities interact and build networks that reinforce interdependence and thus play an important role in the creation and diffusion of technology [37]. To reap the benefits of university research, regions need a strong university research base, a strong industrial research base, and mechanisms to foster industry-university knowledge flow.

Several authors have analyzed how a regional innovation system affects formation of an industry-university relationship. Asheim and Coenen found the role of the innovation system varies according to the technological base of the industry [36]. For industries in which science was an important source of innovation, a strong regional research infrastructure was indispensable for nurturing these science-based industrial clusters and embedding those firms in the region. Science-based industries (e.g. biotech, IT) rely on ties with local universities for accessing researchers and recruiting trained graduate students. For production-intensive industries (e.g. furniture, food), however, inter-firm knowledge transfer played a greater role than universities [36]. Production-intensive industries relied mainly on technical schools and the regional network of suppliers and subcontractors for their innovation efforts.

A final regional attribute explaining the formation of industry-university relationships is economic context and the literature is ambiguous on the direction of the effect. Eisenhardt and Schoonhoven showed that when firms are in difficult market situations, they build more external alliances [21]. In difficult market situations, university alliances can be a means to build legitimacy. The alliances can contribute to the firm's strategy by sharing risks or critical resources (technical equipment, staff, or even research funds). Other authors have found that during economic crises, firms reduce their investment in innovation, and shift R&D resources towards short-term, low-risk projects [38], and away from the generally long-term university research.

Industrial Determinants

Considerable research has been done on how the industrial sector affects the formation of industry-university relationships. Industrial sectors differ in terms of the knowledge sources relevant for advancing their products and processes, the rate of technological change, and the levels of R&D expenditures [39].

Three factors help to explain differences between industrial sectors. First is growth in demand for the industry's products and services. Second is the *technological appropriability*, that is, how much of the returns from R&D the innovator is capable of retaining [22]. This attribute depends on the strength of patents, the existing IP regime and the effectiveness of secrecy and/or first mover advantages. Third is the *technological opportunity*, that is, the productivity of R&D for the firm [22]. Some industries draw more heavily on scientific knowledge so universities are an important source for technological advancement, as with the pharmaceutical industry, which draws from biology. There are positive correlations between the *R&D intensity* of the industry (R&D/Sales), and the degree to which the industry draws from scientific research in their innovative activities [22, 39]. Other industries rely more on the technological advances of firms up and down their value chain, such as suppliers or distributors, with universities playing a secondary role. For example, the pulp and paper industry relies more on machinery manufacturers, and the semiconductor industry relies on equipment suppliers. A third group of industries relies on their past R&D investments as a source of technological advance (e.g. the motor vehicle industry) [39].

At the firm level of analysis, the most important factor in the formation of an industry-university relationship is the firm's *absorptive capacity*, the ability to recognize the value of external knowledge and to acquire and integrate that knowledge towards commercial ends [22]. The absorptive capacity has been measured in terms of the firm's R&D intensity (R&D/Sales), and several studies have shown a positive relationship between R&D intensity and the degree to which firms draw from university research for their innovative activities [22, 28, 40].

Firms with higher absorptive capacity are better able to benefit from university research [41], but for absorptive capacity to be effective, there needs to be a continuous investment and commitment to R&D. Tether and Tajar found that firms that engaged in R&D continuously, rather than sporadically, were more likely to have university links [42]. Bishop et al., found that firms that invest in R&D continuously rather than intermittently obtained a wider range of benefits from university research [43].

A firm's absorptive capacity depends on the absorptive capacities of the employees [22], and another way to operationalize this construct is to calculate the ratio between R&D personnel and all firm personnel [41, 43]. Bishop et al., found a positive relationship between this ratio and the formation of industry-university links [43]. Tether and Tajar found that, in addition to a firm's R&D expenditures, the proportion of graduates in science and engineering in the workforce was positively correlated to the formation of a university link [42]

A firm's absorptive capacity is also influenced by its manufacturing base and organization [22], in other words, how R&D investments, R&D personnel, and manufacturing base are organized and combined [23]. Santoro and Chakrabarti, for example, found that firms that are hierarchical, centralized, and governed by rigid policies were less likely to engage in university cooperative research agreements than decentralized and flatter organizations [44]. Bercovitz and Feldman found that firms with centralized R&D labs invest more on university-based explorative research projects than firms with decentralized labs [13]. Veugelers found that external R&D collaborations only had positive effects when the firm had a formal full-time staffed R&D department [45]

The size of the firm, measured by the number of employees, also affects industry-university links. Veugelers and Cassiman found that size positively affects firm's decision to obtain knowledge from external sources, including universities [46]. Cohen et al., found that large firms benefit more from university research than small or medium firms [47]. Several authors have found positive relationships between firm size and industry-university cooperation [34, 35, 48]. Fritsch and Lukas found that the size of the firm is positively associated with the establishment of a university collaboration, but does not affect the subsequent number of collaborations [49]. Santoro and Chakrabarti found that large firms build university relationships around non-core technologies, whereas small firms build university relationships around their core technologies [44]. Bodas Fretias et al., found that small firms tend to rely more on informal contacts with university researchers rather than formalized agreements [50].

The age of the firm also affects the establishment of a university relationship. Cohen et al., found that startups benefit more from university research than older firms [47]. As industries mature, the focus of innovation shifts from product to processes, the rewards for radical innovations are reduced, products and processes become standardized, and specialized equipment manufacturers have a greater role on process improvements [51]. As industries mature, therefore, they invest less in internal R&D and consequently reduce their absorptive capacity for relating to universities.

Geographical location also plays a role in industry-university relationships. The general view is that geographic distance facilitates industry-university interactions, and that proximity is important when knowledge is complex or has a tacit dimension. Mansfield and Lee (1996), for example, found that the proportion of industry sponsored research received by universities within a 100 mile radius was more than twice the amount received by universities within a 100-1000 mile radius, and more than three times the funds allocated to universities more than 1000 miles apart [52].

The positive effects of proximity are found to be contingent on the type of knowledge being transferred, the type of research project, the quality of the university, the size of the firm, and the management practices of the firm. Laursen et al., observed that the importance of the geographical distance decreased when knowledge was codified into patents or articles [53]. Bishop et al., found that geographical proximity was only important for problem-solving projects [43]. Mansfield and Lee found that geographic proximity was important for applied R&D projects, and also for less prestigious universities [52]. Brostrom found that geographical proximity was relevant for short-term market-oriented R&D projects, but was less important for longer term projects because firms are able to work across distances and modularize projects [54]. Beise and Stahl found that proximity was more important for small firms and polytechnic institutions than for large firms and universities [55]. Finally, geographic proximity is only important if firms act upon the opportunity for increased face-to-face interactions they provide, however, there are other options of increasing these interactions that have little to do with geographic distance [56], such as relocating personnel [54].

A firm's position within a knowledge exchange network also affects the formation of a university relationship. Guiliani and Arza found that well-connected firms formed more university relationships, and that these relationships were more valuable for the firms [57].

The ownership structure of the firm has also been found to affect industry-university relationships, although the evidence is less conclusive on the directions of these effects. Tether, found that firms belonging to wider company groups were more likely to collaborate with universities [48]. Firms that belonged to a national group were found to be more likely to form a university relationship than foreign multinationals [34]. Other authors have seen the probability of forming a local university relationship reduced when the parent firm is from a foreign country [28, 58].

At a micro-level of analysis, the firm's organizational behavior also affects the formation of a university relationship. Firms that drew from a diverse pool of external knowledge sources such as clients, competitors, consultants, government laboratories, and trade associations, were more likely to use university knowledge than other firms [40]. Firms that are technologically open to external sources also form more university relationships [28, 40, 42].

A firm's past experience in university relationships can have an effect. Prior experience working with a university was seen to reduce the difficulties in acquiring and disseminating knowledge [5], and a firm's past experience in university collaborations was positively correlated to the outcomes of subsequent university projects [56].

Project management practices affect the success of industry-university relationships and Pertuze et al., described seven data driven best practices for increasing the impact of industry-university collaborations [56]. Santoro and Chakrabarti observed that managers who are technologically knowledgeable, capable of sensing market trends, and capable of bridging organizational boundaries serve an important role in mediating industry-university relationships [44]. Fritsch and Lukas found that manufacturing companies that have a gatekeeper, that is, a person that screens the environment for innovation opportunities, formed more research collaborations with public research institutions [49].

A final organizational attribute refers to the role of the firm's strategy on the formation and evolution of industry-university relationships. Existing literature has operationalized strategy as exploration or exploitation decision [43]; firms with R&D strategies geared towards exploratory research allocated a grater share of R&D funds to university projects and built deeper relationships with their university partners than firms with exploitative R&D strategies [13].

Academic Determinants

At the university level, the most important factor for explaining industrial relationships is the scientific field and the quality of research conducted at the university. Applied science universities have a higher propensity to engage in knowledge transfer activities with industry than institutes of basic sciences [59]. Some fields contribute to many industries (e.g. computer science), while others contribute to a narrow set of industries (e.g. geology) [60]. In terms of the quality of the research, higher ranked universities attract more industry R&D

than lower ranked universities [52], and the scientific quality of the university positively affects formation of industry links [60].

Other structural university characteristics affecting the formation of an industrial link are the size of the academic institution [59], the proportion of industry-funded research received by the institution [61, 62], and the university's experience in industrial relationships. Past experience positively affects the formation of subsequent industry links [59]. Examples are that the accumulated experience of the technology transfer office can positively affect the formation of academic startups [61] and that the patent stock of the university positively affects the patenting behavior of academics [63].

At the level of the university department, the academic prestige, the size of the department, the amount of research funds received by industry, and the past experience in university collaborations all positively affect the formation of industrial partnerships. Firms that collaborated with "top tier" departments benefited from a wide range of interactions, whereas "second-tier" were limited to specific problem solving interactions [43]. The size of the university department, measured in terms of the academic staff, also affects the formation of a university link [60]. D'este and Patel found that the amount of industry funds received by the department was positively correlated with the variety of interactions with industry [64], and the department's past experience was an important factor for forming new industrial relationships [60].

At a micro-level, there is a large literature on how different characteristics of the academic researcher affect the formation of an industrial relationship. Some authors state these individual characteristics are more important than the academic department or university characteristics for explaining the formation of an industrial relationship [64]. The most common characteristics analyzed in the literature are the scientific discipline of the researchers (e.g. applied sciences), demographic characteristics (e.g. age, gender, minority status), academic status (e.g. tenure, prestige), academic productivity (e.g. publications), funding sources (e.g. grants), and the researcher's social capital, and academic behavior [64-68].

Researchers from applied sciences are more likely to have positive attitudes towards research commercialization than researchers from basic or social sciences [65]. Academic researchers from engineering disciplines were more likely to engage in research collaborations than researchers from other disciplines [64].

In terms of demographics, research conducted at US universities shows that white male researchers interact more with industry than female or minority researchers [66]. In terms of age there are mixed results. It has been reported that younger researchers establish more industry-university linkages and have more positive attitudes towards industry relationships [28]. Others, however, indicate that young scientists are more concentrated in achieving tenure status, and thus academic entrepreneurship is observed mainly at later stages of the academic career. Positive relationships between the academic's tenure status and the probability of forming an industrial relationship have also been showed [66].

Bozeman and Gaughan found that both industrial and federal research grants positively affect the researcher's propensity to work with industry [68]. The number of industry grants received by an academic researcher positively affects their subsequent interactions with industry [66], which reinforces the role of prior experience on the formation of an industrial relationships.

Finally, recent studies have analyzed how the researcher's behavior affects the formation of an industrial relationship. High teaching obligations negatively affect the propensity of a researcher to engage in knowledge transfer activities with industry [59]. Researchers engaged in mentoring, that is, helping junior colleagues and graduate students are also more likely to work with industry and conduct research on industrial applications [67].

2.3. HETEROGENEITY OF INDUSTRY-UNIVERSITY LINKS

The literature describes more than 23 different types of individual links (reading scientific publications, informal contacts, licensing of university patents, funding or graduate students, hiring of graduates, research collaborations, staff mobility, consultancy, and the sharing of facilities, among others) [24]. Each of the individual links can be grouped and combined into different interaction processes [7, 24], but the observation is that not all the interaction processes are equally important. Informal contacts, personnel mobility, consulting, and research collaborations are more frequently used than patenting and spin-off creation [64], and it has been estimated that patents represented less than 10% of the knowledge transfers from MIT labs [69]. De Fuentes and Dutrenit found that different interaction processes yield different benefits for firms [28]; R&D collaborations were important for improving the firm's R&D capabilities and academic training, publications, and participation in conferences were important for improving the quality of company products and processes.

Schartinger et al., organized the individual links according to the degree to which they facilitate face-to-face contacts and transfer of tacit knowledge [60]. Bercovitz and Feldman distinguish between arms-length relationships (e.g. limited transactions) and multifaceted relationships; the latter was the preferred form of interaction for exploratory research projects [13].

Differences in the industrial sector also affect the types of links. The pharmaceutical industry relies more on university patents and open science publications, whereas the communication equipment industry relies more on personnel exchange with universities [47]. R&D intensive manufacturing industries utilize more research-based relationships with universities, whereas service industries rely more on personnel mobility and education-based university interactions [60]. The service sector less likely than the industrial sector to engage in research collaborations with universities [42, 48].

2.4. KNOWLEDGE AND TECHNOLOGY CHARACTERISTICS

The properties of the different technologies being studied affect the types of linkages firms and universities build, the governance structure of these linkages, and the technological trajectories that define the evolution of industries [30, 70], but few studies have analyzed industry-university relationships at the project level.

The most important attribute affecting industry-university relationships is tacit knowledge [25, 26]. When knowledge is tacit, it is important to facilitate personal interactions for transferring knowledge [7, 25, 56, 60]. Knowledge, however, can also be codified into patents, publications, and reports, as well as become embedded into scientific instruments and prototypes, which facilitates its diffusion across institutions. Scientific instrumentation has played a major role in the diffusion of basic research from US universities [71].

Winter distinguished between knowledge that was observable in use compared to not observable, knowledge that was simple compared to complex, and knowledge that was an element within a system compared to independent [72]. The knowledge properties described by Winter affect the speed of technology transfer, and the degree to which a capability can be communicated and understood between organizations [73].

The characteristics of the research project also affect industry-university interactions. Cassiman et al., for example, examined R&D projects analyzing (1) whether the project aimed at fundamental research, (2) the degree to which the project was novel for the firm's existing knowledge base, (3) the degree to which the firm will draw on that knowledge for building a competitive advantage, and (4) the degree to which the project's knowledge can be codified. When the goal of the project was to develop fundamental knowledge, firms were more likely to engage in university collaborations. However, when the firm felt the project was more strategic in nature, they preferred to engage in contract research with universities in order to assure full organizational control of the project. [70]

The lifecycle of the technology and the technological trajectory can also affect industry-university relationships. In the early years of the life science industry technological knowledge was concentrated and it was hard to acquire this knowledge without close interactions with the academic community [30]. As the field matured the knowledge became embedded into technologies and the skills needed to access these technologies became widely available. Biotechnology firms were thus able to produce and screen new molecular structures independent of academic collaborators. The need for close interactions with university centers declined, and the importance of accessing the academic knowledge network reduced.

As technologies mature, not only do they become more accessible, but they also become standardized facilitating their utilization by different players. Firms working on mature technologies thus have fewer incentives for forming a university relationship since they cannot fully capture the returns of those investments [74].

2.5. POSITIVE EFFECTS OF INDUSTRY-UNIVERSITY RELATIONSHIPS

In evaluating the contributions of industry-university relationships we need to take in consideration the different perspectives of the stakeholders involved these relationships. In the following section we review the main effects from the perspective of the regions and the firms and provide an overview of the effects of industry relationships on universities to motivate why universities are willing to engage in these interactions.

REGIONAL EFFECTS OF INDUSTRY-UNIVERSITY RELATIONSHIPS

Universities have been portrayed in the literature as "engines of growth" [40]. As shown in Figure 3, universities contribute to long-term economic development of the region by stimulating industrial R&D and entrepreneurship through three complementary institutional missions: teaching, research, and economic and social development [1, 27, 75].

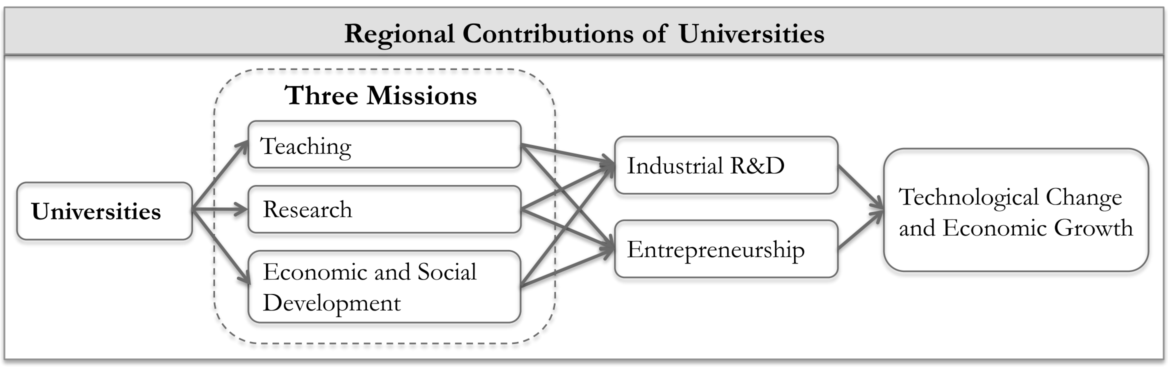

FIGURE 3: REGIONAL CONTRIBUTIONS OF UNIVERSITIES

Academic training has been described as the most important contributor to the economic growth of a region [39, 76]. Trained university graduates help to refresh the firm's R&D knowledge base [39] and contribute to entrepreneurship through the creation of new firms[1] [78]. University research also contributes to technological change and economic growth by stimulating industrial R&D [79] and by creating new industries such as biotechnology and information technologies [76]. Universities have also become more entrepreneurial about contributing to social and economic development [80]. There has been a growth in the patenting and licensing activity of universities, which are common forms of technology transfer to industry [33, 81]. As illustrated in Figure 3, the three institutional missions of universities contribute to the long-term development of regions.

EFFECTS OF UNIVERSITIES ON INDUSTRY

From an industrial perspective, it is important to distinguish the *outcomes* of the university interaction from the *impacts* they produce on the firm's competitiveness and productivity [56]. In Figure 4 we have organized the literature according to this distinction, observing there are multiple knowledge outcomes of potential impact for the firm.

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[1] It is estimated that if all companies created by living MIT alumni formed an independent

Industry Effects		
Knowledge Outcomes		**Competitive Impacts**
Know Why • Fundamental understanding of a particular phenomena *Know What* • New project or research ideas • Technical project assessment *Know How* • Solution to problems • Skillset improvement *Know Who* • Access to scientific networks and invisible colleges		• Introduce new products, processes, or services • Reduce costs and/or time in projects, products, or processes • Improve decision making processes • Increase firm capabilities

FIGURE 4: EFFECTS OF INDUSTRY-UNIVERSITY RELATIONSHIPS ON FIRMS

In terms of the outcomes of university relationships, firms can benefit from theories and fundamental understanding (know why), new research ideas and project assessments (know what), solutions to problems and capability improvements (know how), and access to scientific networks (know who), as shown in Figure 4. Bishop et al. surveyed 475 firms participating in industry-university collaborations in the UK and found that two-thirds of these firms recounted benefits from fundamental knowledge to improve their understanding of particular phenomena (i.e., know why) [43]. Cohen et al., surveyed 993 manufacturing firms in the US and found that universities contributed both to the generation of new research ideas (i.e., know what), and to the completion of existing R&D projects (i.e., know how) in equal measures [47]. Murray showed that the social capital of academic scientists helped biotechnology firms to become embedded in scientific networks that are critical for the firm's innovative performance (i.e., know who) [82].

In terms of the impacts of these knowledge outcomes, there is consensus that industry-university relationships contribute to the firm's competitiveness and productivity. Mansfield analyzed 76 large US firms asking how many of their products and processes introduced in a 10-year time frame could not have been made without recent academic research. The results showed that 11% of new products and 9% of new processes (accounting for 3% and 1% of these firms' sales respectively) could not have been made in the absence of academic research conducted within the last 15 years [2]. In 1998, Mansfield conducted a follow up study, using the same methodology, and found the contributions of academic research had increased, in that it was stated that 15% of new products and 11% of new processes (accounting for 5% of the firm's sales) could not have been developed in the absence of academic research [3]. International studies have obtained similar results. Beise and Stahl using the same methodology as Mansfield analyzed 2300 firms in Germany and found that approximately 9% of all products and innovations introduced by these firms received public research contributions, and that these innovations accounted for 5% of the firm's new products sales [55].

University relationships also contribute to improving existing company products and processes [43]. The data of De Fuentes and Dutrenit, who surveyed 325 Mexican firms participating in public funded R&D programs [28], showed that interactions between firms and public research institutes increased the firm's R&D capabilities and helped these firms improve the quality of existing products and processes.

Not all industrial sectors benefit in the same way from university relationships. Firms in the chemical industry were found to benefit from cost and risk reductions; firms from computer services benefited from the acquisition of technical knowledge; and firms from the agricultural sector benefited from technical assistance in complying with government regulations [41].

Effects of industry on universities

We can also distinguish between knowledge outcomes and scientific impacts of industrial relationships, as shown in Figure 5. Positive correlations were seen between industry linkages and the academic productivity of the university researcher [83]. Universities benefit from access to industrial knowledge, access to research funds and access to specialized industrial technology [59].

<table>
<tr><th colspan="3">University Effects</th></tr>
<tr>
<td>Knowledge Outcomes
Know Why
• Increased academic productivity
Know What
• Access to industrial knowledge
• New research project ideas
Know How
• Access to industrial equipment and technologies
Know Who
• Access to industrial networks and communities of practice</td>
<td>»</td>
<td>Scientific Impact
• Improved scientific impact
• Increased research funding
• Fellowships and employment opportunities for students
• Enhanced network of collaborators</td>
</tr>
</table>

FIGURE 5: EFFECTS OF INDUSTRY-UNIVERSITY RELATIONSHIPS ON UNIVERSITIES

Industry relationships can be aligned with the three organizational missions of universities. Industry researchers can become part-time professors or hold dual appointments between industry and university, contributing to the university's teaching. Industry also contributes to the research mission of universities through financial support of research [64, 84] and through ideas, industrial knowledge, technologies, and research materials [28]. Industry-university relationships contribute to the university's third mission of economic and social development by helping to commercialize university inventions and by becoming partners in technology based academic startups.

There is broad consensus in the literature that industry-university interactions produce positive knowledge outcomes for universities [59]. There is debate, however, on whether intellectual property restrictions have negative impacts on the diffusion of university knowledge. If relevant science is patented, the patent holder can monopolize and eventually suppress technological advance [85]. Studies have shown that the citation rate of scientific discoveries falls between 10 and 20 percent after the provision of a patent [86]. Further, when IP restrictions are lifted, there is an increase in the levels of follow on-research [87]. Murray et al., found that after the NIH negotiated an agreement to allow the academic community to access genetically engineered mice protected by IP belonging to DuPont, there was an increase in the levels of follow-on research, and in the diversity of downstream research paths [87]. Openness helped the expansion of research along a given technological trajectory, and led to more scientific experimentation along different technological paths [88]. Excessive IP enforcement at early stages of the research line can thus hamper innovation. There is ongoing discussion on how to improve the existing intellectual property regime, but that issue is beyond the scope of this dissertation.

In summary, the message of this chapter is that industry-university relationships have positive effects on regions, industries, and universities. The attributes described affecting industry-university relationships are not equally important and their importance depends on the vantage point of the stakeholder. The ever-growing number of attributes has caused an increased fragmentation in the literature. The overemphasis of the structural characteristics of the collaborating partners has clouded the path-dependent processes leading to the formation and evolution of an industry-university relationship, which is found to be the most important gap in the literature.

2.6. Literature Gap: Coevolution of industry-university links

Almost all studies in the literature have analyzed industry university relationships at a particular point of time. This approach fails to capture the dynamic nature of industry-university relationships [11]. If we analyzed industry-university relationships over the lifecycle of the firm, we would observe a dynamic behavior different than inferred from the previous sections. In particular, industry-university relationships are inserted in a dynamic environment and we expect them to coevolve [89].

We found only four articles that have analyzed industry-university relationships from coevolutionary perspective. In describing the process of how small Japanese firms transitioned from contract services and auxiliary technologies to higher positions in the value chain Lynskey analyzed the coevolution of biotechnology firms and the Japanese innovation system [32]. As firms moved up the value chain, their ties with academic institutions and with other firms intensified, several new academic startups were formed, and new institutions such as technology transfer offices were created.

Chaminade and Vang analyzed the coevolution of small and medium enterprises (SMEs) from the IT sector and the regional innovation system (RIS) of Bangalore, India [90]. They described how SMEs transitioned from being low-cost service providers to knowledge-driven positions in the value chain, and how Bangalore's RIS was upgraded in response to this transition. As these SMEs began accumulating technical and human capital, they began forming strong and diverse linkages with Bangalore's university system, home of some of India's best educational and research institutions. New institutions also emerged to support these industry-university interactions and to foster technology transfer after the system gained critical mass.

Owen-Smith et al., analyzed the evolution of industry-university relationships in the US and European life science sector [30]. In the US the heterogeneity of public research institutions, funding sources, and small biotechnology firms conducting research across multiple areas allowed the development of an innovation network that allowed the industry to flourish. European biomedical networks, in contrast, were less diverse and the research conducted at public research institutions focused on a narrow set of therapeutic areas. The European life science industry thus evolved in a different trajectory and lagged behind their American counterparts.

Hatakenaka described how social demands and historical events defined the evolutionary trajectories of MIT, Cambridge University, and Tokyo University's industrial relationships [29]. WWII was an episode that marked the US, UK, and Japanese innovation systems in different ways. During the postwar period the US created several institutions such as the NSF to promote peacetime research, and there was an increase in industrial support of university research. On the other hand, after the war the Japanese university system became isolated from industry and this trend continued until the late 1980s [29].

The industry-university relationships described are characterized by path dependencies in that decisions taken in the past determine the landscape for future interactions. Japan and India industry's decision to move up the value chain triggered a transformation of the regional innovation system, and the emergence of new institutions to foster industry-university relationships. Similarly, the different starting points of the US and European innovation systems affected the diffusion of knowledge and the way the life science industry developed in the two regions.

To our knowledge, no studies have analyzed the coevolution of industry-university relationships from the perspective of changes in the strategy of participating firms. This is an important gap because university relationships are embedded within the firm's strategic portfolio, and thus coevolve with strategy and competitive dynamics [14]. This thesis addresses the gap through analysis of industry-university relationships in a dynamic sense, exploring both the origin of the relationship and its coevolution with the firm's strategy.

3. Research Question and Methodology

In this chapter we define the research question and describe the methodology used to analyze industry-university relationships coevolution. Specifically we:

- Define the research question
- Justify why a case study research design offered the best methodological fit to answer the research question,
- Present the nine firms examined and explain the selection criteria,
- Define the units of analysis for the case studies (firm strategy, technological priorities, people flows, and university networks),
- Explain the data sources used,
- Describe the data analysis protocol for the case studies and the techniques for cross-case analysis of the nine cases.

3.1. Research question

The literature review showed that industry-university relationships have not been analyzed in terms of the changes in a firm's strategy. This thesis thus seeks to answer the question:

- How do industry-university relationships coevolve with firm strategy?

As shown in Figure 6, the coevolution of a university relationship is the result of (1) the outcomes and impact of the relationship on firms and universities (inter-organizational changes), (2) the actions and reactions of each partner (intra-organizational changes), and (3) the environmental context including industrial, societal, and technological trends (extra-organizational changes) [91].

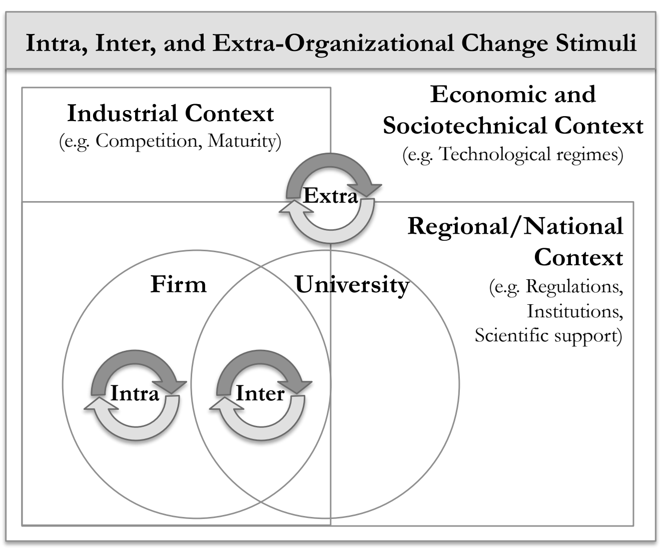

FIGURE 6: DYNAMIC CONTEXT OF INDUSTRY-UNIVERSITY RELATIONSHIPS

Given the multiplicity of factors potentially affecting industry-university relationships, we need a methodological approach that allows examining and preserving rich details about the context in which these relationships coevolve. Case studies were most appropriate.

3.2. CASE STUDY RESEARCH METHODOLOGY

Analyzing the coevolution of industry-university relationships requires data covering long periods (decades) [91], and we thus undertook a longitudinal[2] approach consisting of multiple case studies. Case studies have been used for modeling and assessing complex relationships [92] and have been found useful in illuminating decisions [93], both of which enable understanding how firms change strategy, and how these strategic changes affect university relationships.

To examine the interaction between two organizations it is important to use a methodology that highlights and preserves detail about the context [20]. Longitudinal case studies enable us to explore the historical, technological, and social contexts of industry-university relationships. The collection of qualitative evidence allows us to identify key process variables and to develop and refine our constructs.

3.3. FIRM SAMPLE DEFINITION

We focused on the forest products industry, an important renewable material and relevant economic sector for several countries. This is a mature industry with manufactured products that predate the emergence of forestry or chemical engineering as scientific fields. This industry provides a useful research setting to display the coevolution of industry-university relationships, because forest products firms have differed in their competitive strategies over time [15] and have forged different links with university partners.

We centered our study on three regions: Northern Europe, North America, and Southern Europe. Northern Europe has a long tradition in forest products with companies that have existed for several centuries. The North American forest products industry began growing in the 1850s, and have been world leaders in the greater part of the 20th century [15] although in the 1960s new entrants, Southern European manufacturers, in particular, have eroded Northern American and Northern European market shares. As in Figure 7, North American and Northern European producers led paper and paperboard exports in the 1960s, but by 2010, producers from Southern Europe, Asia, and South America gained a considerable market share. Increased competition triggers firms to modify their strategy [16], providing a background for answering the research question.

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[2] Longitudinal refers to the study of a case at different points in time

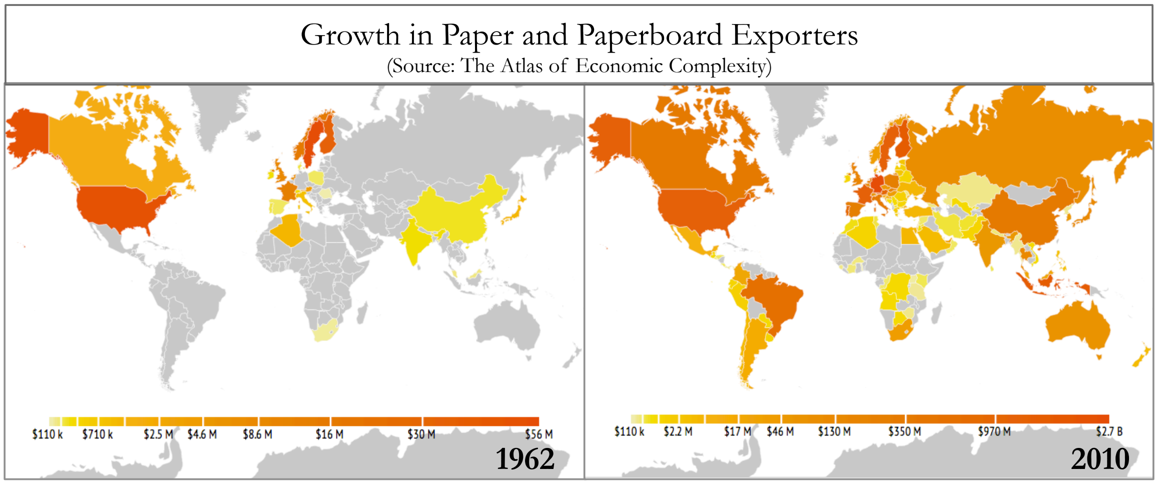

FIGURE 7: EVOLUTION IN PAPER AND PAPERBOARD EXPORTERS (1962-2010)

To analyze the coevolution of industry-university relationships, we need to find companies that have changed their business strategy over time. We also require companies with a track record in R&D, since the capacity of a firm to take advantage of external research depends on its absorptive capacity (see Chapter 2) [22]. Finding forest product companies with a track record in R&D is not easy as the industry has low R&D intensity [39]. We thus chose to concentrate on large firms, which are responsible for over 60% of the industrial R&D expenditures in Canada and Portugal, and over 80% of the industrial R&D expenditures in the United States, Sweden, and Finland [94]. Further, industry-sponsored research projects at universities are predominantly funded by large firms [13]. We also needed access to these company's corporate histories to understand the changes in the firm's strategy. Based on these three criteria of strategic change, R&D intensity and data access, we selected nine companies, three in each region.

Table 1 summarizes the characteristics of the firms in our dataset. The nine have diverged in their strategies as judged by the variation between their initial and current business lines.

TABLE 1: FIRM SAMPLE CHARACTERISTICS

	Company	Country	Est.	Initial Business	Current Businesses	Sales (US$ 2011)	R&D (US$ 2011)	R&D/ Sales
North America	International Paper	USA	1898	Pulp	Pulp, paper, packaging	$26 B	$13 M	0.05%
	Weyerhaeuser	USA	1900	Timber	Timber, pulp, paper, packaging, plywood, engineered woods	$6.2 B	$30 M	0.45%
	Domtar	Canada	1903	Chemicals	Paper, Personal Care	$5.6 B	$20 M*	<0.5%*
Southern Europe	Portucel Soporcel	Portugal	1953	Pulp	Pulp, Paper	$2 B	$7.6 M	0.38%
	Amorim	Portugal	1870	Cork stoppers	Cork stoppers, Raw & Composite materials, Building materials	$0.7 B	$2.8 M**	0.45%**
	Sonae Industria	Portugal	1959	Panels	Panels, decorative laminates, chemical resins	$1.8B	$2 M	0.11%
Northern Europe	SCA	Sweden	1929	Pulp	Personal Care, Tissue	$16 B	$125 M	0.79%
	StoraEnso	Finland	1896	Timber	Pulp, Paper, Timber, Packaging, Joinery, Engineered woods	$14.9 B	$106 M	0.7%
	UPM	Finland	1873	Pulp	Pulp, Paper, Timber, Plywood, Labels	$13.7 B	$68 M	0.5%

* Approximate values based on firm interview data
** 2008 values

3.4. FOUR EMBEDDED UNITS OF ANALYSIS

We have used four complementary units of analysis as summarized in Table 2. The table shows that changes in the firm's strategy were assessed by examining the firm's capability set and organizational form. This meant analyzing over time the firm's position in the value chain, its industrial base, and the location of the company's operations. Because measuring and statistically assessing industry-university relationships over time is complex given the immaterial character of knowledge flows [60], we decided not to focus on one type of industry-university relationships, but to analyze three complementary units of analysis: research priorities, people flows, and institutional networks. In the following sections we explain the different indicators used for analyzing the four units of analysis in Table 2.

TABLE 2: UNITS OF ANALYSIS AND INDICATORS

Concepts	Units of Analysis	Indicators
Strategic Change	1. Firm's capability and organizational form	• Changes in CEO • Changes in value chain position • Changes in the industrial base • Changes in geography of operations
University Relationships	2. Research priorities	• Technological areas of collaboration • Evolution in collaborations
	3. People flows	• R&D personnel academic and professional trajectories
	4. Institutional networks	• Geographic network of university partners

3.4.1. Strategic change

For each company in the sample, we created a database containing a chronology of strategic events such as mergers, acquisitions, expansion of operations, formation of strategic alliances, new products or services, and R&D activities [15, 95]. In this we benefited from work of other authors that have analyzed the historic trajectories of some of the firms in our dataset (e.g. [15]). These secondary sources of information were particularly useful for firms whose archival data was hard to obtain (most European firms fall in this category), and firms whose historical reports were written in languages not accessible for the author.

3.4.2. Research Priorities

Changes in the firm's technological priorities were analyzed using patents and publications records. Patent records were useful for understanding in which technological areas the company was active. Publication records allowed us to define in which of these technological areas the firms had collaborated with universities. The companies in the dataset have coauthored approximately 1,300 papers with universities. Each of these papers has been classified along the firm's value chain to determine the evolution of the firm's university collaborations and technological priorities.

3.4.3. People Flows

For each company, we distilled names of authors and inventors from corporate publications and patent records. We analyzed the academic and professional trajectories of each individual utilizing several data sources including online social media (e.g. LinkedIn), public university records (e.g. thesis repositories), and biography databases (e.g. Marquis Who's Who). We also checked for additional patents and publications made under different organizational names to infer past or post employers. About 900 names were examined in total of which about 600 corresponded to company employees.

Analyzing the flows of people between industry and university was useful for measuring transfer of technology between these two institutions. To our knowledge there is no other example of this approach in assessing industry-university links.

3.4.4. Institutional Networks

The firm's publication record was also used to map the evolution of the firm's university network. For each company in our dataset, we analyzed the publications from the Institute of Scientific Information's (ISI) Web of Science to determine whether it was written in collaboration with a university or a public research institution. We then created a second database linking each company to different university partners as a function of time.

Co-authoring is commonly used to infer industry-university relationships [96, 97], but this metric has limitations. Not all companies are equally prone to publish because of secrecy

[98]. Further, publications do not represent the full extent of a university's links to industry because there are roughly 20 different types of industry-university interactions that go beyond the joint publication of a paper [24]. It is also not evident that a joint publication is sufficient for inferring a relationship between the university and the industrial partner. Some articles have coauthors from multiple universities and it is unlikely that the company would have an ongoing relationship with all of these authors at the same time[3]. To address this last issue, we used two joint publications between the firm and the academic institution as the threshold.

An alternative quantitative metric for analyzing industry-university links would have been a patent analysis [30, 99], but the forest products companies in our dataset have few patents jointly granted with a university partner; Weyerhaeuser has one patent and International Paper has three patents with university partners.

Another alternative is surveys, which have been used in the literature for assessing industry-university relationships (see [100] for a review). They are useful for cross-sectional studies, but they are not well suited for longitudinal research because interviewees have difficulties in recalling events distant in time. We acknowledge the limitations of publication analysis, but this was judged the best metric for quantifying and mapping the diversity of university partners over time.

3.5. Data Sources

A challenge in analyzing industry-university interactions is to obtain fine-grained longitudinal data at the firm level [100], which is why we used on multiple data sources for our analysis. Figure 8 presents a summary of the different data sources and their connection to the four units of analysis from Section 3.4. As in the first column of the figure, we used company historical annual reports as the primary source for analyzing the evolution of company strategy. Management's letters to the shareholders were particularly useful for providing a longitudinal perspective on the view of the company's leadership about the present and future perspectives and the justifications for changing strategy. The data from the annual reports was supplemented with secondary sources of information, including journals, press articles, and company historical retrospectives to allow data triangulation [101].

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[3] The article *"Soils on exposed Sunda Shelf shaped biogeographic patterns in the equatorial forests of Southeast Asia"*, for example, was written by 28 different researchers, one of which was affiliated to one of the company's in our dataset. It is unlikely, however, that this researcher had a working relationship with all remanding 27 institutions.

Data Sources	Firm Strategy	Technological Priorities	University Network	People Flows
Articles		✔	✔	✔
Patents		✔		✔
Books	✔			
University Reports			✔	
Gov. Funded R&D Projects			✔	
Linkedin				✔
Internet				✔
Annual Reports	✔	✔	✔	
Moody's	✔			
Interviews	✔	✔		

FIGURE 8: DATA SOURCES AND USES

The second column of Figure 8, shows the changes in the firm's technological priorities. We analyzed these using patents and publication records plus annual reports and interviews as secondary sources. Major breakthroughs in company R&D were advertised in the annual reports, or identified by interviewees.

The firm's ISI publications were the primary data source for identifying the network of university partners. This data, as in the third column of Figure 8, was complemented by secondary sources such as university reports and data on government funded R&D projects. We also examined the university websites to find additional evidence of industry links, beyond the publication of a paper, which allowed us to enhance characterization of the firm's institutional relationships.

Finally, we traced professional and academic trajectories of R&D personnel utilizing public sources of information such as online media and thesis repositories as shown in the fourth column of Figure 8. For tracing younger generations of researchers, online data sources such as Linkedin were an effective tool. The professional career of older generation individuals was harder to trace, especially if the person had not patented or had coauthored under a different corporate or university name.

3.6. Data Analysis Protocol

Figure 9 shows the procedure for analyzing the companies in our dataset. The first step was to collect data and create a database containing a chronological description of relevant strategic events [15]. This enabled us to create individual company case studies that highlighted changes in their strategy along with the factors that prompted the different courses of action [102]. We divided each company's history into different periods by observing patterns of firm behavior [103]. We used changes in the CEO as an indicator of boundaries between strategic periods as it has been shown that succession of a CEO is well correlated with major transformations in the firm's capability set and organizational form [17, 104]. The individual case studies were complemented with interviews with senior managers at each one of these nine companies to assess whether we had adequately captured the strategic changes. When possible, we interviewed more than one person at each firm. In total, 24 people were interviewed with most of these interviews conducted on-site.

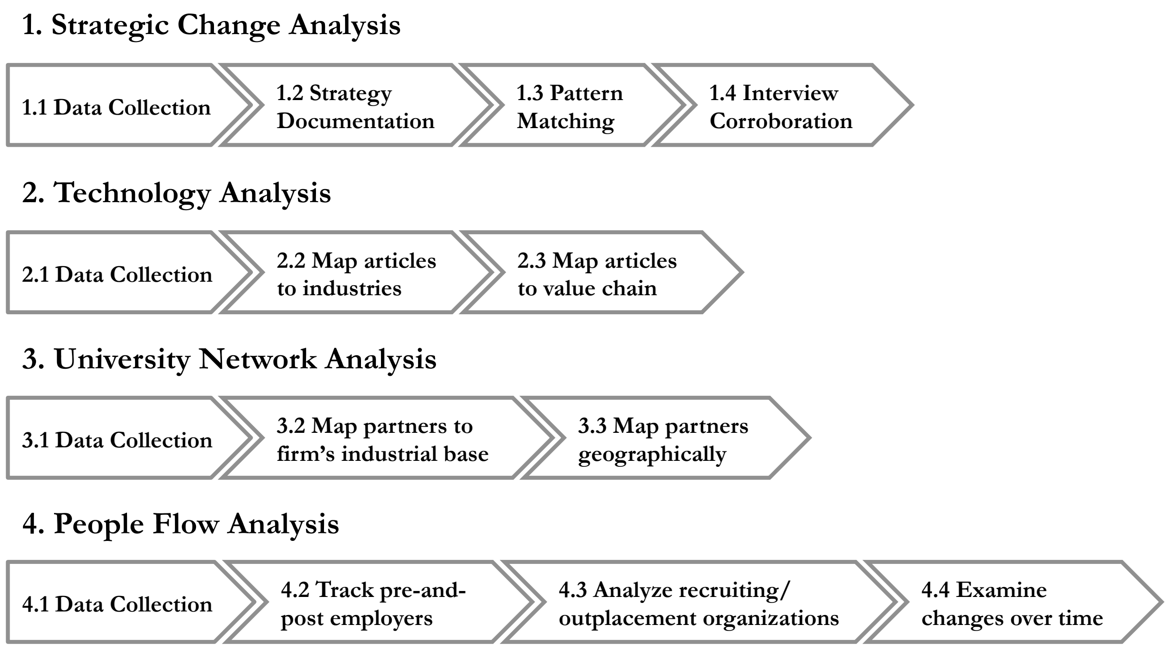


FIGURE 9: DATA ANALYSIS PROCEDURE

To define the evolution of the firm's technological priorities, we began by collecting data on the different products commercialized by these firms as shown in Figure 9. We organized this product information into different industries according to the North American Industry Classification System (NAICS). Figure 10 lists all the industrial sectors in which the firms in our dataset were active. This figure shows that, in addition to forest products, the firms in our dataset have diversified into aquaculture, shipbuilding, and other non-related industries. We have mapped the different articles published by firms, in collaboration with universities, into the different industrial sectors listed in Figure 10.

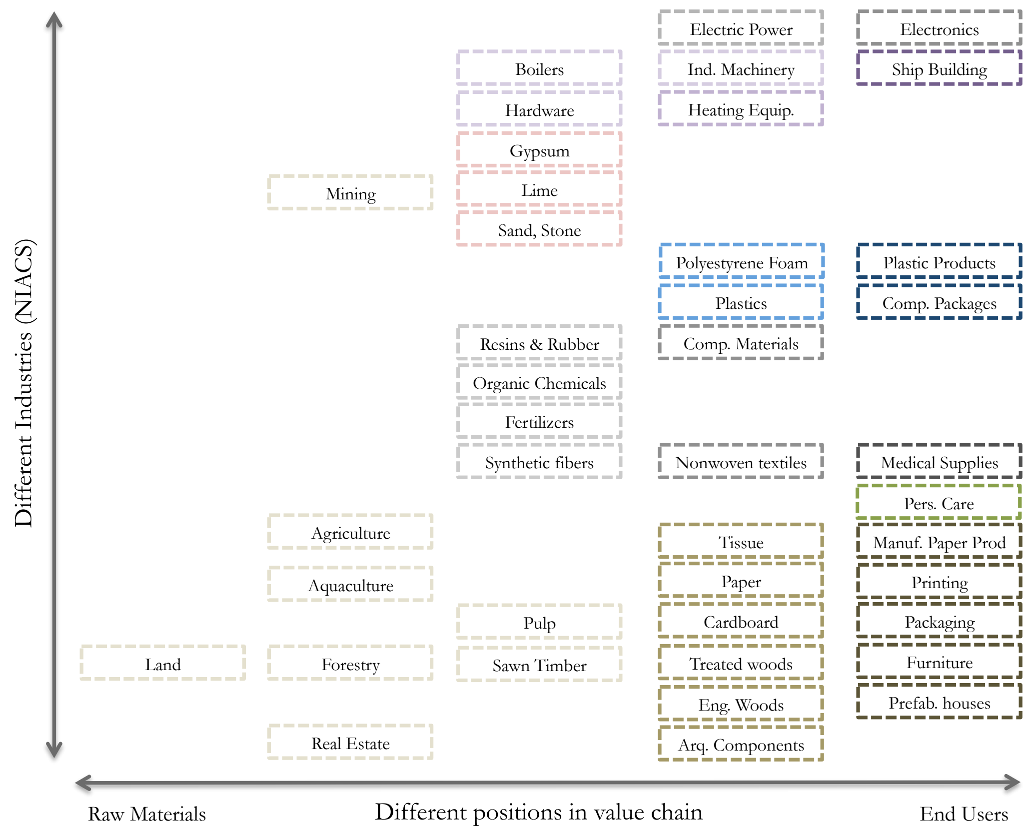


FIGURE 10: DIFFERNET INDUSTRIES AND POSITIONS IN THE VALUE CHAIN OCCUPIED BY THE FIRMS

For each industrial sector in which the company had publications, we mapped the individual publications to specific segments of the value chain. As illustration, we distinguish between articles aimed at improving forestry conditions from articles aimed at improving different pulping technologies. Figure 11 is the template utilized for mapping articles into the different segments of the pulp and paper value chain. Other templates were created to assess industry-university interactions along the value chain of different industries.

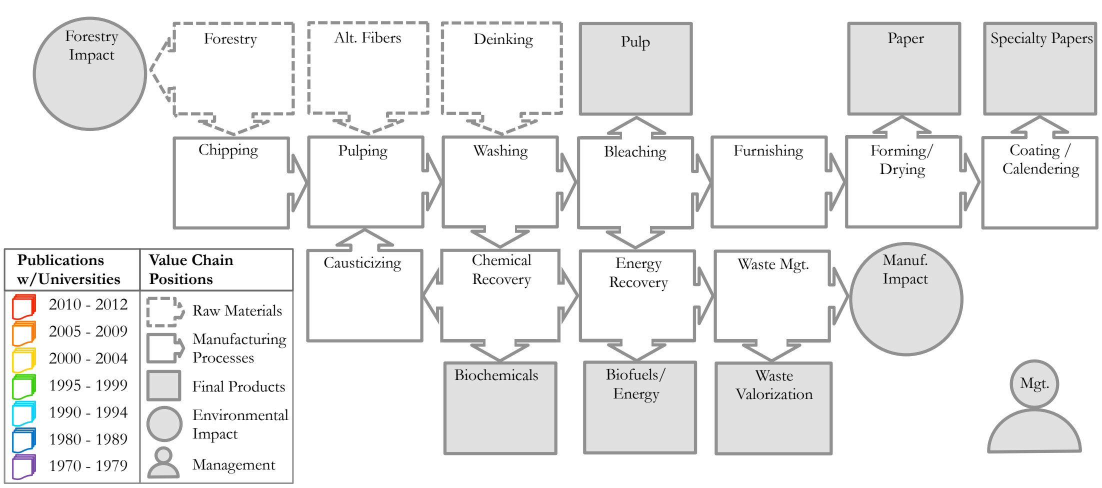


FIGURE 11: PULP AND PAPER VALUE CHAIN

Mapping the individual publications to specific value chain segments provides fine-grained longitudinal information on which technologies the companies had collaborated with universities, and how these research interests evolved.

As in Figure 9, to analyze the evolution of the university network we mapped university partners to the different research or production facilities of the firm and used Google Maps to visualize connections between coauthors. We built a network with links proportional to the number of publication between each partner, and we colored those links according to the first year of publication. The result was a graphical representation of how the firm's university network had evolved over time.

People flows between the firms and the universities have been tracked utilizing public sources of information. As given in Figure 9, we retrieved biographic information including academic training (e.g. universities attended, field of study, degrees) and also data on the employees' professional careers. This allowed us to examine the evolution, in the size and composition, of the firm's R&D personnel. It also allowed us to assess the effects of the firms hiring routines and the role of the employee's personal network on the formation of industry-university relationships.

A final aspect was conducting a meta-level analysis across cases. This involved analyzing the qualitative evidence compiled in the case studies, through process tracing techniques [92, 102, 105], to develop a model on how industry-university relationships coevolve with changes in the firm strategy. The findings from the cross-case analysis and the theoretical framework will be presented in Chapter 5.

4. THEORETICAL FRAMEWORK

This chapter provides a theoretical framework based on the strategic management literature and a set of propositions related to the research question: how do industry-university relationships coevolve with firm strategy.

4.1. INDUSTRY-UNIVERSITY RELATIONSHIPS AS A COUPLED SYSTEM

The concept of coupling is useful for describing how two organizations interact with each other [106]. Coupling between two organizations can be characterized along the two dimensions of distinctiveness and responsiveness [19, 106] (See Figure 12). Distinctiveness refers to the capacity of organizations to preserve their own identity and institutional boundaries [19, 107]. Responsiveness refers to how changes by one of the organizations affect the other [19, 20]. Based on this characterization, we can distinguish three different types of industry-university systems: decoupled, loosely coupled, and tightly coupled systems.

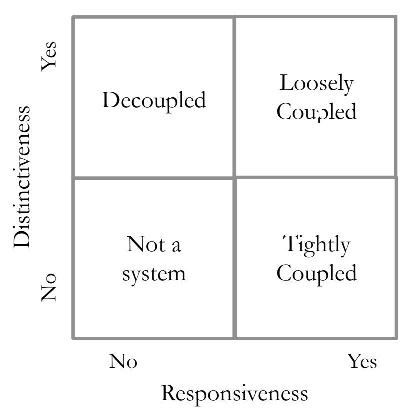


FIGURE 12: COUPLING STRENGTH OF INDUSTRY-UNIVERSITY SYSTEMS

In decoupled systems, firms and universities react to environmental stimuli distinctively, but not responsively. For example, the environmental movement of the 1970s prompted several firms we studied to invest in pollution control technologies. It also triggered the formation of environmental research centers at different universities. These two actions were distinctive and uncoordinated.

In tightly coupled systems, firms and universities react to environmental stimuli jointly and without distinctiveness. An illustration is an academic startup, which is similar to the academic research group from which it was spun-off. We would expect these two organizations to share a similar identity (i.e., not to be distinctive) and to have a high-degree of coordination between their actions. For example, changes in research funding affecting both the academic research group and the startup would prompt a coordinated response. Other tightly coupled systems are industry-funded research centers at universities. At these hybrid industry-university organizations, institutional boundaries are blurred and there are no distinctions between industry and university researchers who define and execute a common research agenda. Since there is also a high degree of coordination between the two we expect changes in one of the partners to significantly affect the other.

The Institute of Paper Chemistry is an example of a tightly coupled system. "By the mid-1980s, the Institute could no longer ignore the fact that the pulp and paper industry was in the midst of significant change. Foreign competition, the development of a world market, and a wave of mergers and consolidations all transformed the industry in numerous ways. These changes, in turn, affected the Institute, which depended on the industry for its survival" [108]. The Institute of Paper Chemistry consequently migrated from Appleton, WI to Atlanta, GA following the relocation of the US pulp and paper industry to the southern states.

In loosely coupled systems, firms and universities are responsive to each other, but preserve their own identity and distinctiveness. Most industry-university links fall in this category. Research collaborations, in which firms and universities work in coordination and preserve their organizational identity, are an example. A joint research project can result in a thesis, which is a distinctive university outcome, as well as a design concept for an industrial partner.

Framing industry-university relationships in terms of coupling allows us to understand which relationships are more likely to be affected by a change in the firm's strategy. In particular, for tightly coupled systems changes in firm strategy have an immediate and significant effect on the university partner, whereas for loosely coupled systems these effects might take time to manifest or be negligible.

4.2. Strategic Change as a Punctuated Equilibrium

Punctuated equilibrium theory gives a framework to examine a firm's strategic change process. The concept is that firms experience long periods of stability (equilibrium) followed by short periods of major transformation (revolutionary punctuations) [16, 17]. During periods of stability, firms adapt to internal and external stimuli through incremental changes that reinforce a pre-set strategic course, but do not materially alter the firm's core capabilities and organizational structure. During short periods of punctuated revolution, however, firms undergo fundamental transformations in their core capabilities and organizational structure, culminating with the definition of a new strategy and a new period of stability.

Punctuated revolutions produce unpredictable organizational outcomes [16]. Similar firms facing similar environmental conditions may opt to pursue different strategies, emphasizing different capabilities and organizational configurations after the transformation periods conclude [17].

We assume there are four possible outcomes of a punctuated revolution. A firm can expand or contract its capability set, and it can also fragment or consolidate its organizational form.

We label these strategies integration, diversification, internationalization, and focalization as in Figure 13.

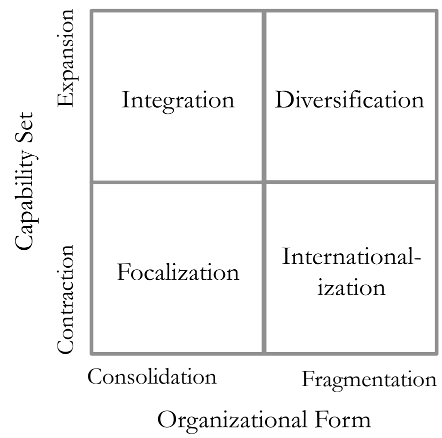


FIGURE 13: STRATEGIC OUTCOMES OF ORGANIZATIONAL CHANGE

Integration refers to the expansion of a firm's capability along an existing value chain. This usually takes the form of mergers or acquisition of the firm's suppliers or distributors or with some of the firm's competitors as a means to achieve more control over the value chain [109]. There is thus consolidation of different segments of the value chain under a new organizational form and expansion of the firm's capability set into new knowledge areas.

Diversification refers to the expansion of a firm into new businesses and industries. When firms diversify, they expand their capability set in different technological trajectories. As a result, firms usually create new divisions or technological units, which can cause fragmentation of the firm's internal environment.

Internationalization refers to the geographic expansion of a firm's manufacturing base, which fragments the firm's organizational form. The decision of a firm to expand internationally might come at the cost of contracting the firm's capability set, as firms need to free resources for financing the expansion.

Focalization refers to the contraction of a firm's capability set and the consolidation of the firm's organizational form, generally in the form of closure or divesture of existing company business lines, or withdrawal of operations from different countries.

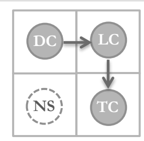
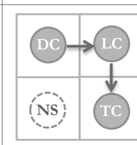
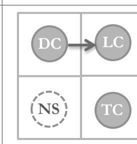
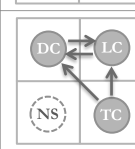
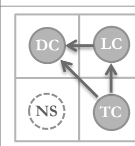
Framing strategic change as a punctuated equilibrium process has important implications for our analysis. We should be able to distinguish periods of stability punctuated by revolutions that lead to periods of different strategies (the four quadrants in Figure 13). In periods of stability we should observe incremental changes to the firm's capabilities and organizational configuration and a stable pattern of industry-university relationships. After periods of punctuated revolution, however, we expect to observe major changes in the firm's university relationships because the capacity of a firm to take advantage of external sources of knowledge depends on both the new capability set and the new organizational form adopted by the firm [23, 110]. These ideas are made more specific in Section 4.3.

4.3. Research Propositions

Punctuated equilibrium theory supposes that industry-university relationships change after periods of punctuated revolution. The organizational coupling framework explains that not all industry-university systems will be affected equally after a period of strategic change. If we combine these two streams of literature we can derive specific propositions contingent on both the coupling of the system and the type of strategy pursued by the firm.

Table 3 presents a summary of proposed effects of changes in firm strategy on industry university systems. In the left column the different strategic periods are presented. In the center columns we explain what happens to the firm's capability set and organizational form when firms adopt different strategies. The right column of the table illustrates the impacts of these strategic transitions on decoupled (DC), loosely coupled (LC) and tightly coupled (TC) industry-university systems. Specific propositions on how changes in strategy affect industry-university systems are discussed in the next sections.

TABLE 3: PROPOSED EFFECTS OF STRATEGIC CHANGE ON INDUSTRY-UNIVERSITY SYSTEMS

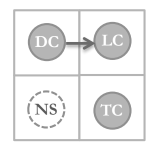
	Firm Capability Set	**Organizational Form**	**System Coevolution**
Stable Period	*Stable* • Unchanged recruiting and knowledge searching routines strengthen coupling	*Stable* • Tightly coupled organizational forms created to facilitate cross-boundary coordination	
Integration	*Expansion* • Technological depth can induce coupling of new, and strengthening of old systems	*Consolidation* • Complementarity among technological units can increase coupling strength	
Diversification	*Expansion* • Technological breadth can induce coupling of decoupled systems	*Fragmentation* • New units induce coupling of new university systems	
International-ization	*Contraction* • Capability reduction weakens tightly coupled systems	*Fragmentation* • Geographic proximity can induce coupling in new regions	
Focalization	*Contraction* • Capability reduction weakens tightly coupled systems and capability withdrawal leads to decoupling	*Consolidation* • Geographic withdrawal leads to decoupling	

4.3.1. Industry-University relationships in periods of stability

As discussed in Chapter 2, the capacity of a firm to take advantage of external sources of knowledge depends on the firm's existing capabilities and on its organizational form [23, 110]. In periods of strategic stability, these two organizational attributes change little and there is steady accumulation of knowledge in areas of strategic interest for the firm. The knowledge accumulation process is self-reinforcing: the accumulation of knowledge in the past allows more efficient accumulation in the future [110]. In the absence of revolutionary punctuations firms gradually increase their knowledge endowments, enhancing the firm's capability for searching and exploiting external sources of knowledge, and stimulating the establishment of a university link. This leads to Proposition 1:

Proposition 1:

- In periods of strategic stability decoupled industry-university systems become loosely coupled.



Different technological, behavioral, and organizational dynamics suggest that over time, and in the absence of revolutionary punctuations, loosely coupled industry-university systems will become tightly coupled. From a technological perspective, firms and universities can increase interactions and facilitate people flows across organizational boundaries to facilitate technology transfer. Through interactions, researchers develop a common set of practices, shared experiences, shorthand languages, and knowledge base, facilitating the creation and transfer of knowledge [111, 112]. Managers strengthen the coupling of an existing industry-university system as a means to facilitate knowledge transfer, especially when knowledge has a tacit dimension [26, 113, 114].

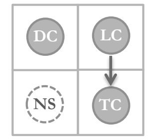
From a behavioral perspective, firms search for knowledge in the places where they have had past successes [115] and thus positive experiences with a university partner reinforce the firm's decision to strengthen that relationship.

The firm's recruiting routines also suggest that over time, loosely coupled systems will become tightly coupled. Firms recruit from universities that have developed expertise in knowledge areas relevant for the firm, and company personnel utilize their personal networks for finding collaboration partners [112]. Recruiting behavior thus reinforces preexisting university relationships, thus strengthening industry-university systems.

From an organizational perspective, firms develop hierarchical structures as a means to increase coordination [116]. Universities create technology transfer offices to coordinate their relationships with external firms and firms that increase their relationships with a university partner tend to develop new organizational forms for managing and coordinating these university relationships. Thus, over time, we would expect the emergence of hybrid industry-university organizations, characteristic of tightly coupled industry-university systems. This leads to Proposition 2:

PROPOSITION 2:

- The longer the period of strategic stability, the stronger the coupling of industry-university systems.



4.3.2. INDUSTRY UNIVERSITY RELATIONSHIPS AFTER PUNCTUATED REVOLUTIONS

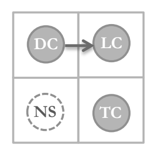
As described in Section 4.2, after periods of punctuated revolution firms modify their capability set and organizational form. For each one of the strategies shown in Figure 13 we have defined specific propositions depending on the prior state of the firm's university relationships.

When firms follow an integration strategy (upper-left quadrant in Figure 13), they expand their capability set and consolidate their organizational form. Increased technological depth can result in the formation of new university links and decoupled industry-university system can evolve to loosely coupled. For example, if a pulp and paper company integrates through the acquisition of forest lands, we expect to observe the formation of new relationships with forestry schools because the firm needs to acquire new knowledge of fertilization, plant breeding, and other forest management techniques.

When firms integrate new segments of the value chain through acquisitions, they can also inherit the university relationships and research laboratories of acquired companies thus forming (for the firm) new university relationships. This idea leads to Proposition 3:

PROPOSITION 3:

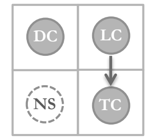
- Integration of new segments of the value chain can induce decoupled industry-university systems to become loosely coupled.



If a firm is working with universities on a particular area of the value chain, increased technological depth can result in new projects with the university partner and we expect strengthening of the system coupling. Universities with good pulp and paper research programs might, as an illustration, develop expertise on packaging technologies. If a pulp and paper firm integrates into packaging, it can increase the range of collaborations with that same university partner because firms search for knowledge in the places where they have had past successes [115] and the existence of previous relationships is positively correlated with outcomes of subsequent university projects [56]. This leads to Proposition 4:

Proposition 4:

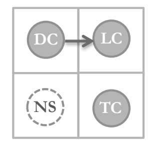
- Integration of new segments of the value chain can strengthen pre-existing industry-university systems.



When firms diversify (upper-right quadrant in Figure 13), they expand their capability set into different technological areas. Creation of new technological units and business lines can induce the coupling of industry-university systems in these new technological areas, particularly when the firm enters industries for which university research is a source of innovation. If a pulp and paper company diversifies into chemicals, we might see formation of new university connections in this new business area, again tending to increase industry-university system coupling. This leads to Proposition 5:

Proposition 5:

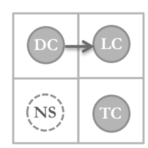
- Diversification into science based industries can induce decoupled industry-university systems to become loosely coupled



When firms internationalize (lower-right quadrant in Figure 13), they fragment their organizational form. From the perspective of the receiving country, the installation of a regional subsidiary can result in the formation of new university relationships. If a firm moves its manufacturing base into a new country, there might be formation of local university relationships for both recruiting and problem solving. Literature on organizational behavior shows that firms look for solutions close to where problems arise [115] and if a regional subsidiary faces manufacturing problems, company personnel will likely seek local experts [43]. This leads to Proposition 6:

Proposition 6:

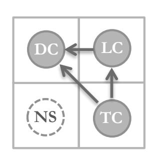
- Internationalization of the firm's manufacturing base can induce coupling of industry-university systems in new countries.



From the perspective of the home country, the creation of regional subsidiaries can weaken tightly coupled industry-university systems because different regions compete for the same company resources. In the most extreme case, if the company completely relocates the manufacturing base, this decouples the industry-university systems.

Proposition 7:

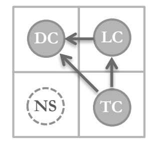
- Competition among international units can weaken pre-existing tightly coupled industry-university systems. As a limiting case offshoring of the firm's manufacturing base can lead to system decoupling.



Firms can also decide to contract their capability set and consolidate their organizational form following focalization (lower-left quadrant in Figure 13). When this occurs, tightly coupled industry-university systems can become decoupled after the firm closes or divests its technological units. If a firm exits a segment of the value chain, or sells a business division, it is unlikely that the firm will continue funding university research programs in these areas. The same trend can occur at a regional level. If the firm withdraws manufacturing operations from a country, it is likely they will decouple those regional industry-university systems. This leads to Proposition 8:

PROPOSITION 8:

- The reduction of the firm's capability set and/or the firm's geographic withdrawal can decouple industry-university systems.



5. Cross-case findings

In this chapter we provide a cross-case analysis of the individual firms in our dataset, to assess the validity of the theoretical framework and propositions described in Chapter 4. We:

- Demonstrate that punctuated equilibrium theory offers a good fit for explaining the strategic change process of forest products firms, and that changes at the CEO level punctuate different strategic periods (Section 5.1).
- Assess the eight propositions (Chapter 4) concerning the effects of changes in firm strategy on a firm's university relationships (Section 5.2).
- Provide a framework to illustrate how industry-university relationships coevolve with firm strategy (Section 5.3)

5.1. Strategic Change as a Punctuated Equilibrium

The historical trajectories of the nine firms in our dataset show periodic transitions between four generic strategies: Integration, Diversification, Internationalization, and Focalization. We map these strategies in Figure 14. The figure shows the strategies were pursued at different points in time and with different durations.

Integration refers to company actions aimed at achieving new positions within the current value chain. Examples are pulp companies entering the paper business (forward integration), companies acquiring forestlands to feed their mills (backward integration), or companies acquiring competitors (horizontal integration). As shown in yellow in Figure 14, integration was the most common strategy, especially in the early years of these firms [117].

Diversification refers to the expansion of a firm into new industries. Some of the companies in our dataset entered real estate, finance, chemical, and even the food industry, all of which are different from the company's original core focus on forest products. As shown in green in Figure 14, diversification was the least commonly used strategy.

The data in Figure 14 also gives representation of regional effects behind the firm's decision for diversification. For example, Portuguese firms Amorim and Sonae Industria diversified during the 1980s, taking advantage of the economic liberalization and privatizations in Portugal during that period. In North America, in contrast, diversification occurred earlier and was a common corporate strategy during the post World War II period[4]. For Finnish firms StoraEnso and UPM, diversification occurred even earlier, after Finland obtained its independence in 1917.

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[4] Rummelt (1982), for example, estimated that between 1949 and 1974, the proportion of US largest 500 industrial firms that were diversified increased from 30 to 63% 118. Rumelt, R.P., *Diversification Strategy and Profitability*. Strategic Management Journal, 1982. **3**(4): p. 359-369.

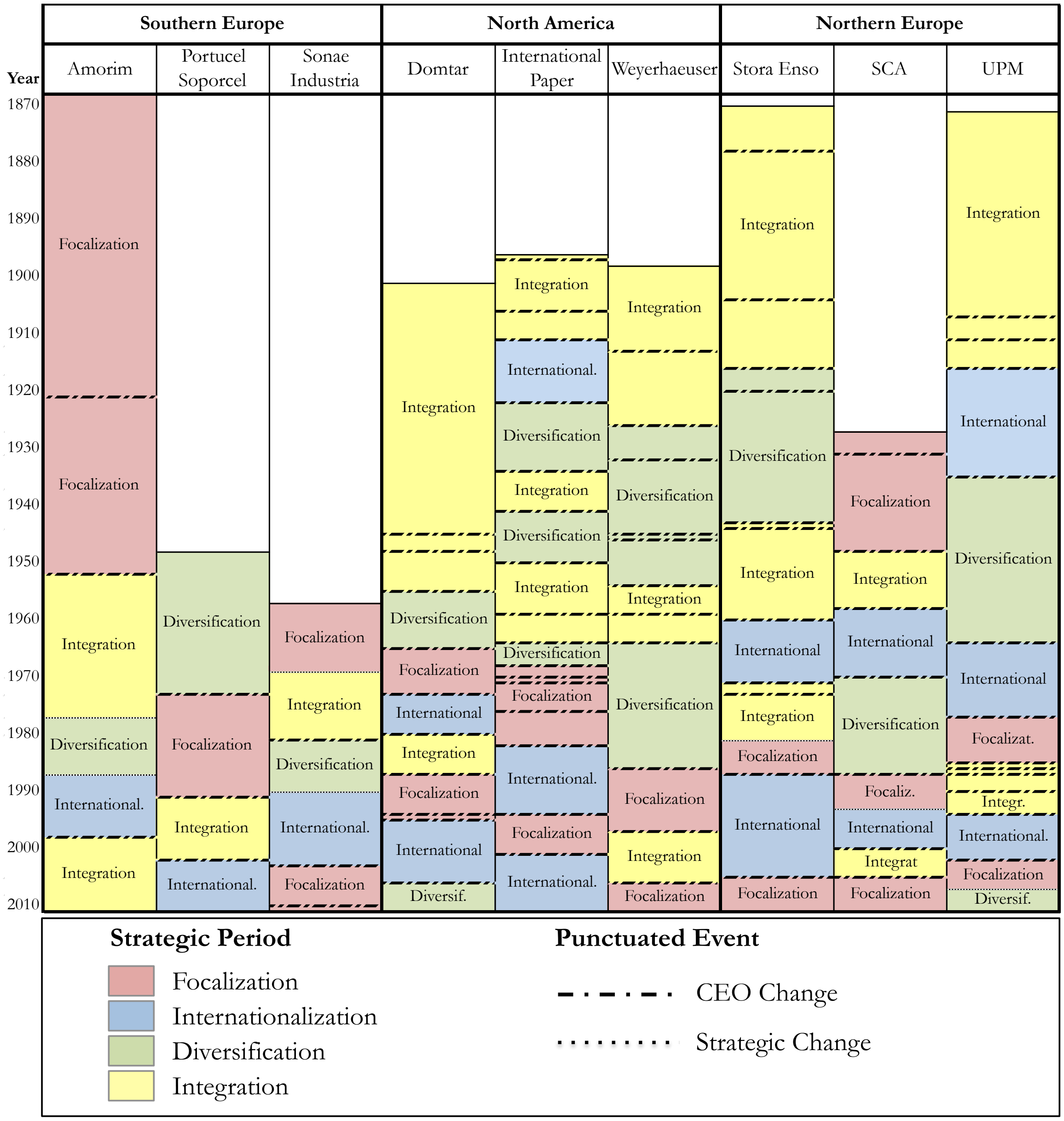


FIGURE 14: STRATEGIC PERIODS IN THE FOREST PRODUCTS INDUSTRY

Internationalization, the geographical expansion of the firm's manufacturing base, is indicated in blue in Figure 14. This strategy has become more common since the 1980s, coincident with the globalization of the economy and the trade liberalization of the regions under study. Several companies in our dataset have recently expanded their operations towards the southern hemisphere to benefit from faster tree growth and from emergent markets.

Focalization, which refers to actions aimed at narrowing the company's business base usually through divestures or downscaling operations, is in red in Figure 14. This strategy coincides with periods of economic downturn, a cyclical characteristic of capital-intensive industries [119]. The oil crisis of the 1970s, for example, increased production costs for the pulp and paper industry. As a result several companies in our dataset had to divest or close unprofitable units. More recently, the housing market crisis of 2007 has negatively affected some of these firms, which have closed or narrowed their business lines.

In Figure 14 we also observe that transitions between the four strategies tends to coincide with changes at the CEO level (marked by the dashed lines). Interviews with senior managers confirmed this observation; several of the interviewees spontaneously mentioned that changes in the CEO altered the firm's strategy, and in turn, altered the firm's university relationships. Below are some of the comments:

- "During the [1990s early 2000s] period, we had 3 different CEOs. The three CEOs were quite different and the pressures from their board were very different over that period of time. So we saw changes in the corporate university relationships based on CEOs [120]."
  Former R&D Manager, International Paper

- "A new wave of management came in and changed the strategic focus of the [sawmilling] business. Then another wave came in and decided to focus on pulp and paper as core businesses. So there was less strategic focus on making sawmilling a highly profitable business. It is a management decision [121]."
  Senior Manager, StoraEnso

- "When he became CEO, it was a period when [cork stoppers] were going down because of synthetic [corks]. Thus he decided to create a new R&D unit to find new and more value-added applications [for cork]."
  R&D Manager, Amorim

We did observe a few examples of changes in the company strategy without the change in the CEO (dotted lines), as well as examples of changes in CEO where a previously set strategic course was maintained. This was common in the initial years of some of these firms. Since the 1970s, however, changes at the CEO level have been a good proxy for inferring strategic change in these companies.

A final observation is that the firms in our dataset transitioned between the four strategies without a clear pattern. In Table 4, we summarized each firm's strategic transitions since the 1970s. The columns represent all possible combinations of strategic change; after internationalizing, for example, firms were almost equally likely to pursue a focalization or integration. The only strategy less likely to be chosen was diversification. This finding is consistent with the punctuated equilibrium theory, which states that organizational transformation occurs rapidly through revolutions that yield unpredictable organizational outcomes [16, 17]

TABLE 4: STRATEGIC TRANSITIONS OF FOREST PRODUCTS FIRMS (1970-2012)

	From	Diversification			Integration			Internationalization			Focalization		
	To	Integr.	Focal.	Inter.	Focal.	Inter.	Div.	Div.	Focal.	Integr.	Inter.	Integr.	Div.
Southern Europe	Amorim			1			1			1			
	Portucel Soporcel		1			1						1	
	Sonae Industria			1			1		1				
North America	Domtar				1			1		1	2		
	International Paper								1		2		
	Weyerhaeuser		1		1							1	
Northern Europe	Stora Enso				1				1	1	1		
	SCA		1		1			1		1	1		
	UPM					1			2			1	1
	Total	0	3	2	4	2	2	2	5	4	6	3	1

5.2. Proposition Assessment

In the following section we assess the 8 propositions by analyzing changes in the firm's research priorities, people flows between the firms and universities, and changes in the firm's network of university partners. We have conducted assessment of each of the companies in our dataset, but in this section we only report the most illustrative cases that support or falsify these propositions. A detailed examination of individual firms is given in the extended company case studies in the Appendix.

5.2.1. Industry-university relationships in stable periods

Punctuated equilibrium theory predicts that in periods of strategic stability, firms will adapt to internal and external stimuli through incremental changes that reinforce a pre-set strategic course [16, 17]. In stable periods we should thus observe incremental changes to the firm's capabilities and organizational configuration and a stable pattern of industry-university relationships so there is a gradual buildup of industry-university linkages as in the first two propositions:

Proposition 1:

- In periods of strategic stability decoupled industry-university systems become loosely coupled.

Proposition 2:

- The longer the period of strategic stability, the stronger the coupling of industry-university systems.

To assess proposition 1 and 2, we have relied on interviews with senior company managers who provided qualitative evidence on the formation and evolution of their university relationships. In most cases the managers described a gradual process, starting with small projects that were scaled-up and institutionalized over time. There was only one example of a firm that built a university relationship over a short period of time. For the other eight companies, university relationships emerged gradually and were strengthened over time, consistent with Propositions 1 and 2. The three cases below illustrate the point.

AMORIM'S MARKET ORIENTED RESEARCH GROUP

In 2007, Amorim, a Portuguese cork manufacturer, decided to create a research group to find new applications for cork. The creation of the group was triggered by use of synthetic corks, which threatened to disrupt the cork stopper market, the company's main business line. As explained by a company R&D manager, Amorim belonged to a traditional industry and had no R&D in this area. To address the situation, she began visiting universities with experience in cork and made presentations to faculty to explore possible areas for collaboration "I made the decision to visit them and said: we are open to work with you in cork, we have these areas of interest, but if you think of other areas or uses for cork, we are totally open to work with you"[122].

Out of these visits, university projects were born. Usually, these are small projects with go/no-go outcomes. If the project is successful, the company makes efforts to internalize the knowledge through the creation of a business unit. As explained by the manager, "before I start a big project, I do a go-no go smaller project. For example, if I want to see whether cork can be applied to fish food, I subcontract a small activity with [a] university. It is a shot, and we see how it goes. Once I have a good result, I go to the executive commission and explain what we have done, and why we think this project is interesting. I present the milestones leading to the proof-of-concept, which will put us with the knowledge to go to the market." The formation of a new university relationship thus starts with small projects (see Proposition 1).

UPM'S PROCESS FOR SELECTING UNIVERSITY PARTNERS

In 2008, UPM decided to concentrate their R&D efforts on microfibrils, biocomposites, biochemicals, and biofuels. These were new areas for the company, and UPM's R&D manager defined a "really precise process" for finding new university partners. First they conducted an Internet search looking for research groups with expertise in the areas. They analyzed where those groups were located, and narrowed the list to 5 or 10 potential partners to visit. The company then evaluated different aspects prior to making a final decision; such as whether the university group had enough resources to support the collaboration, and whether they were willing to work with the firm. The company then made a selection and signed an agreement with the university group. As explained by the R&D manager "[We] start with one project, if that is successful, then we can continue to bigger programs, so it's a continuous process of deepening the cooperation with the university" [123]. Strengthening of the industry-university relationship is thus a gradual process (see Proposition 2).

SCA/Mid-Sweden University as an exception to the gradualist rule

An exception to the gradualist approach in building university relationships was SCA's involvement with the Mid-Sweden University (MSU). This collaboration was the result of extraordinary circumstances in the Swedish higher education system. It was initiated by MSU's President Kari Marklund who convinced SCA's Executive VP Alf de Ruvo to establish an on-campus research center at MSU.

In 1993, two Swedish Colleges merged forming the Mid-Sweden College. This new institution wanted to achieve full university status; but to do so it first needed to achieve critical research mass. In 1994, the Swedish Ministers of Labor and Education decided to invest SEK 30 million for developing a new forest engineering research center in Sweden. MSU saw these funds as an opportunity to gain research mass and obtained SEK 10 millions from government to build a research center in Fiber Sciences. To leverage these funds, Kari Marklund contacted SCA's Executive Vice-President and said: "I have 10 millions, and if you invest 10 we have 20 millions. What can we do for that money?"[124]. SCA saw this as an opportunity to shift from traditional consortia research models and believed it could get a more creative and entrepreneurial atmosphere by having an on-campus presence at MSU [125]. In 1999, therefore, SCA agreed to establish an on-campus research center. In addition to the economic resources, SCA also transferred two senior researchers, who became full-time professors at MSU.

Before 1999, SCA had not had any publications in collaboration with MSU and had only recruited one person from this institution. From 1999, however, SCA coauthored 52 articles with MSU, recruited 5 researchers, and sent 3 SCA researchers to become full-time faculty at this university. MSU built a research program in Fiber Sciences that allowed obtaining full university status in 2005. Firms and universities can architect a tightly coupled industry-university system over a short period of time, but this was an extraordinary exception and not the norm.

5.2.2. Effects of Integration

When a firm grows by integrating new segments of the value chain, it will expand its capability set and consolidate its organizational form (Chapter 4). Increased technical depth can result in the formation of university relationships in new segments of the value chain. If the firm had already been working with a university, this technical depth can strengthen pre-existing university links. These ideas are captured in propositions 3 and 4:

Proposition 3:

- Integration of new segments of the value chain can induce decoupled industry-university systems to become loosely coupled.

PROPOSITION 4:

- Integration of new segments of the value chain can strengthen pre-existing industry-university systems.

To assess these two propositions, we analyzed each of the firm's publications with universities and organized them according to the different segments of the forest products industry value chain. Figure 15 shows the different value chain segments and final products manufactured by the firms in our dataset. The companies have been active in different segments of this value chain and have varied their product portfolio within these segments.

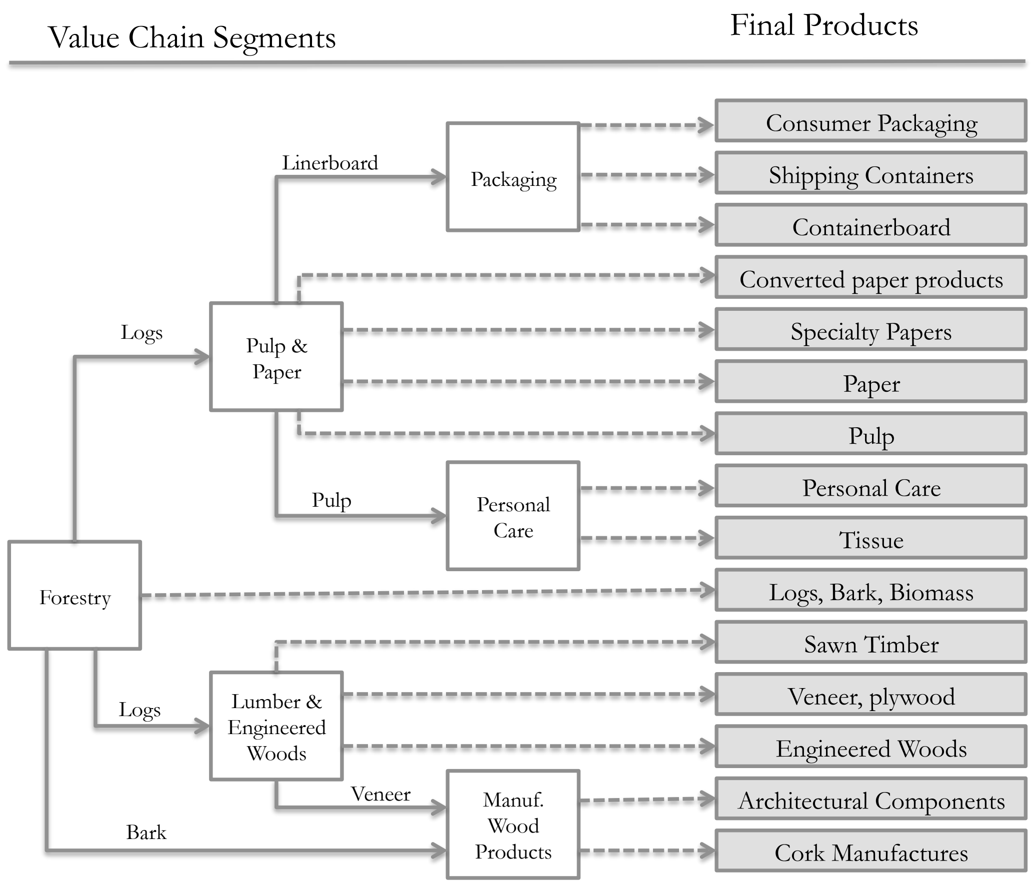


FIGURE 15: FOREST PRODUCTS VALUE CHAIN

The firms in our dataset coauthored 1,337 articles with universities, of which 91% (1,216) correspond to publications related to the forest products value chain. The rest of the articles (90) correspond to diversified business lines, and 31 articles could not be classified or corresponded to unrelated research interests of company employees. In Table 5 the forest-related articles are organized according to the different segments of the value chain.

Table 5 shows that firms have varied in terms of the degrees of vertical integration. Areas in green represent the different value chain segments in which the firms *are* active. Areas in red represent segments in which they *have* been active. Weyerhaeuser has been the most vertically integrated company and was active in all six segments of the value chain during the 1980s. Weyerhaeuser, however, exited the personal care industry in 1992 through the divesture of their diaper business unit, and is no longer active in the personal care business (as shown in red).

The Portuguese firms in the dataset have traditionally been niche players, concentrated on few segments of the value chain. They have thus established fewer university collaborations and are less integrated than their North American and Northern European counterparts.

TABLE 5: EFFECTS OF INTEGRATION ON INDUSTRY-UNIVERSITY CO-PUBLICATIONS (1970-2012)

		Forestry	Pulp & Paper	Packaging	Personal Care	Lumber & Eng. woods	Manuf. wood products	**Total**
Southern Europe	Amorim						2 (22%)	**2**
	Portucel Soporcel	25 (43%)	24 (41%)	1 (2%)				**50**
	Sonae Industria					1 (17%)	1 (17%)	**2**
North America	Domtar	6 (11%)	49 (88%)					**55**
	Int. Paper	106 (48%)	65 (30%)	4 (2%)		10 (5%)	1 (0%)	**186**
	Weyerhaeuser	343 (68%)	88 (17%)	5 (1%)		38 (7%)	4 (1%)	**478**
Northern Europe	SCA	1 (1%)	106 (64%)	18 (11%)	20 (12%)			**145**
	Stora Enso	18 (9%)	151 (77%)	13 (7%)		12 (6%)		**194**
	UPM	20 (17%)	84 (71%)					**104**
	Total	**519 (43%)**	**567 (46%)**	**41 (3%)**	**20 (2%)**	**61 (5%)**	**8 (1%)**	**1216**

Table 5 also shows that approximately 90% of all industry-university co-publications have been in the areas of forestry, pulp and paper, consistent with strong industry-university linkages between forestry science and the forestry/wood industry [60], and between chemical engineering and the pulp and paper industry [47, 60]. In contrast, university relationships have played a smaller role for packaging, personal care, lumber, and manufactured wood products.

When companies move into different segments of the value chain, we observe the formation of university collaborations in these new segments, as in Proposition 3. Similarly, we observe that the integration of new segments of the value chain did not diminish the firm's prior university relationships, as in Proposition 4. Firms continued working with their previous university partners and even increased the number of collaborations. The case study below illustrates the role of integration on industry-university relationships.

PORTUCEL'S INTEGRATION INTO PAPER PRODUCTION

In 2000, Portucel, a Portuguese manufacturer of Bleached Eucalyptus Pulps, decided to vertically integrate into paper production by acquiring INAPA, a paper manufacturer, and, in 2001, Soporcel, a Portuguese manufacturer of pulp and paper products. These acquisitions had consequences for the firm's university relationships.

Figure 16 shows the evolution of Portucel's publications with universities, which we organized according to the different processes involved in pulp and paper production. Prior to the integration into paper, Portucel's university relationships had been concentrated in forestry and pulp production (in green in Figure 16). This was confirmed by senior company managers "all the research was in the forestry side, and some in pulp. Nothing in paper" [126]. After the acquisitions, there were new university projects in paper production (e.g. paper formation, paper characterization). The integration of new segments of the value chain thus stimulated the formation of new university links, consistent with Proposition 3.

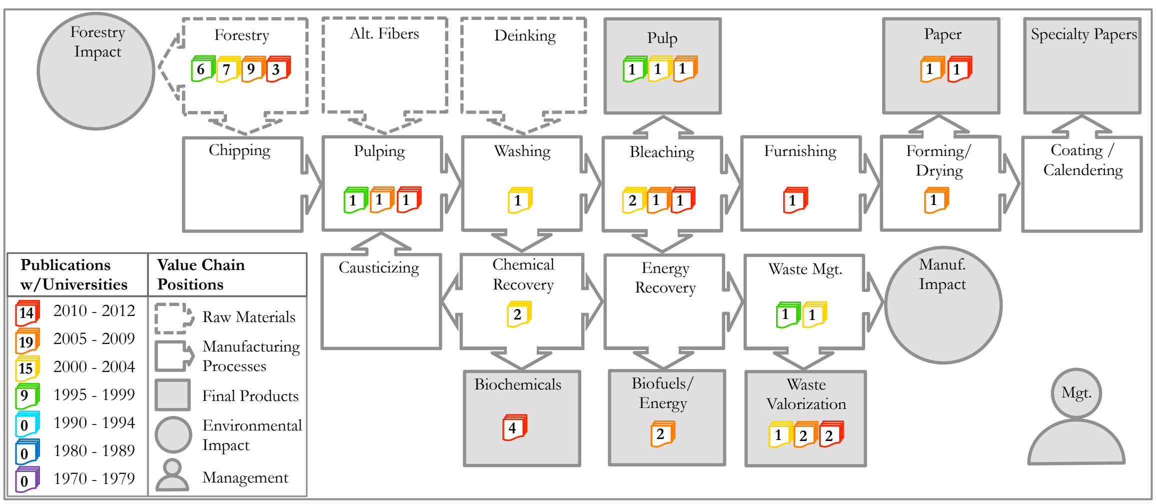


FIGURE 16: EVOLUTION OF PORTUCEL SOPORCEL'S UNIVERSITY CO-PUBLICATIONS

After the integration into paper production, Portucel continued working with its university partners, the University of Aveiro and the Univeristy of Coimbra on pulping technologies and environmental management. Soporcel had been working since the 1980s with the Higher Institute of Agronomy of the Technical University of Lisbon (ISA-UTL) on eucalyptus forestry. When Portucel began discussing the merger with Soporcel, they decided to merge the R&D labs of each company forming an independent research institute called RAIZ (Instituto de Investigação da Floresta e Papel). The Universities of Aveiro, Coimbra, and ISA-UTL became partners with Portucel and Soporcel in this new institute, with the universities holding 6% of the shares of RAIZ. This case shows that integration of new segments of the value chain can strengthen the firm's prior university relationships. The creation of the RAIZ institute as a tightly coupled industry-university system is consistent with Proposition 4.

5.2.3. Effects of Diversification

As discussed in Chapter 3, when firms expand their capability into new technological areas, we expect the formation of new university connections for these diversified business lines, as in Proposition 5:

Proposition 5:

- Diversification into science based industries can induce formerly decoupled industry-university systems to become loosely coupled

To assess this proposition, we utilized data on the different products commercialized by the firms, which we organized into different industries utilizing the North American Industry Classification System (NAICS). We then mapped each firm's publications in non-forest areas into these diversified businesses. The results are displayed in Table 6, which summarizes the university co-publications according to the industries in which the companies *have* (in green) or *had been* active (in red).

TABLE 6: EFFECTS OF DIVERSIFICATION ON INDUSTRY-UNIVERSITY CO-PUBLICATIONS (1970-2012)

		Southern Europe			North America			Northern Europe			
NAICS Codes	Industry	Amorim	Portucel Soporcel	Sonae Industria	Domtar	Int. Paper	Weyer-haeuser	SCA	Stora Enso	UPM	Diversified Business Lines
32519, 32521	Chemicals	4 (44%)	7 (12%)	4 (67%)	1 (2%)		6 (1%)	2 (1%)		3 (3%)	
32619, 32739	Wood-Plastic composites	2 (22%)	1 (2%)				3 (1%)				
21232, 21223	Mining, Oil & Gas						1 (0%)		1 (1%)		
33441	Electronics							4 (2%)		2 (2%)	
11114, 11115, 11132	Crop Production						8 (2%)				
32599	Photographic papers					17 (8%)					
32522	Textiles							3 (2%)		6 (5%)	
33911	Medical Supplies					2 (1%)		10 (6%)			
33324	Ind. Machinery							2 (1%)		1 (1%)	
22111	Electricity Generation										
53113	Real Estate										
51721	Telecoms.										
4441, 4442	Retail Trade										
11251	Aquaculture										
32311	Printing										
52231, 52211	Finance and Insurance										
Publications on diversified areas (% of total firm Pub.)		**6 (66%)**	**8 (14%)**	**4 (67%)**	**1 (2%)**	**19 (9%)**	**18 (4%)**	**21 (12%)**	**1 (1%)**	**12 (11%)**	**90**

Approximately 7% of all company publications with universities correspond to the diversified business lines identified in Table 6. This low number was not a surprise because since the 1970s few firms have pursued diversification (red predominates in Table 6). As discussed in Chapter 2, some industrial sectors draw more heavily on scientific knowledge and thus universities are an important source for technological advancement. Other sectors, however, rely more on the technological advances of firms up and down their value chain, so universities play a secondary role [39]. While some of the firms in our dataset diversified into real estate management, housing, and financial services, we did not observe new university publications in these areas, consistent with the finding that the service sector is less likely than the industrial sector to engage in research collaborations with universities [42, 48].

When firms diversified into science-based sectors, such as chemicals, wood-plastic composites, or medical supplies, as in Table 6, we observed both an increase in the number of publications in the new technological areas and an expansion in the network of university partners, consistent with Proposition 5. This expansion was usually result of three strategic actions that occurred in periods of diversification: (1) new company acquisitions, (2) new personnel hires, and (3) the training of company R&D personnel at new universities. The following case studies illustrate these ideas.

INTERNATIONAL PAPER'S ACQUISITIONS IN PHOTOGRAPHIC CHEMISTRY

During the late 1980s, International Paper began a series of acquisition of small startups in unrelated business lines including nonwoven textiles, oil and gas, and photographic papers, among others. In 1987 the company acquired Anitec Image Technology Corp, a producer of photographic papers and films for the graphics art industry, which had a research lab in Binghamton, NY. In 1989, the company acquired the Ilford Group a British producer of photographic paper, which had two research laboratories, one located in Mobberley, England, and the other in Fribourg, Switzerland. Figure 17 shows the number of publications in imaging science over time. After the acquisitions there was an increase in the number of company publications with universities in the field of imaging science.

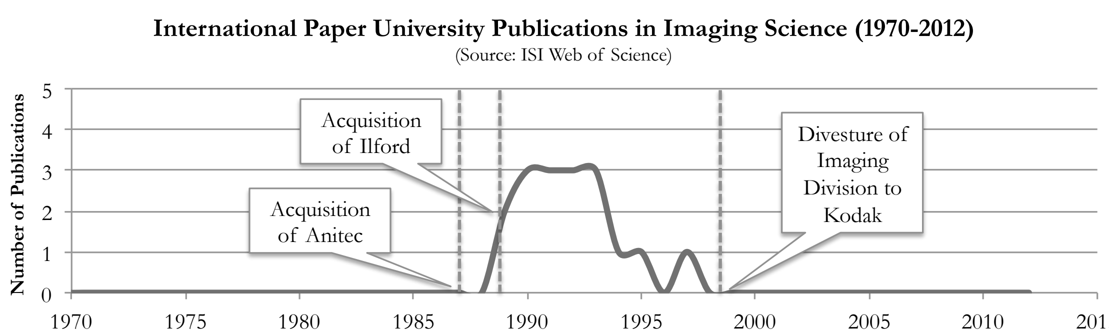


FIGURE 17: EVOLUTION OF INTERNATIONAL PAPER'S UNIVERSITY PUBLICATIONS IN IMAGING SCIENCE

International Paper also increased the diversity of university partners after these acquisitions. Figure 18, shows the evolution of this university network. New publications in the area of imaging science, with universities in Switzerland, England, and the United States, were authored by researchers of the recently acquired R&D labs. The message is that diversification of the firm into science-based industries can stimulate the coupling of new university systems (Proposition 5) and that company acquisitions can be an important vehicle behind the expansion of the firm's university network.

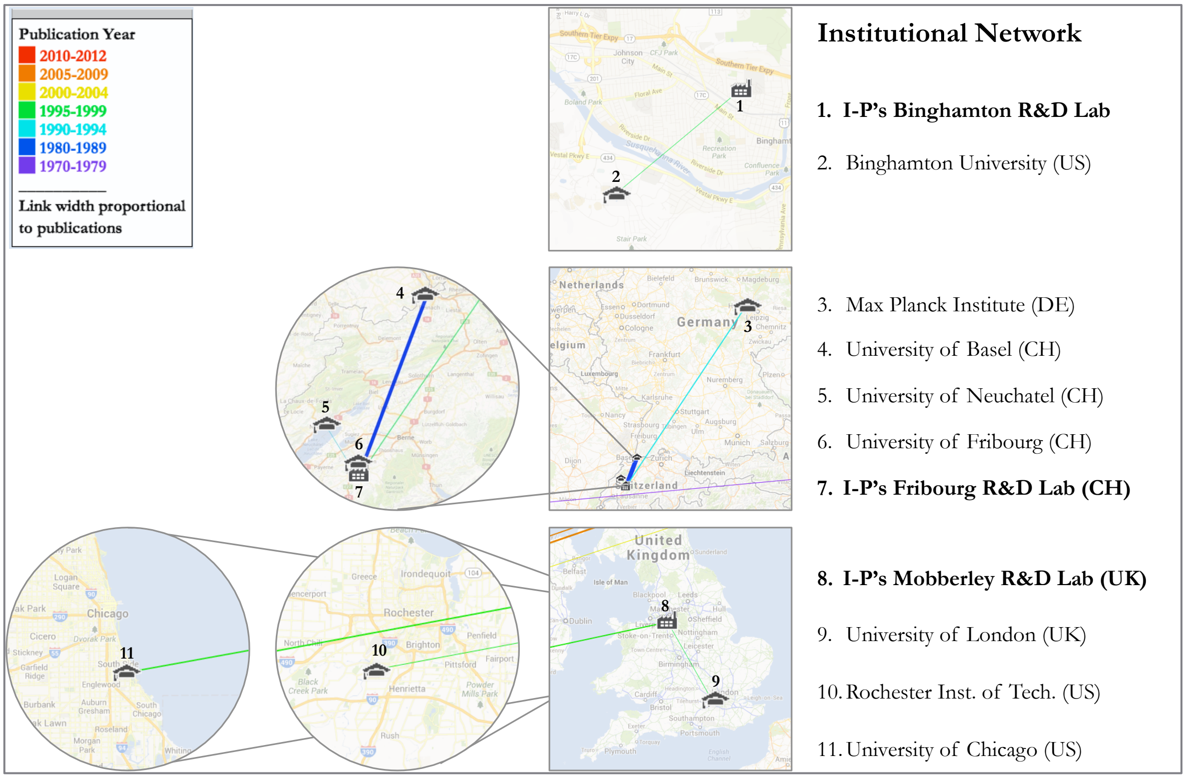


FIGURE 18: I-P'S INSTITUTIONAL NETWORK OF UNIVERSITY PARTNERS IN IMAGING SCIENCE

WEYERHAEUSER'S NEW RECRUITS IN FORESTRY MACHINERY

In 1966, George H. Weyerhaeuser became president of Weyerhaeuser and diversified the company [127]. During the 1970s the company entered different industries including real estate, gardening, machinery, and even the food industry, through salmon ranching and hydroponic lettuce growing. During this period we observed new publications stemming from some of these diversified business units. In the area of forest machinery Weyerhaeuser coauthored publications with new universities including UC Davis, Michigan State, and the University of Hawaii. Examination of the academic and professional trajectories of the authors revealed that recent hires were responsible for the expansion of the company's university network.

In 1976, Weyerhaeuser recruited Dr. Robert B. Fridley, the chairman of the Department of Agricultural Engineering at UC Davis to become manager of the Silviculture Operations Section of Weyerhaeuser's Raw Materials R&D Division. At Weyerhaeuser, Fridley continued working with his peers at UC Davis on non-destructive methods for fruit and vegetable harvesting. He also worked on the development of tree plantation and harvesting machinery. Fridley returned to UC Davis in 1986 where he helped setup a scholarship with the Weyerhaeuser Company Foundation [128]. Weyerhaeuser has continued working with UC Davis ever since, although in different technological areas.

In 1977, Weyerhaeuser hired Dr. John Ben Holtman, professor in the Agricultural Engineering Department of Michigan State University. Dr. Holtman became manager of the Systems and Control Group at Weyerhaeuser's Silvicultural Engineering Department. He continued working with his peers at Michigan State on agricultural field machinery, and also worked with former PhD students on new technological areas. For example, there were two articles published on agricultural field machinery by Dr. Holtman in collaboration with Dr. Devindar Singh from the Agricultural Engineering Department of the University of Hawaii, who had been a PhD student of Dr. Holtman.

UPM's Corporate R&D reconfiguration through university training

In 2008, UPM decided to focus its research strategy towards microfibrillated cellulose and other value-added forest byproducts. Because these were new areas for the company, they decided to update the capabilities of UPM's R&D staff and sent 40 researchers, approximately a third of the company's research workforce, to a two-year training program at different universities. UPM obtained funds from Tekes, the Finnish Funding Agency for Technology and Innovation, to build a new Center for Nanocellulosic Technologies in collaboration with VTT, the Technical Research Institute of Finland, and also with Aalto University (the former Helsinki University of Technology, TKK).

The UPM competency reconfiguration highlights the role of university relationships when firms are diversifying their technical base. As summarized by a senior R&D manager within UPM's existing business lines, the company already knows well what can be done in terms of research. As the company moves into new areas of knowledge, however, you might not find those competencies inside your firm. In these situations, "you need much more connections to [university] networks"[123].

5.2.4. Effects of Internationalization

Internationalization is an increasingly utilized strategy for the firms in our data set but internationalization of a firm's manufacturing base can have different consequences for industry-university systems. From the perspective of the receiving country, the installation of a new manufacturing unit can result in the formation of new university relationships. From the perspective of the home country, however, offshoring of the firm's manufacturing can negatively affect the firm's pre-existing university linkages. These ideas are captured in propositions 6 and 7.

PROPOSITION 6:

- Internationalization of the firm's manufacturing base can induce the coupling of industry-university systems in new countries.

PROPOSITION 7:

- Competition among international units can weaken pre-existing tightly coupled industry-university systems. As a limiting case offshoring of the firm's manufacturing base can lead to system decoupling.

To assess these propositions, we analyzed the geographical evolution of the firm's university networks. Utilizing publication data, we obtained the addresses of the firm's university partners and georeferenced them on Google Maps (see Chapter 3). As firms expanded their manufacturing base into new countries, we found they formed new local university connections, consistent with Proposition 7.

Three mechanisms were behind the internationalization of the university networks. First, firms established local university connections for recruiting purposes. Second, when firms internationalized through acquisitions, they inherited the university partners of the acquired firms. Third, firms also decided to establish local R&D laboratories to acquire knowledge in areas outside the firm's domains. In the area of forestry the knowledge about pests, plant diseases, and terrain conditions is context-dependent and thus tied to local universities.

We found only partial evidence to support of Proposition 8. Internationalization per-se does not necessarily weaken pre-existing industry-university networks. It affects the firm's pre-existing relationships when, as a result of the internationalization process, the company also decides to change their capability set and/or narrow their product range to generate resources to support the expansion. The following case study illustrates this point.

INTERNATIONAL PAPER'S UNIVERSITY NETWORK EVOLUTION

During the late 1980s, International Paper (I-P) began expanding into Europe and the Pacific Rim through a series of acquisitions. In 1985, I-P bought two packaging plants in Taiwan and Korea. In 1989, I-P acquired Aussedat Rey of France, and Zanders Finepapiere of Germany, two manufacturers of fine papers. In 1995, I-P acquired a controlling stake in Carter Holt Harvey, a New Zealand-based forest products company with strong presence in Australia and Chile.

These acquisitions impacted the company's university network. The maps in Figure 19 show how International Paper's university network was modified as a result of the company's internationalization strategy. Link in the figure represent publications between a company unit and a university. We have colored each link according to the year of the first publication and have adjusted the width of the links to make them proportional to the total number of articles written between those partners.

Before the expansion, I-P had concentrated its university network in North America as shown by the links in letters A and B in the figure. As the company expanded into Europe and the Pacific Rim during the 1990s, we observe new publications with universities located in these regions, as shown by the links in maps C, D, and E.

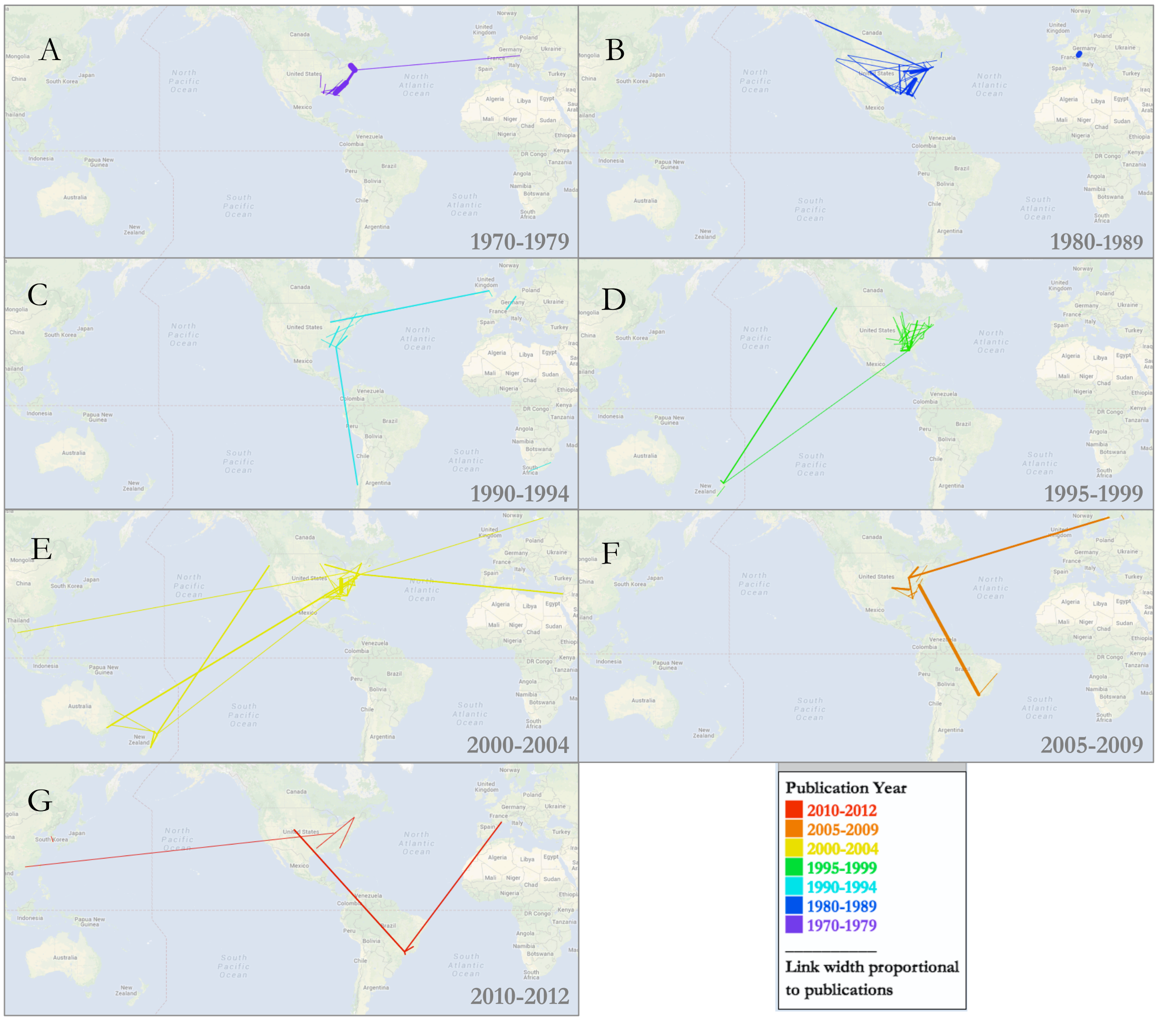


FIGURE 19: EVOLUTION OF INTERNATIONAL PAPER'S UNIVERSITY NETWORK

International Paper's expansion into the Pacific Rim and Europe during the 1990s did not weaken the firm's pre-existing university relationships. As explained by a former R&D manager, during that period there "was a growing mentality around how does one move from a commodity paper business to say a communications business. That triggered a lot of innovation, and product development became very strategic" [120]. International Paper expanded its R&D expenditures during this period from US$40 millions in 1986 to US$113 millions in 1996. International Paper was internationalizing and moving into value-added products at the same. We do not thus observe negative effects of resource competition but rather see the firm tapping into a wider network of universities, both in the US, where they became members of MIT's Media Lab as a way to "stimulate even further our internal process for enhancing product development" [120], and abroad.

More recently, International Paper has been expanding into Brazil, Russia, India, and China (BRIC Economies). In 2000, International Paper acquired Champion International, an integrated forest products company with operations in North America and Brazil. In 2005, they licensed 500,000 acres of timberlands in Russia, and since 2006, International Paper has joint ventures with Chinese paper manufacturers. In 2010, International Paper acquired SCA's packaging operations in Asia and in 2011 they acquired a 75% stake in Anhdra Papers of India.

These recent acquisitions changed the company's university network. In maps F and G of Figure 19 we see new publications with universities in Brazil, Russia, China, and Korea, consistent with Proposition 7, although the interactions in these countries have been smaller and less research oriented than the relationships with US universities. As explained by a senior R&D manager after visiting Chinese and Indian universities, "there are a lot of talented people there," but the research facilities were not yet adequate for International Paper's interests [129]. As in Proposition 1, coupling of new university systems is a gradual process. The fact that International Paper is visiting universities in these countries suggests the demand for collaboration exists and that visits might evolve into research collaborations.

International Paper's recent internationalization into the BRIC economies contrasts with the 1990s internationalization into Europe and the Pacific Rim. During the 1990s, the company was moving towards value-added products and internationalizing. The company's recent expansion, however, follows a different strategy. In 2005, International Paper decided to focus on just two commodity products: uncoated papers and packaging. Because the demand for uncoated papers in North America was declining, the company decided to expand into Eastern Europe, Latin America, and Asia, where the paper market was growing [130]. This second internationalization was thus linked to a reduction in the firm's product range.

During this second the company shifted its research focus towards short-term projects that were aimed at cost-reduction and increasing production of existing company assets. As summarized by a senior R&D manager "our emphasis is to be the lowest cost producer" [129]. International Paper also stopped internal work on fundamental pulping or bleaching technologies, leaving those long-term projects to universities. The company reduced R&D expenditures from US$63 million in 2005 to US$13 millions in 2011.

These strategic actions have affected the firm's relationships with universities and research institutes. As explained by a senior executive of the Institute of Paper Science and Technology (IPST), "research centers in Canada, Sweden, Finland, and Brazil have all undergone transformation in their research programs as a result of a number of factors, one of which is that corporations are investing less in traditional research areas of pulping and bleaching. Because of that decline, most of the research groups aligned with the industry have moved into areas such as biorefining and into new materials such as nanocrystalline cellulose. The pulp and paper companies are keeping alert and tracking [these areas] but they are not driving their development. Other industries, such as the chemicals and composite materials industries are driving the investment and research at the university level. They also are hiring the PhDs whereas the traditional pulp and paper companies are not hiring PhD candidates. These new industries are recruiting and thus influencing what universities are focusing on in response to that demand" [131]. In other words, even though International Paper is relying on universities for new bleaching and pulping technologies, universities might not be able to deliver since companies have reduced their university support. As explained by an IPST executive "if you were to look at the graduate programs in the world, except for China, you would see that most of the graduate programs [in pulp and paper] are declining in terms of participants and the capacity to deliver on research by the numbers and experience of the faculty" [131].

We presented this case to illustrate the different effects of internationalization on a firm's university relationships. In accordance with Proposition 6, the internationalization of the firm's manufacturing base induced the coupling of industry-university systems in new countries. Contrary to Proposition 7, however, we did not observe a reduction on the firm's pre-existing university relationships as a direct consequence of internationalization. Only when the firms internationalize and narrow their capability set at the same time was there a reduction of the firm's pre-existing university relationships. The effect of the reduction of the firm's capabilities on university relationships, however, is better captured in Proposition 8.

5.2.5. Effects of Focalization

A known characteristic of capital-intensive industries is their cyclicality [119]. Especially during periods of economic downturn, firms reconfigure their manufacturing base divesting "non-core" assets, reducing their manufacturing capacity, or withdrawing from regional markets. This focalization strategy (Section 5.1) is usually followed after periods of growth through diversification, integration, and internationalization. As discussed in Chapter 3, when firms narrow their business base or contract their geographical scope, they also reduce their network of university partners, as in Proposition 8:

Proposition 8:

- The reduction of the firm's capability set and/or the firm's geographic withdrawal can decouple pre-existing industry-university systems.

We assessed this proposition in multiple ways. First, we analyzed what happened to each firm's university publications after the divesture or closure of a business line. This is seen in Table 7, which shows in red all the industrial sectors exited by the firms and enumerates all articles written when the firms were active in those industries. We extracted the names of the universities that had participated in the publications listed in Table 7. We found that after the firms exited an industry; they also ceased to conduct research in those areas. In most of the cases we did not observe new publications with those same university partners. After International Paper divested its imaging division to Kodak in 1998, we did not see new publications with the universities mentioned in Figure 18 of Section 5.2.4.

TABLE 7: EFFECTS OF DIVESTURES ON INDUSTRY-UNIVERSITY RELATIONSHIPS

		Southern Europe			North America			Northern Europe			
NAICS Codes	Industry	Amorim	Portucel Soporcel	Sonae Industria	Domtar	Int. Paper	Weyer-haeuser	SCA	Stora Enso	UPM	
32121	Manuf. Wood Products					1 (0%)					Traditional Lines
32111	Lumber & Wood					10 (5%)					Traditional Lines
32221	Packaging		1 (2%)					18 (11%)			Traditional Lines
32519, 32521	Chemicals										Diversified Business Lines
32619, 32739	Wood-Plastic composites						3 (1%)				Diversified Business Lines
21232, 21223	Mining, Oil & Gas						1 (0%)		1 (1%)		Diversified Business Lines
33441	Electronics							4 (2%)		2 (2%)	Diversified Business Lines
11114, 11115, 11132	Crop Production						8 (2%)				Diversified Business Lines
32599	Photographic papers					17 (8%)					Diversified Business Lines
32522	Textiles							3 (2%)			Diversified Business Lines
33911	Medical Supplies					2 (1%)		10 (6%)			Diversified Business Lines
33324	Ind. Machinery							2 (1%)		1 (1%)	Diversified Business Lines

The university relationships most affected during periods of focalization were ones established in response to the firm's diversified business lines. In 2005, SCA divested its healthcare division. Prior to that divesture, there were collaborations with the Huddinge University Hospital[5] on microbiological studies of wound dressings, with the Sahlgrenska University Hospital on patient draping, with the Helsinki University Central Hospital on surgical gowns, with the University of Mainz Medical Center on wound dressing permeability, with the University Hospital of Uppsala on wound contamination and with the Danish Statens Serum Institute on sterilization technologies. After the divesture of this business unit, we observed a reduction in the firm's publications with these hospitals.

To analyze the effects of geographical contraction on the firm's university relationships, we examined what happened to a firm's university relationships after the company had sold or

[5] Currently the Karolinksa University Hospital

closed an international subsidiary. After firms exited a country, they ceased to support university research in that country. UPM expanded in the early 2000s into Canada by acquiring Repap Enterprises, a magazine paper manufacturer with a mill in Miramichi, New Brunswick. After this acquisition, new collaborations between UPM's Miramichi Mill (as the facility was renamed) and the university of New Brunswick were observed. In 2004, however, UPM began a period of focalization that led to the closure of several of the company's mills, including Miramichi in 2007. After the closure of this mill, we have seen no evidence of research collaboration between UPM and the University of New Brunswick.

Focalization not always manifests as a discrete event (e.g. the exit or closure of a business or region), and can also occur as a reduction in the company's operations. International Paper has not exited completely the forestry business, but it has significantly reduced its timberland holdings from 19 million acres worldwide in 2003, to 450,000 acres in 2008, most of which are located in Brazil [132]. As a result, we see a reduction in the firm's publications with North American universities in the area of forestry, as shown in Figure 20, which is a plot of all of the company's publications in the area of forestry. As summarized by a senior R&D manager, "because we don't have that business, we don't need R&D [in forestry]" [129]

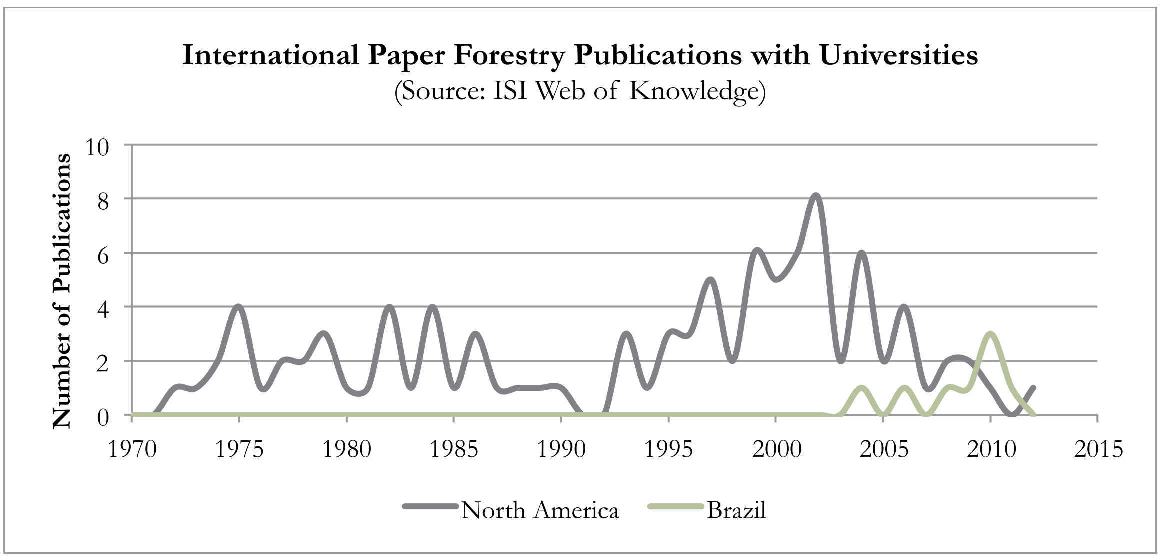


FIGURE 20: EVOLUTION OF INTERNATIONAL PAPER'S UNIVERISTY CO-PUBLICATIONS IN FORESTRY

Once the period of focalization is over, companies again start to grow through the different strategies described earlier (integration, diversification, internationalization). For some of the companies analyzed, this meant rebuilding lost capabilities. The cyclicality of the forest products industry translates into a periodic "reinvention of the wheel" for some of these firms. The following two case studies illustrate how these competence-destroying cycles operate, and the role of universities in helping firms to regain lost capabilities.

DOMTAR'S BIOREFINING COMEBACK

In 2000, Domtar decided to close down its central research laboratory in Senneville, Quebec. According to a senior company executive, the lab closure was part of a larger trend within the Canadian forest products industry. Not only Domtar, but "a very long list of corporate research facilities got closed in a span of about 5 years right about that time [early 2000s]" [133]. One reason for the closure was the economic difficulty faced by the Canadian pulp and paper industry in the early 2000s. "As I recall, and the industry of course is very cyclical, those were difficult times in the US and Canada because we just came out of a pretty significant expansion in the capacity. There were a lot of new projects that put new capacity in pulp and paper, and there were also a lot of expenditures incurred to address environmental issues in the 1990s. Then the market hit a soft spot and it became exceedingly difficult to maintain those labs" [133].

The closure of Domtar's Senneville lab can be contrasted with the company's recent efforts to restart an internal R&D group. In 2008, Domtar hired an R&D director and formed a new R&D group. The company also initiated a series of collaborations with universities aimed at establishing a bio-refinery program. In 2009, Domtar established a joint venture with FP Innovations to build and operate a commercial-scale nanocrystalline cellulose plant in Windsor, Quebec (Project CelluForce). Ironically, Domtar had the internal capability to produce biochemicals during the 1960s, but those capabilities were lost over time. As explained by a senior manager "the essence of the biorefinery is that we can make lumber and pulp, but on top of that, we can also make value-added byproducts such as lignin. [We] were doing this in the 1960s, and the reason it stopped is because the economics of it didn't make any sense. So we are sort of reinventing the wheel"[133].

StoraEnso's building systems comeback

During the 1970s, Enso-Gutzeit[6] was a diversified company with presence in multiple industries including chemicals, shipping, electricity, and prefabricated housing industry. During the mid 1980s, the company decided to focalize on paper and pulp, divesting several of these unrelated assets. To support the flow of raw materials to the company's pulp mills, Enso-Gutzeit scaled down its sawmilling operations and divested (in 1990) most of its value-added production units including the plywood, fiberboard, and prefabricated homes businesses. As explained by a senior company manager "there was less strategic focus on making sawmilling into a highly profitable business, it was more about a necessity to ensure the flow of logs. That is why we had the sawmills [during the 1990s]."

Since 2007, however, StoraEnso has made efforts to move up the chain into value-added wood products. In 2008, the company opened a cross-laminated timber (CLT) mill in Austria, and in 2010 they acquired Eridomic, a manufacturer of roofing, walls, floors, and housing solutions made from CLT. So the company is again in the housing construction business. In the process of capability buildup, Stora Enso is relying on an expanded network

[6] Finnish Enso-Gutzeit merged with Swedish Stora, forming StoraEnso in 1998

of university partners. "There are certain universities in Europe that are progressive in terms of wood-based construction and design. It is key to have good professors at those universities, and we try to team up with the best ones. Now we have a wider network of architects, structural engineering professors, and wood modification professors at different research centers. We also sponsor master's thesis, and sometimes even doctoral work. We look at these students as potential future employees"[121].

The StoraEnso case illustrates the competency-destroying cycle of the forest products industry. As explained by a senior company manager "When you enter the housing business, you follow directly the construction cycles. As soon as the economy goes down, however, your profitability drops, and you are stuck with fixed assets that then get divested. That is exactly what happened in the 1980s, and it will happen again, and it will keep happening like that. It is frustrating because you build up competencies and knowledge and then when bad times come it is all swept out and then you have to start from scratch again after 10-15 years"[121].

The problem with this competency destroying cycle is that it affects the local universities and their research agendas, and it raises questions on whether those capabilities can be successfully regained after universities turn their attention to other areas. As explained by a senior manager "if you take for example VTT, which is the state research institute, you can see the same cycles. In the peak time they had maybe 20-30 people working on forest and wood products. Now maybe it is just a handful, so it also fluctuates. But then the question is do they ever come back? What we see in organizations like VTT and when I talk to the state funding organizations in Finland, is that more and more of their money goes to the [mobile] gaming industry, for example, to people inventing 'Angry Birds[7]'. Money is going somewhere else, and it doesn't seem to be coming back [to the forest industry]" [121].

5.3. A SYSTEMS VIEW OF INDUSTRY-UNIVERSITY RELATIONSHIPS

In sections 5.1 and 5.2 we showed that forest product firms undergo periodic strategic changes that have consequences for the firm's university relationships. In this section we summarize these consequences, and present an integrative framework to illustrate how industry-university relationships coevolve with changes in the firm's strategy.

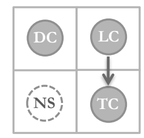
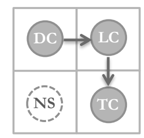
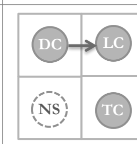
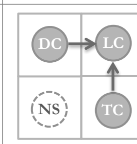
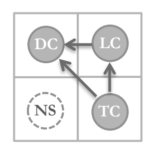
5.3.1. PROPOSITION ASSESSMENT SUMMARY

In Chapter 4 we utilized the organizational coupling framework to distinguish between three types of industry-university systems: decoupled, loosely coupled, and tightly coupled systems. We explained that not all industry-university systems would be affected equally after a period of strategic change because changes are contingent on both the prior state of the

[7] Angry Birds is a popular gaming application for smartphones created by Rovio Entertainment, a Finnish computer game developer.

system and the type of strategy pursued by the firm. We derived 8 propositions that were assessed in the previous section. The main findings of this assessment are summarized in Table 8. The first column shows the different strategic periods of analysis. The center columns describe the effects of strategic periods on the firm's capability set and organizational form. The rightmost column presents the observed consequences for the firm's university systems.

TABLE 8: PROPOSITION ASSESSMENT SUMMARY

	Firm Capability Set	Organizational Form	System Coevolution
Stable Period	*Stable* • Unchanged recruiting and knowledge searching routines strengthen coupling	*Stable* • Tightly coupled organizational forms created to facilitate cross-boundary coordination	
Integration	*Expansion* • Technological depth can induce coupling of new, and strengthening of old systems	*Consolidation* • Complementarity among technological units can increase coupling strength	
Diversification	*Expansion* • Technological breadth can induce coupling of formerly decoupled systems	*Fragmentation* • New technological units induce coupling of new university systems	
International-ization	*Contraction* • Capability reduction weakens tightly coupled systems	*Fragmentation* • Geographic proximity can induce coupling in new countries/ regions	
Focalization	*Contraction* • Capability reduction weakens tightly coupled systems • Capability withdrawal leads to decoupling	*Consolidation* • Geographic withdrawal leads to decoupling	

During periods of strategic stability, we found that industry-university systems gradually gravitate towards tightly coupled structures. Transitions towards tightly coupled structures were supported by unchanged recruiting routines, for example, an overlap between the firm's recruiting and their university publication partners. We also observed that formation of tightly coupled industry-university structures, such as research consortia, was often preceded by a previous relationship between the different partners, which points to the gradual buildup of industry-university systems.

When companies integrated new positions of the value chain, we observed the coupling of new university systems. Because the integration of new segments did not alter the firm's prior positions in the value chain, we saw strengthening of the firm's prior industry-university systems. The most common vehicle for integrating new segments of the value chain was the acquisition of distributors, suppliers, or competitors. When the companies merged or acquired other firms, they also inherited their university relationships, which explains in part the coupling of new university systems.

During periods of diversification, we saw coupling of new university systems in new technological areas. These new relationships, however, were generally smaller in magnitude than ones established in forest products, and they depended on the characteristics of the industry which the firms were diversifying into. University relationships also played a greater role for science-based industries than for the service sector.

During periods of internationalization, coupling of new university systems occurred in the regions of expansion. When the internationalization process also included the reduction of the firm's product range, there were negative effects on the firm's pre-existing tightly coupled university systems.

Finally, during periods of focalization, a decoupling and weakening of industry-university systems was seen as a result of the contraction of the firm's capability base and the geographical contraction of the firm's manufacturing base.

5.3.2. Coevolution of industry-university relationships: an integrative framework

Figure 21 presents an integrative framework for the coevolution of industry-university systems. At a macro level firms and universities are both embedded in the same dynamic environment. Environmental stimuli such as social trends, technological advancements, and political decisions continuously shape industry-university links so these relationships never reach a static equilibrium condition [11].

The historical trajectories of the firms show multiple examples of social, political, technological, and natural events that prompted them to change strategy and prompted universities to revise their research agendas (see letter A in Figure 21). An example is the environmental movement of the 1970s that pushed firms to invest in clean technologies and motivated universities to start research lines in environmental management at the same time.

When firms changed strategy, they also changed their knowledge base and organizational structure, affecting the coupling of industry-university systems. When universities changed their research agenda they modified their research staff and graduate educational programs, and also altered the organizational interfaces and research facilities. These aspects affected the coupling of industry-university systems.

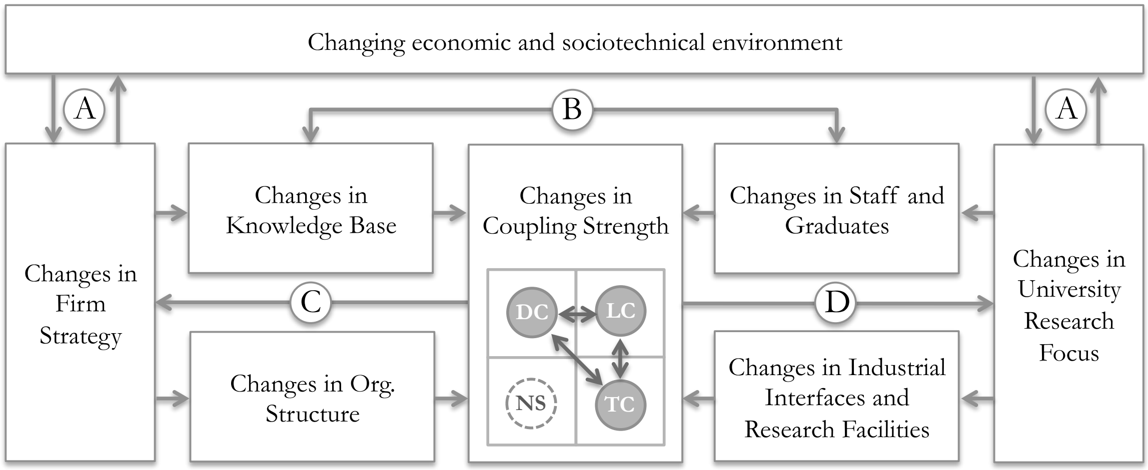


FIGURE 21: INTEGRATIVE FRAMEWORK OF THE COEVOLUTION OF INDUSTRY-UNIVERSITY SYSTEMS

Bidirectional flows of people are an important factor in the coupling of industry-university systems (letter B in Figure 21). Analysis of the academic and professional trajectories of approximately 600 researchers of the firms in our dataset revealed strong overlap between the academic institutions attended by these researchers and the firm's academic coauthors. Companies recruit from universities that have developed expertise in knowledge areas relevant for the firm. Further, when people move across organizations they move with their networks.

We found 70 company researchers who had become full-time academics after leaving the nine firms (see Table 9). A number of company personnel also occupied part-time faculty positions, participated research steering committees, and supervised graduate theses. All these practices contribute to strengthening industry-university systems.

TABLE 9: SOURCES AND DESTINIES OF FIRM R&D STAFF

		R&D Staff Analyzed	Recruited from Academia		Left firm to join Academia	
Southern Europe	Amorim	14	7	(50%)	1	(7%)
	Portucel Soporcel	22	8	(36%)	2	(9%)
	Sonae Industria	28	9	(32%)	1	(4%)
North America	Domtar	81	27	(33%)	11	(14%)
	Int. Paper	118	42	(36%)	18	(15%)
	Weyerhaeuser	120	70	(58%)	22	(18%)
Northern Europe	SCA	85	42	(49%)	3	(4%)
	Stora Enso	78	28	(36%)	8	(10%)
	UPM	68	21	(31%)	4	(6%)
	Total	**614**	**254**	**(41%)**	**70**	**(11%)**

Finally, one of the most interesting aspects of the forest products industry is its cyclicality, which manifests in periodic changes in the company's strategy. During periods of focalization we saw firms destroy accumulated capabilities and knowledge, which in turn affected the university research agendas (as symbolized by letter D in Figure 21). Knowledge at the firm level was lost, although knowledge at the university survived. Thus, firms could regain lost capabilities and to acquire new ones by tapping into the university system (as symbolized by letter C in Figure 21). Universities thus play an important role as "knowledge buffers" for cyclical industries.

6. SUMMARY AND CONCLUSIONS

6.1. INDUSTRY-UNIVERSITY RELATIONSHIPS COEVOLUTION: SUMMARY OF FINDINGS

In this thesis we set out to answer *how do industry-university relationships coevolve with firm strategy*? In the process we both developed insight into how firms change strategy and on how industry-university relationships evolve. The main findings are summarized below.

6.1.1. STRATEGIC CHANGE PROCESS

- The forest products firms in our dataset all pursued four strategies at different points in time: integration, diversification, internationalization, and focalization. They implemented the strategies in different ways.
- Within each strategic period, there were incremental changes in firm capabilities and organizational form, and a stable pattern of industry-university relationships.
- Changes in CEO led to major changes in the firm's capabilities and organizational forms, leading to a new strategy and a different pattern of university relationships.
- Universities did not play a role in defining strategy for the firms. Once the strategic decision was made universities played a supportive role through helping firms to reconfigure internal capabilities.
- When forced to change, firms moved downward as well as upward on the value chain. When the former occurred they divested technological capabilities specially during periods of economic downturn.

6.1.2. EVOLUTION OF UNIVERSITY RELATIONSHIPS

- We found it is useful to distinguish three types of industry-university systems: (1) decoupled, (2) loosely coupled, and (3) tightly coupled systems. In decoupled systems there is no coordination between firms and universities. In loosely coupled systems firms and universities are responsive to each other while preserving their own identities. In tightly coupled systems, organizational boundaries are blurred and there is a high degree of coordination between firms and universities.
- Construction of industry-university systems was found to be a gradual process (several years to decades). In periods of strategic stability with firms and universities having common research interests, decoupled systems evolve to loosely coupled systems. Through bidirectional flows of people and the creation of new organizational forms loosely coupled systems become tightly coupled.
- New university systems were formed in periods of firm growth. When firms grew by integrating new segments of the value chain, diversifying their industrial base, or expanding geographically, they formed new university connections. When firms contracted their product or geographical scope, they narrowed university networks.

- Not all industry-university systems were equally affected by changes in strategy. Modifications in a firm's university network were contingent on the strategy pursued by the firm, and the pre-existing industry-university system. Tightly coupled university systems were most affected when firms stopped funding because research and graduate programs were reduced and faculty attention shifted towards other areas.
- Changes in strategy occurred more frequently than the time required for technologies to mature. As a result, we found multiple examples of abandoned corporate technologies. These areas, however, were further developed at universities, which acted as "knowledge buffers" enabling technologies to mature.
- The existence of "competency-destroying" cycles in the forest products industry often translated into "reinvention of the wheel" for some of these companies. In these instances we found that firms relied on universities to rebuild internal capabilities that they had lost.
- The university "knowledge buffering" did not always occur; universities sometimes modified their research and graduate programs in response to industrial demand. Long-term decoupling of industry-university systems can thus lead to system-wide capability loss.

6.2. Secondary Findings

6.2.1. Academic findings and implications

The longitudinal research design allowed definition of (1) which strategic situations were conductive to the formation of a university relationship, (2) how the geographical organization of the firm's R&D laboratories affected university relationship, and (3) how the diversity of manufacturing operations contributes to the firm's absorptive capacity. The main findings are related to existing literature below.

- When firms were in difficult market situations, they narrowed their business base and reduced university links. This finding contrasts with the literature on strategic alliance formation which finds the rate of external alliance formation is higher when firms are in difficult market situations [21].
- The territorial diversity of firm R&D centers offered increased opportunities for the formation of new university relationships. This finding contrasts with the literature on industry-university relationships that found that firms with centralized R&D labs allocate a greater share of their R&D expenditures on universities [13].
- The capacity of a firm to engage in university collaborations depends not only on R&D intensity, as modeled in the literature [22], but also on the firm's organizational form, in particular, the diversity of the firm's manufacturing operations and the geographic diversity of those operations.

6.2.2. Managerial findings and implications

- University managers of tightly coupled industry-university systems (e.g. research consortiums) should be aware that changes in CEO can trigger abrupt changes in the firm's strategy.
- University managers seeking industrial collaborators should approach growing firms. Firms that were narrowing their business base or regional scope formed fewer links with universities.
- University "knowledge buffering" is limited, so that lack of industrial investment in university research can lead to a permanent capability loss if there is redirection of the university research focus to other areas
- There was overlap between the universities attended by the firm's R&D staff and the firm's most frequent university partners, implying a role of social capital on the formation of an industry-university relationship. If so, an implication is that industry managers can modify their university network by recruiting R&D personnel with different academic backgrounds.
- Between 10-15% of the scientists we tracked left companies to join university research labs. Universities thus benefit from industrial relationships not only from research funds and student employment opportunities, but also from industry-trained researchers, who can help universities liaise with firms.

6.2.3. Policy findings and implications

- The finding that universities act as "knowledge buffers" for cyclical industries has important implications because if industries stop investing in university research during periods of economic downturns, capabilities can be lost permanently. Regions might consider countercyclical investments in university R&D as a means of preventing the loss of specific capabilities.
- Since the locus of the firm's absorptive capacity also resides in the firm's manufacturing base, reductions of the industrial capacity of a region (i.e., firms shifting their manufacturing operations) also poses risks for universities and their research agendas with industry.

6.3. Generalizability of findings and future research areas

The idea that firm strategy affects the formation and evolution of university relationships can be generalizable to other industries. More research, however, is needed to assess if the strategic change process described, involving the 4 generic strategies, is applicable for other industries. We believe the strategic change process described would be useful in analysis of other commodity-grade, capital-intensive industries, such as the mining, metal, or oil and gas industries. It is not clear, however, that non-cyclical or technology-advanced industries will follow the same strategic change process.

The firms analyzed are now experiencing increased competition from southern hemisphere manufacturers. A venue of future research would be to use the same methodological approach to study the coevolutionary patterns of industry-university relationships from the southern hemisphere in which the firms and universities are younger than in the northern hemisphere. We might expect weaker institutional ties and possibly a different pattern of interaction because the formation of an industry-university system might take decades to build.

The firms in our dataset often relied on startups and equipment suppliers to develop and diffuse university technologies. An interesting question is how these equipment manufacturers are affected by the changes in firm strategy and whether they also establish and modify university relationships as influenced by cyclical downturns of the industry.

APPENDIX I: CORTICEIRA AMORIM

1. INTRODUCTION

Corticeira Amorim is the world largest cork manufacturer. The company was founded in 1870 for the production of natural cork stoppers for the Portuguese port wine industry, and over the years it diversified into five business areas: cork stoppers, floor and wall coverings, composite corks, insulation corks, and raw materials.

Amorim is a vertically integrated company with direct presence in mayor cork-producing countries including Portugal, Spain, Morocco, and Tunisia. It also has sales offices in mayor wine-producing countries including France, USA, Australia, Italy, Chile, and South Africa. The company employs 3,470 people worldwide [134], and on 2011 it achieved a sales volume of M€ 495, out of which 58.9% came from the sales of natural cork stoppers, its main business line [135].

Figure 22 presents an overview of Amorim's sales and R&D expenditures versus time. Only partial information could be found on the firm's R&D expenditures, which have varied between 0% and 1% as a fraction of the firm's sales.

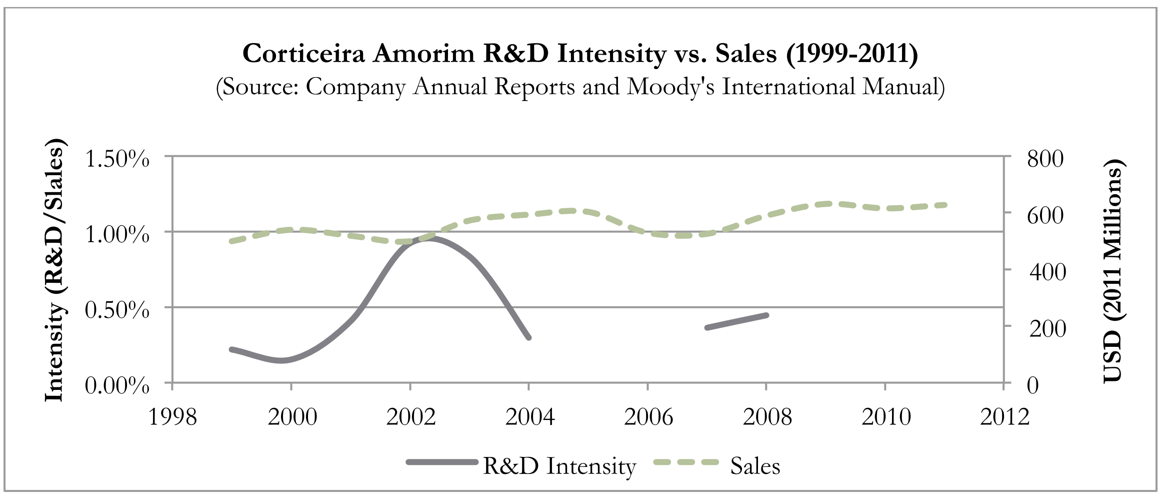


FIGURE 22: EVOLUTION OF AMORIM'S R&D INTENSITY

This case study presents a longitudinal review of changes in (i) the company's businesses, (ii) research strategy and (iii) connections to universities and public research institutes during each strategic period of the firm.

Section 2 characterizes the different strategic periods of Amorim. Section 3 describes the origins and evolution of the firm's university relationships as judged by changes in the research priorities of the firm, changes in the firm's university network, and people flows between partnering institutions. Section 4 summarizes the main findings and lessons.

2. Historical Changes in Amorim's Strategy

Data on Amorim's strategy was obtained by analyzing the company's annual reports and secondary sources of information, including journals, press articles, and company historical retrospectives. We also conducted two on-site interviews and two telephone interviews with senior managers of the firm. Based on the data, we defined 5 different strategic periods as in the left hand side of Figure 23. The right hand side of the figure shows the trajectory followed by Amorim.

Strategic Periods

Period 1 (1870-1952): Focalized cork stopper producer

Period 2 (1953-1978): Integration into cork agglomerates

Period 3 (1979-1988): Diversification into non-related industries

Period 4 (1989-1999): Internationalization

Period 5 (2000-Present): Integration and supply chain control

Strategic Trajectory

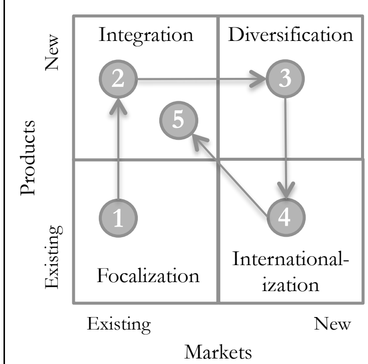


FIGURE 23: AMORIM STRATEGIC PERIODS

Period 1 (1870-1952): Focalized cork stopper producer

In 1870, Antonio Alves de Amorim formed a cork stopper factory at Vila Nova de Gaia to supply cork stoppers for the local Port Wine industry. The company grew in size fueled by increased exports of Portuguese wine. At the beginning of the 1900s, Antonio Amorim had a legal dispute with his financiers and retired to the village of Lamas. His wife, however, was determined to rebuild the family's business and in 1908 she initiated a new factory in Santa Maria de Lamas with two cork stopper machines [136]. Business prospered and by 1922 the company had 17 machines. That year Antonio Amorim died and a new generation of Amorim's—eight brothers—took over the company incorporating it as Amorim & Irmãos, Lda.

During the 1920s the cork industry grew fueled by the utilization of cork in several industries as an insulation material, an acoustic shield, and in several products that required an airtight seal. During the 1930s, civil unrest in Algeria and the Spanish Civil war destroyed large amounts of cork forests in those countries, and Portugal emerged as the world's leading cork-producing nation [136]. Portuguese cork exports were 95% raw materials, and much of the raw cork harvested was under control of foreign companies. To ensure a steady supply of raw materials, in 1935 Amorim opened a small warehouse in Abrantes, near the heart of the country's cork oak forests. In 1939, this facility started producing cork planks, a step in the manufacture of cork-stoppers. During these years, Amorim also expanded by exporting products to more than 10 different nations including the US, and Japan.

During WWII, the Army and Navy Munitions Board at Washington classified Cork as a "critical material" for the war because it was used in airplane insulation, life preservers, ammunition plugs, gas-mask seals, and automotive gaskets [137]. Germany imposed a blockage that impeded ships from Portugal to export cork to the US, which, at the time, was consuming about 60% of the worlds cork production and Amorim's exports were negatively affected. In 1944, fire destroyed Amorim's Santa Maria de Lamas facility and the company was almost wiped out [136]. Amorim began a period of reconstruction, but it was not until the 1950s that the company regained its position as the biggest cork manufacturer in Portugal.

PERIOD 2 (1953-1978): INTEGRATION INTO CORK AGGLOMERATES

In 1953, a third generation of Amorims took over the company, in a postwar period marked by an increased demand for cork. The company began a territorial expansion, and remained vertically integrated, controlling the production, distribution, and harvesting rights to several cork oak forests in Portugal [136]

During the 1960s, the company began exploring alternative uses for the waste material of the cork-stopper manufacturing process (almost 70% of the bark of the tree), and in 1962, the company made a strategic decision to vertically integrate into cork agglomerates to better utilize cork-stopper waste material. In 1963, Amorim built an industrial complex for manufacturing cork agglomerates, which were used in flooring, insulation, car gaskets, and other materials for the automotive industry. In 1966, the company opened a factory in Algarve for the production of thermal and acoustic insulation products. That same year Amorim acquired Inacor, a company that produced expanded corkboards. In 1969 Amorim created a specific unit for the production of parquet, decorative items, and started experimenting with mixtures of cork and rubber. At the beginning of the 1970s, the Portuguese cork industry had transformed from a raw-material supplier into a manufacturer of value-added products, which represented 75% of the value of Portuguese cork exports.

During the 1960s, the company also began internationalizing their exports. In 1960, the company opened an office in Brazil, and in 1968 another office in Austria. That year, the company formed a joint-venture in Hungary, forming Hungrakork to serve the eastern bloc countries in the midst of the cold war [136]. During the 1970s, Amorim also expanded into Morocco, acquiring Comatral, a local cork producing company. In 1976 Amorim acquired Samec, a large Spanish cork manufacturer.

PERIOD 3 (1979-1988): DIVERSIFICATION INTO NON-RELATED INDUSTRIES

At the beginning of the 1980s, Amorim was the world's largest producer of cork stoppers, with a diversified portfolio of other cork-related products. During this period, under the leadership of Americo Amorim, the company began a series of investments into unrelated industries. In 1979, Amorim acquired an insurance company and in 1984 they entered the banking business through the creation of the Banco Comercial Portuges (BCP). That same year, Amorim created a trading company for exporting different products including footwear, textiles and wine. In 1987, the company formed a joint venture with French Accor group to enter the hotel business. In 1988, Amorim acquired Velpor, a Portuguese decorative textile manufacturer and in 1990 the company entered the real estate business by acquiring the concession of a Casino in Figueira. In 1991, Amorim entered the telecommunications business through Telcel, Portugal's first mobile phone operator, and in 1995, the company acquired a large stake in Petrogal, Portugal's leading oil company. Given this diversification, the Amorim Family decided in 1988 to restructure its properties under a new holding company called Amorim Investimentos. All cork-related business lines were placed under Corticeira Amorim, which remained the main business of the conglomerate.

PERIOD 4 (1989-1999): INTERNATIONALIZATION

The 1990s was a disastrous decade for the Portuguese cork stopper industry, as the emergence of synthetic wine closures and screw caps threatened Amorim's main business line. The problem with natural cork stoppers was the presence of TCA, a chemical compound that caused a moldy taste in wine. The cork taint problem was not new. In the late 17th Century, wine manufacturers had reported the presence of a moldy taste of wine, which they attributed to cork (thus the word corky wine) [138]. Cork manufactures had denied the problem, blaming wine manufactures for their product's taste. In 1981, however, Swiss researchers from the Wädenswil Institute working in collaboration with Gültig Corks, a German cork producer, found that trichloroanisole (2,4,6-TCA) was responsible for cork taint, and that even low concentrations of this compound could ruin the quality of wine [139]. In 1982, several governments banned the use of chlorine for cork bleaching but cork taint remained a large problem for the wine industry. It is reported that during the 1990s, approximately 5% of the wine bottles sold in the UK had to be returned because of this problem [138].

During the 1990s, a plastics entrepreneur from Seattle invented a colorful plastic cork stopper sold under the brand SupremeCorq. These synthetic wine stoppers were an immediate success, especially in the New World wine producers (e.g. Australia, Chile) as it solved the TCA problem, and they also provided an alternative to natural cork stoppers. In 1995 Supreme Corq entered the Australian wine market, and soon other wine manufactures in California, Chile and Africa began using these closures [138]. During this period, screw caps also began acquiring larger shares of the market, especially in white wines and low-cost red wines.

In the late 1990s, a third cork stopper technology entered the scene. Sabaté, a French cork manufacturer, discovered that by grinding natural cork into small granules, they were able to isolate most of the phenolic compounds causing TCA. The granules were later reconstituted into the shape of a cork stopper through the use of polymer microspheres that replicated the permeability and elasticity properties of natural cork. Sabaté sold these reconstituted stoppers under the brand Altec, and they were an immediate success as they had a price advantage with respect to natural cork (no waste material) and greatly reduced the TCA problem [138].

Period 5 (2000-Present): Integration and supply chain control

In 2000, Americo Amorim announced he was stepping down as CEO of Corticeira Amorim, being succeeded by his nephew, Antonio Rios de Amorim in 2001. Antonio took the company in the midst of a crisis. The company was not only facing increased competition from the synthetic cork propducts, but also two senior managers who had recently left Amorim had formed their own company and competed in the natural cork stopper business. Amorim had historically been a natural cork producer, and there was fear among the members of the board of directors that entering the synthetics market would cannibalize their core business [138]. Antonio Amroim, however, knew that if the company continued with business as usual, "they would be out of business in fifteen years" [138].

The company responded with three parallel strategies. To address the threat of synthetic closures, they launched a new line composite cork closure called Twin Top. These were similar to the Altec reconstituted ground cork stoppers, but had two high-quality natural cork discs on the ends. These technical cork stoppers, as the industry called them, were an immediate success, especially in entry-level wines.

Another strategic action was to vertically integrate and gain control of the cork supply chain. This decision was in response to a study that traced the origins of TCA to several places in the production chain [138]. The company opened two new facilities in Ponte-de-Sor and Coruche, near Portugal's cork oak forests, and revamped their facilities in the north with new machinery aimed at reducing the formation of molds in the bark of the tree, and improving the production process of natural cork stoppers. Similarly, they began selectively buying small Portuguese cork companies and developed tighter control over the Spanish supply chain by opening two companies that bought the oak's bark directly from farmers. While about 75% of Amorim's raw material came from outside providers in 1990, by 2006, 95% came from the company's own production [138]. A third action was to build a new research and development facility, whose main purpose was to find a solution to the TCA problem. For these purposes, in 1999, Antonio Amorim hired a microbiology professor from the university of Porto, who was put in charge of starting the company's first research and development lab.

Amorim Investimentos, corticeira's parent company, also began to concentrate back on their cork business. In 2000, they acquired a controlling share of Chilean company Industria Corchera, and in 2001 the company acquired a mayor share in SNL Cork Company, which had just been privatized by the Tunisian government. In 2005, Amorim Investimentos, divested its real estate and tourism business units, and aquired Equipar, a machinery manufacturer for the cork industry. That same year they acquired Bouchons Trescases, a French manufacturer of natural cork stoppers and in 2007, they acquire a large stake in the Oller Group, a Franco-Spanish producer of champagne stoppers.

The company continued losing terrain against alternative wine closures, especially to screw caps, which found a niche in white wines (See Figure 24). Amorim launched a marketing campaign highlighting the environmental benefits of natural cork: renewable material with low carbon footprint. In 2008, they started a cork-recycling program, and they raised awareness internationally on the importance of preserving the Portuguese natural oak forests.

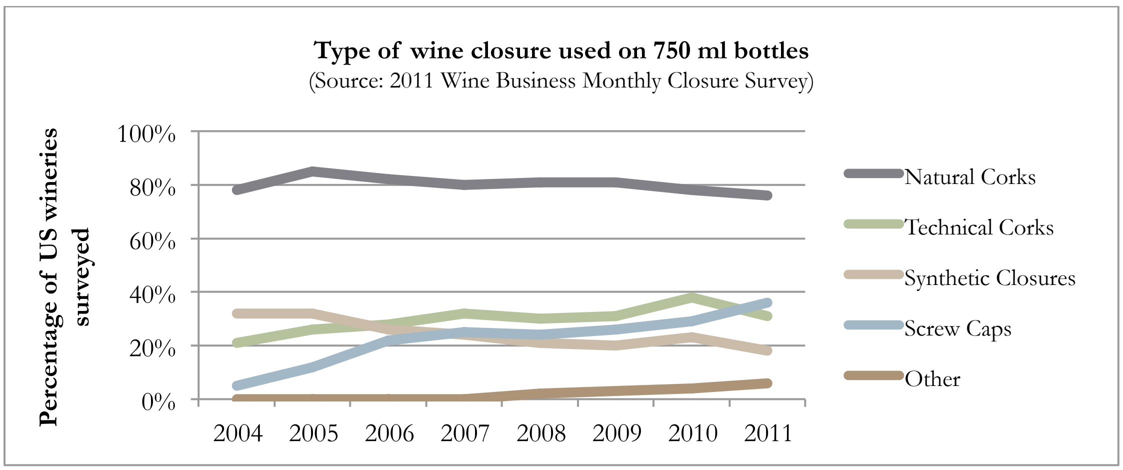


FIGURE 24: WINE CLOSURE UTILIZATION TREND

Amorim also consolidated the rubber and agglomerated cork business units to form Amorim Cork Composites, a new unit in charge of launching value-added cork products. To support these actions, the company created a new research department for Market Oriented Research (MOR) with the task of finding additional uses for cork. Amorim also acquired 25% of US-based Floors, Inc., and 100% of the German company Cortex, two important distributors of cork floors.

3. The Origins and Coevolution of Amorim's University Relationships

Amorim has historically been reactive in terms of research and development activities. Their first laboratory, Labcork, was created in 1983 in response to the tracing of TCA to cork stoppers. The laboratory was in charge of conducting quality assurance tests, but no real research was done because there were no serious alternatives to natural cork stoppers. This situation changed during the 1990s with the raise of synthetic wine closures, but it was not until 1999 that the company created a formal R&D department to address the TCA problem.

In 1999, Antonio Amorim hired Miguel Cabral, a professor of microbiology at the University of Porto, to organize the company's research efforts to finding a solution to TCA. The initial group was composed of four people, a Swedish chemist from the Catholic University of Porto, a North American technologist, and a Portuguese researcher with knowledge in cork quality assurance. The initial department had a budget of 6 million euros, and had the mandate of understanding the taint problem and coming up with solutions [138]. After two years of work, this group patented a treatment for cork stoppers that was able to reduce TCA by 80% in cork granules.

At the end of the 1990s, US wine producers began using Gas Chromatography and Mass Spectrometry (GC-MS) to analyze the corks imported from Portugal. US wineries had established a mandatory rejection level for TCA of 6 parts per trillion, above which the whole batch of corks would be rejected and shipped back to Portugal. In 2000, Amorim acquired the first of several GC-MS machines to conduct quality assurance tests before shipping the corks to their clients [134]. As a result, the rejection rates of Amorim corks fell sharply. Solving TCA is still a research area for the company, but its incidence is much lower than in the previous decades [138].

Because of the increased use of screw caps in 2004 the company hired prof. Rui L. Reis from University of Minho to find alternative uses for cork. Prof. Reis was in charge of designing a new research line in composite materials and cork-polymer structures [134]. In 2007, the company expanded the scope of this program by creating a market-oriented research (MOR) department to find additional uses of cork outside their existing business lines (cork stoppers, composites, flooring, and insulation). Current lines of research are aimed at analyzing whether cork can be used as an absorbent, and whether the chemical properties of the bark of the tree have applications in the food, cosmetics, or pharmaceutical industries.

As explained by the manager of the MOR department, the objective is to explore new applications for cork, in areas where the company does not have existing capabilities [140]. Most of the research projects are done in collaboration with external partners and the idea is to develop proof-of-concepts in areas that have the potential to become new business units for the company. For example, in 2009 they undertook a study with the universities of Minho and Lisbon (FCUL) to find whether cork could be used for decontaminating water. Similarly, in 2010, they undertook a project with the university of Porto to find whether the absorbent properties of cork could be utilized in the treatment of oil spills. Out of this research, in 2011 the company launched a new business unit called Corksorb to commercialize a new line of cork-based absorbent products.

The creation of the Market Oriented Research department (MOR) marked an inflection point in terms of the company's university relationships. Between 1999 and 2006 the company participated in 13 university projects, but since 2007 the company has participated in 22 different projects, with a range of university partners. Figure 25 shows the different industrial sectors in which the company has been active and the number of university projects within each sector. As indicated, since 2007 the number of projects between Amorim and its university partners has been growing.

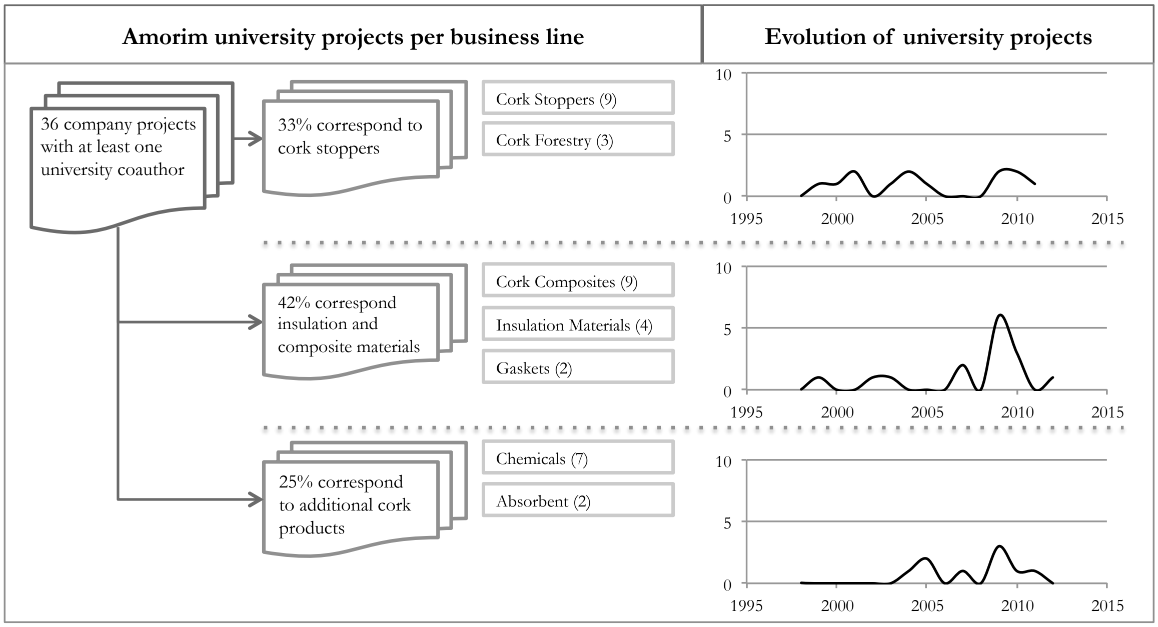


FIGURE 25: COEVOLUTION OF UNIVERSITY PROJECTS AND AMORIM'S BUSINESS LINES

An area in which the MOR department has been active is in finding value-added chemicals from cork which have applications in the food, cosmetics and pharmaceutical industries. In 2004, the company worked with IBET a Portuguese Biotechnology Institute to utilize supercritical fluid extraction of chemical compounds present in the bark of the cork oak, a project that was continued with the university of Minho in 2007. In 2005, the company collaborated in two European-funded consortiums aimed at finding value-added chemicals in waste effluents from cork manufacturing (project WaCheUp) and another for finding adhesives and ecological binders from the bark of the trees (project Ecobinders). In 2007, Amorim undertook a follow-up study with the university of Minho aimed at obtaining natural adhesives from the bark of the cork oak. In 2009, the company participated in a consortium with the universities of Coimbra and Minho to extract cork tannins, and in 2010 they collaborated with IBET and the university of Coimbra on a project aimed at analyzing the anti-oxidant properties of cork for the food industry.

The MOR department has also participated in several research consortiums aimed at developing new materials and components for the automotive, aeronautical, and public transportation industries. In 2009, they worked with the University of Minho on a project aimed at developing new aircraft materials (AeroCork), and also at developing new automotive paddings (Plascork) with improved acoustic shielding properties. That same year researchers at Amorim worked with the University of Porto on a project aimed at designing eco-friendly aircraft cabin materials, and a second project aimed at designing new seats for the Portuguese train system. In 2010, the company participated on a similar projects aimed at designing new seats for buses, and also for developing eco-friendly materials for train interiors with the university of Minho (EcoTrain).

3.1. Research priorities along Amorim's value chain

We have organized Amorim's university relationships from a value chain perspective. Figure 26 shows the different processes involved in the manufacture of cork products. Most of Amorim's university projects have been on end products, in particular, on natural cork stoppers, cork composites, and value added chemicals.

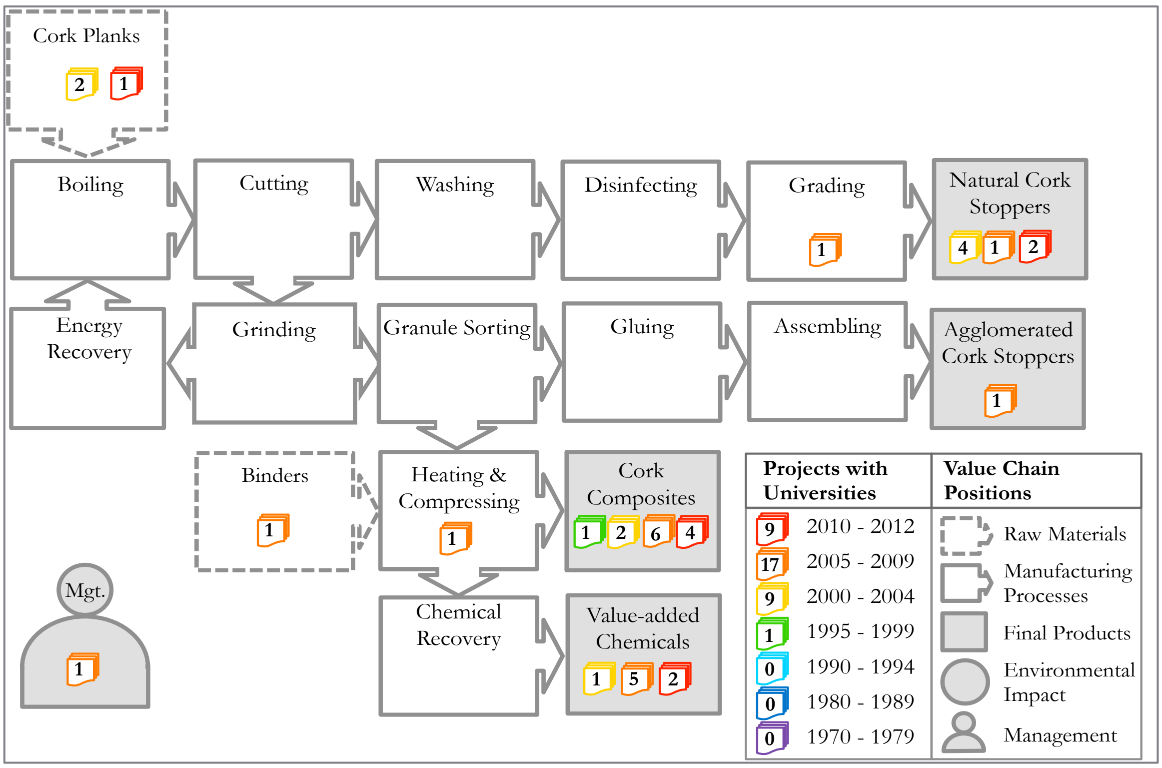


FIGURE 26: EVOLUTION OF AMORIM'S UNIVERSITY PROJECTS ALONG VALUE CHAIN

In the area of cork stoppers, the company has undertaken studies aimed at understanding the fungal colonization process with the Higher Institute of Agronomy (ISA) and IBET. In 2001, Amorim provided partial support for a PhD dissertation at the University of Porto aimed at understanding the influence of pesticides in the formation of TCA. That same year, the company worked with the University of California, Berkeley in the US to breakdown the TCA chain to better understand the chemical properties of this compound. In 2002, after three years of in house R&D, the company launched ROSA, a cork steaming process that reduced TCA by 80%. In 2003, the company hired the Excell Laboratories (France), the Australian Wine Research Institute (AWRI), the Geisenheim Research Institute (Germany), and Campden & Chorleywood Food research institute (UK) to independently validate the performance of ROSA [134]. In 2004, Amorim funded the PhD thesis of a student at the University of Bordeaux, France, aimed at defining the oxygen transfer rates associated with the different wine closures. This study revealed that natural corks were able to preserve wines better than synthetic wine closures. In 2005, the company worked with the University of Loughborough (UK) to create a new composite cork stopper and in 2009, the company collaborated with ISA and the New Jersey Institute of Technology on a project aimed at utilizing terahertz imaging for screening and sorting natural corks stoppers, a process which is currently done by hand. In 2010, Amorim collaborated with the universities of Porto and Coimbra to develop a surface treatment for cork stoppers to prevent migration of cork tannins and phenolic compounds into wine and spirits. In 2011, the company started working with the Higher Institute of Technology (IST) on a project aimed developing another technique for removing TCA from natural cork stoppers.

In the area of composite materials, the company has undertaken several projects aimed at improving and expanding their current product line, especially through collaborations with the universities of Minho and Porto. In 2002, they worked with the university of Minho on a project to improve the company's cork gaskets. In 2003, Amorim participated on a research consortium aimed at developing new cork-based materials for the Portuguese footwear industry.

In the area of insulation materials, in 2005 the company signed a collaboration agreement with the construction department of the university of Coimbra (ITeCons). Since then, Amorim and ITeCons have collaborated in several projects aimed at improving the thermal and acoustic properties of cork panels used in flooring, ceiling, and wall covering industries. In 2009 they developed ISOL+, an energy efficiency software, that calculates the energy savings of introducing cork in to the built environment. In 2010 these two partners worked on a project called Wallinblock to develop a modular partitioning system for interior and exterior walls with improved thermal and acoustic shielding properties. Finally, in 2012, the company formed a research consortium to develop a new construction brick using a mix of lightweight concrete and expanded cork granules [135].

3.2. GEOGRAPHY OF UNIVERSITY PARTNERS

Figure 27, based on Amorim's publication records, shows the geographic distribution of the company's university network. Amorim's university network has historically been concentrated in Portugal, with universities located near the company's production sites in the North of Portugal (U. Minho and U. Porto). Amorim's international network of university partners is smaller, and mainly concentrated with research institutes at wine producing regions including Excell Laboratories (France), the Australian Wine Research Institute (AWRI), the Geisenheim Research Institute (Germany), Campden & Chorleywood Food research institute (UK), University of Loughborough (UK), New Jersey Institute of Technology (US), and the University of California, Berkeley (US).

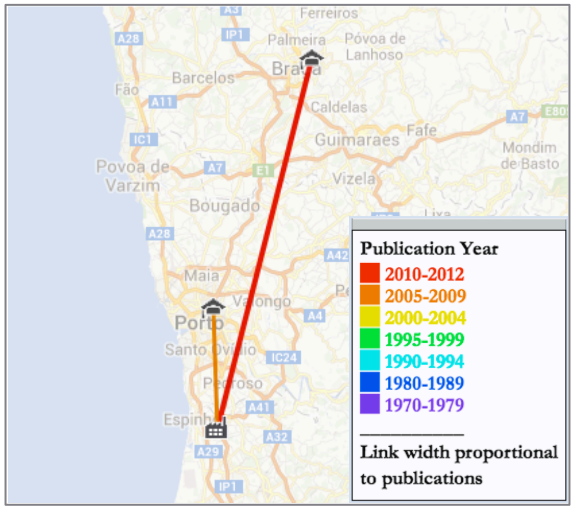


FIGURE 27: AMORIM'S NETOWORK OF UNIVERSITY COAUTHORS

3.3. TECHNOLOGY TRANSFER THROUGH PEOPLE FLOWS

To analyze the academic and professional trajectories of Amorim's most prolific authors and inventors we used Amorim's publications and patenting records to develop a list of 14 people involved in the company's R&D activities. Each individual in the list has either patented or published at least one paper under Amorim's name.

Figure 28, which shows the evolution of Amorim's research staff, indicates that most of Amorim's R&D personnel were recruited from academia. The firm's R&D staff began growing in the 1990s and has stabilized in recent years. Since Amorim's R&D departments are rather new, most of the firm's personnel are still working for the firm.

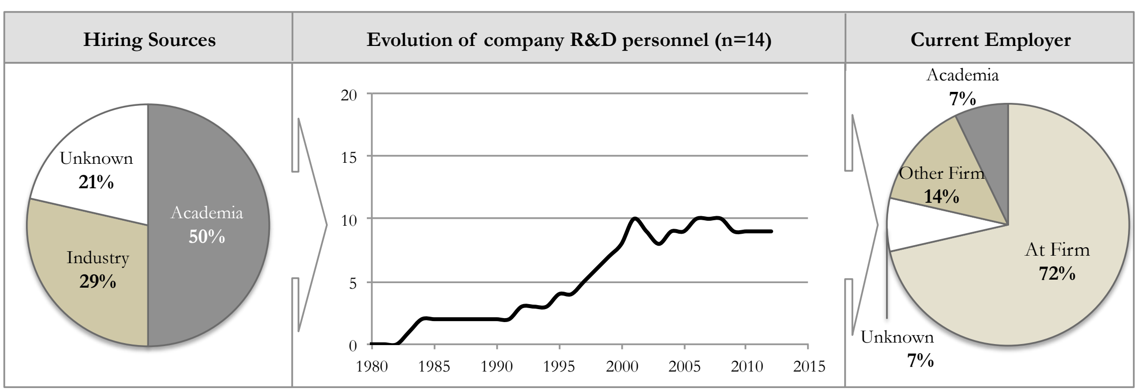


FIGURE 28: EVOLUTION OF AMORIM'S R&D PERSONNEL

Analysis of the academic training of Amorim's researchers shows an overlap between the academic institutions attended by these people and the company's publication partners (See Figure 29). Most of the firm's research staff have been recruited from the University of Minho and the University of Porto, which are also the firm's most common publication partners.

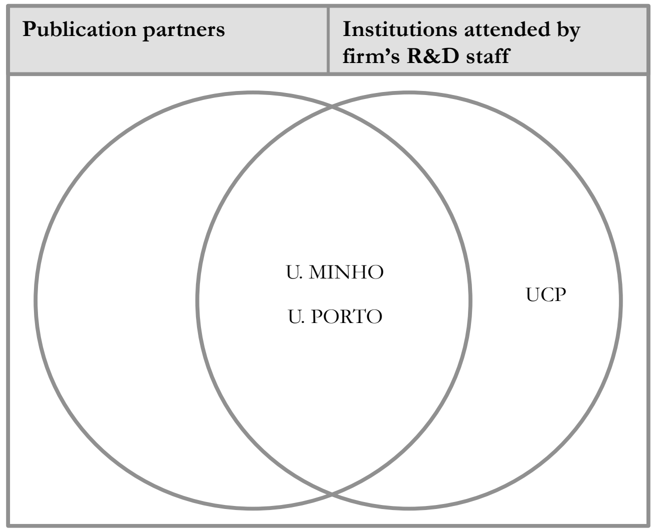


FIGURE 29: OVERLAP BETWEEN AMORIM'S HIRING AND PUBLISHING PARTNERS

4. CASE STUDY DISCUSSION

Amorim has endured several strategic changes and participated in a diverse set of industries and regions over time. Table 18 presents a summary of the history. As discussed in Section 3, Amorim was initially reactive in terms of R&D investments and we could not find any university engagement before the formation of the firm's first R&D lab in 1999. Table 18 thus shows a summary of the last three strategic periods of the firm, and how Amorim's research priorities, people flows, and institutional networks were modified as a consequence of the observed changes in the firm's strategy.

TABLE 10: SUMMARY OF HOW AMORIM'S UNIVERSITY RELATIONSHIPS COEVOLVED

University Links / Firm Strategies	Research Priorities	People Flows	Institutional Networks
Period 3: **Diversification** (1979-1988)	**Quality Assurance** • Trace contamination sources of TCA	**First quality assurance lab** • Hired technicians to monitor quality of corks	**Growth of Portuguese Univ.** • No evidence of formal university relationships
Period 4: **Internationalization** (1989-1999)	**Solve TCA** • Initiated studies to eliminate TCA • Creation of new stoppers to mitigate TCA	**First R&D Lab** • Initial R&D staff of 4 people with advanced degrees • Growth R&D staff	**First sponsored R&D projects** • Hired Prof. from U. Porto to head first R&D lab
Period 5: **Integration** (2000-Present)	**Find additional uses for cork** • Composite materials • Chemical byproducts • Cork-based absorbents	**Market Oriented R&D Lab** • Creation of new lab for finding additional uses for cork	**Growth in University network** • Increased sponsored projects in Portugal • First international collaborations

The case of Corticeira Amorim also illustrates how changes in the economic context (e.g. increased competition) determine the need for establishing university links. It was only after the emergence of synthetic cork stoppers that the company decided to invest in R&D and to solve the TCA problem. As explained by a senior company manager: "the trigger was that the most important application of cork, which was—and still is—is the cork stoppers, was challenged and put at stake in the world market. Cork as a stopper was invented by Dom Perignon in 17th century, and since then cork was basically the only closure to wine or sparkling wine bottles. And that was challenged with the introduction of plastic stoppers in the late 1990s. The cork industry had to react and Amorim had to react as the market leader. You really need to mark the way in difficult moments like that. This was when we got to do the homework and started to invest in R&D, creating new teams of R&D, not only in the cork stoppers, but also in the other divisions, and 10 or 12 years later, things are really looking up for us again. But I think that the spark that provoked all this was that our most important application, cork stoppers, was threatened with alternative closures"[141].

More recently, Amorim is taking actions to find additional uses for cork in which the company is relying on an extended network of university partners, who are used as exploration vehicles for finding new applications and developing proof-of-concept information about new business lines. This is consistent with the literature on industry-university relationships that has found that firms with R&D strategies geared towards exploration allocate a greater share of their resources towards university research projects, developing deep and multifaceted links with their academic partners [13].

Appendix II: Portucel Soporcel

1. Introduction

The Portucel Soporcel Group (PSg) is one of Europe's largest manufacturers of Bleached Eucalyptus Kraft Pulp (BEKP) and of uncoated woodfree printing and writing papers (UWF). The 2011 sales were approximately US$2.1 billions, 95% of which came from exports to 115 countries [142]. The company has a workforce of 2300 employees, and manages 120 thousand hectares of timberland in Portugal (approximately 300,000 acres). Since 2007 the company has also been active in the generation of electricity from biomass, currently accounting for 4% of Portugal's electricity generation [142].

PSg has three industrial complexes in Portugal, one for Pulp production in Cacia, and two integrated paper and pulp facilities in Figueira da Foz, and Setúbal. The company has also one central R&D lab, the Raiz Institute, which conducts research in forestry and paper making processes. PSg currently spends US$ 8 millions on R&D, and ranks number 40 among Portugal's R&D spenders [143]. Figure 30 shows the evolution of the firm's R&D intensity and sales volume.

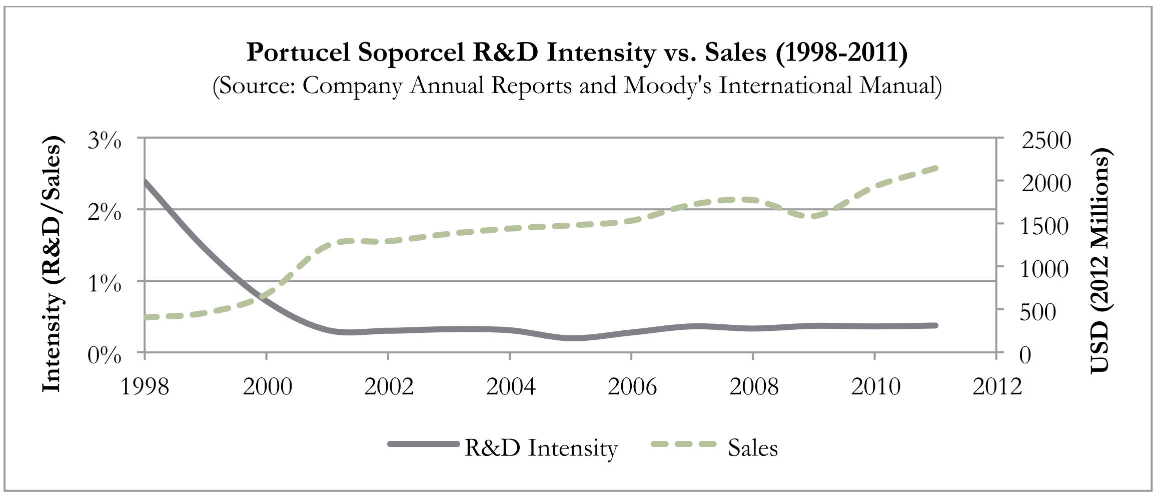


FIGURE 30: EVOLUTION OF PORTUCEL SOPORCEL R&D INTENSITY

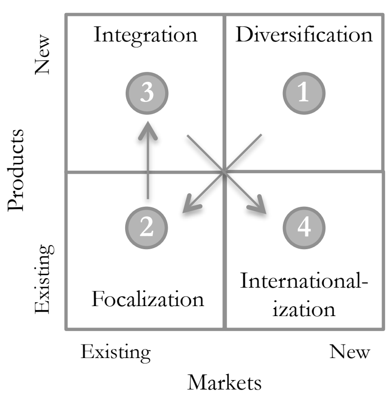
To analyze how Portucel Soporcel's university relationships have coevolved with changes in the firm's strategy we conducted a longitudinal analysis of the different strategic actions taken by the firm, distilling four different strategic periods. We then characterized the firm's university relationships, and analyzed how these relationships evolved during each strategic period of the firm.

The case proceeds as follows. Section 2 provides a characterization of the different strategies pursued by gPS. Section 3 describes the origins and evolution of the firm's university relationships as judged by 1) changes in the research priorities; 2) changes in the network of university partners, and 3) people flows between partnering institutions. Finally, section 4 summarizes the main findings and lessons from the Portucel Soporcel case.

2. HISTORICAL CHANGES IN PORTUCEL SOPORCEL'S STRATEGY

Data on Portucel Soporcel's strategy was obtained by analyzing the company's annual reports, and through secondary sources such as journals, press articles, and company historical retrospectives. We also conducted three on-site interviews with company managers, and researchers involved in R&D. Based on the data, we defined four strategic periods (see Figure 31).

STRATEGIC TRAJECTORY



STRATEGIC PERIODS

Period 1 (1950-1974): Diversified forest products company

Period 2 (1975-1992): Nationalization and focalization in bleached eucalyptus pulp

Period 3 (1993-2003): Privatization and integration into uncoated woodfree papers

Period 4 (2004-Present): Internationalization into Africa

FIGURE 31: PORTUCEL SOPORCEL STRATEGIC PERIODS

PERIOD 1 (1950-1974): A DIVERSIFIED FOREST PRODUCT COMPANY

During the 1940s, the Portuguese government began an industrialization effort. Portugal's domestic pulp and paper industry was then composed of small producers that lacked the scale and technology to compete with Northern European manufacturers. Because the country relied almost exclusively on Nordic pulp and paper imports, the development of a modern paper and pulp industry became a national priority [144].

In 1950, Portugal secured US$4 millions from the Marshall plan to create the Portuguese Celulose Company (CPC). With these resources, CPC bought machinery from North American and Northern European suppliers, inaugurating in 1953 a mill in Cacia for the production of Kraft pulp from pine trees.

Since the Kraft sulfate production process was new for Portugal, CPC contracted Finnish engineer Karl Amperla to start the pulping production at the Cacia Mill, and between 1953 and 1957, Finnish technicians were in charge of training the company's technical staff. CPC then internalized this knowledge and began conducting research into improving pulp quality and developing new bleaching technologies [144].

The Portuguese government's goal for CPC was to substitute pulp and paper imports to the country. CPC was thus initially designed to produce a wide array of products. In 1955, the company started producing mechanical pulp for newsprint, corrugated containerboard, and Kraft paper bags [144]. During the following years, CPC became a conglomerate of different factories producing mechanical and chemical pulps, writing papers, newsprint, corrugated cardboard and packaging boxes, Kraft paper bags, and adhesive tapes.

The CPC's manufacturing costs, however, were high compared to the economies of scale achieved by international pulp and paper producers. For example, Portugal's electricity cost—approximately 30% of paper making production costs—was four times that of Scandinavian manufacturers [144]. In 1956, therefore, CPC began importing Norwegian pulp for producing newsprint. In parallel, Portugal began discussions to create an Economic Free Trade Association (EFTA) with Norway and Sweden.

In-house innovation: Bleached eucalyptus kraft pulps

In 1956, the CPC research lab started experimenting with the production of pulp from eucalyptus trees (*eucalyptus globulus*). This species was already available in Portugal, it grew faster than Northern European species, and when harvested it could grow again up to three times from the same stump [145]. There were doubts, however, on the technical viability of utilizing the Kraft process for producing eucalyptus pulps.

Since the 1920s, Eucalyptus pulps had been manufactured in Portugal through the bisulfite process. The resulting pulps were short and soft, limiting their application for papermaking and they were generally used as a filling material, which needed to be combined with long pulp fibers for the production of paper.

In 1957, CPC succeeded in adapting the sulfate process for pulping eucalyptus, becoming the first European manufacturer of bleached eucalyptus pulp (BEKP). The resulting pulp was suitable for the production of fine papers and offered high yields. When compared to the resinous tree species of Northern Europe, Eucalyptus trees grew faster, and required fewer chemicals to be pulped and bleached. The availability of this raw material provided the CPC with an opportunity to become an exporter of fine papers.

Increased competition and the raise of the environmental movement

During the 1960s, other domestic and foreign competitors began producing bleached eucalyptus pulp. CPC had developed internal know-how for the production of pulps, and several companies sought their technical assistance. The Cacia mill was known as "the university of cellulose" [144], and the CPC's technical staff provided technical assistance to paper and pulp manufacturers in Portugal, Spain, France, Brazil, Yugoslavia, and Angola. In 1959 the Sociedade Industrial de Celuloses (Socel) hired CPC technicians for providing the know-how for establishing a new pulp mill in Setubal. Socel became operational in 1964, and CPC obtained 25% of the shares of this company.

The entrance of new players to the Portuguese market increased competition for raw materials and caused shortages in the local supply of wood. Landowners responded by planting new forestlands, and Portugal's landscape became occupied with eucalyptus trees. This sparked an environmental movement against eucalyptus trees, which were seen as an invasive species. Pulp mills also came under tight scrutiny for their environmental practices and in 1972 the CPC had to pay compensations to local farmers for the pollution of the Vouga River [144].

Supply of raw materials was the main concern for the Portuguese paper and pulp industry and, in 1969, to solve this problem several large players in the forest products sector decided to form Madeiper, a wood procurement agency in charge of "acquiring all eucalyptus produced in Portugal" [144]. This monopsony was in place until 1975, when it was dissolved after the Nationalization of the industrial sector.

Seeking raw materials and new growth opportunities, in 1973 CPC planned an expansion into Angola through the creation of a company named Cenangol. CPC bought a new pulp mill, which was ready to be shipped to Angola. The 1974, Portugal's Carnation Revolution changed these plans. Angola became an independent nation in 1975 and the Portuguese paper and cellulose industry became nationalized.

Period 2 (1975-1992): Nationalization and Production Expansion

In 1975, the Portuguese government nationalized the country's pulp industry and created a consolidated company called Portucel. This company took control of CPC's Cacia Mill, and also Socel's forestlands and Setubal mill. That same year Angola gained independence from Portugal, and this changed CPC's plans to open a pulp mill in that country. Since the pulping mill had already been bought, Portuguese officials decided to create a new company, Soporcel and to install this pulping mill in Figueira da Foz, Portugal.

During the late 1970s, most of Portucel's strategic actions were aimed at increasing pulping capacity, and diminishing environmental impacts of its operations. Portucel's production capacity rose from 150,000 tons/year in 1970, to 500,000 tons/year in 1980 [144, 145]. This represented approximately 70% of all cellulose produced Portugal [145]. Portucel's expansion, coupled with the beginning of Soporcel's pulping operations in 1984, increased the demand for eucalyptus wood. As a result, Portucel began investing heavily in forestry, going from controlling 9,300 hectares of eucalyptus in 1970 to 100,000 hectares in 1990 [144, 145]. Portucel also placed increased attention on environmental impact. Between 1978 and 1988, the company began a stepwise plan to install air filters and effluent treatment plants to reduce the contamination of the Vouga River [145].

Period 3 (1993-2003): Privatization and Vertical integration

In 1993, Europe established a common currency, and transitioned towards the reduction of trade barriers among Union members. To allow companies to better compete in the international market, in the 1990s Portugal began a period of privatization of public assets [145]. In 1993, Portucel Industrial was incorporated as a manufacturer of eucalyptus pulp with two mills in Cacia and Setubal. In 1995, this company was privatized, and the government sold 44.3% of Portucel to local investors. At this time, Portucel had 14% of the world eucalyptus pulp market, and was responsible for 2% of all Portuguese exports [145].

Because there was not enough raw material for Portucel to continue growing in pulp, in 2000 the company began a period of forward integration into paper production [126]. Portucel acquired INAPA in 2000, a paper manufacturer with production units adjacent to Portucel's mill in Setubal, and, in 2001, Soporcel, which was partially owned by the Portuguese government and by Arjo Wiggins a UK manufacturer of paper products. That year, the company's President challenged Portucel's technical staff to decide whether the company should produce coated or uncoated papers[126], and a strategic decision was made to concentrate on uncoated woodfree papers [146].

The decision to move into paper production also had consequences for other business lines of the company. In 1999, Portucel spun-off its kraft paper bags division, creating a new company called Kraftsack [147], and in 2000 they divested Gescartao, its packaging materials subsidiary, which represented almost 30% of the company's sales [145].

Period 4 (2004-Present): Capacity expansion and Internationalization

In 2003, the Portuguese government sold its remaining stake in Portucel, and in 2004, the company came under the control of the Portuguese group Semapa. Portucel now faced increased competition from low cost manufacturers of pulp in the southern hemisphere. To reduce its exposure to fluctuations in the pulp market, Portucel built a new paper mill in Setubal [148], with a capacity of 500,000 tons of paper. The mill began operations in 2009.

In 2008 the company began to expand into the southern hemisphere. It reached agreements with the governments of Uruguay and Mozambique for exploring investment opportunities [149]. In 2009, Portucel signed an agreement with the government of Mozambique to exploit 183 thousand hectares in the Zambezia Province, and in 2011, the company obtained a second land use license for 220,000 hectares in the Manica Province [150]. Currently, the company is testing more than 50 different varieties of eucalyptus to find the right trees for the soil and climate conditions of this country [142]. The company also expects to open a pulp mill for producing cellulose in 2020-2025 [151].

3. THE ORIGINS AND COEVOLUTION OF PORTUCEL SOPORCEL'S UNIVERSITY RELATIONSHIPS

After the 1974 Revolution, the Portuguese higher education system experienced a period of transformation and rapid growth. During the 1970s and 1980s, new public and private universities, including polytechnic institutes, were established, and enrolment rates went from approximately 30,000 students in the 1960s to 400,000 students by the end of the 1990s [152].

Of particular importance for Portucel's future industry-university relationships were the creation of the University of Aveiro in 1973; the creation of a Faculty of Sciences and Technology at the University of Coimbra in 1972; and the creation in 1976 of the Center of Forestry Studies (Centro de Estudios Forestais – CEF) at the Technical University of Lisbon (ISA-UTL). In 1995, all these institutions became partners with Portucel and Soporcel in the creation of the Raiz Institute.

The University of Aveiro, located six miles away from Portucel's Cacia Mill, was founded to provide research and qualified professionals for the local industry [153]. The University has created new programs in areas not explored by traditional Portuguese universities, including ceramics, telecommunications, and environmental engineering [154]. In 1976, the Chemical Department was formed, and during the 1980s the university began offering a bachelors degree in chemistry.

The University of Coimbra, one of the oldest universities in Europe (dating back to 1290), also began a transformation process during this period. In 1972, the University created a degree in Chemical Engineering and in 1989, a Masters and PhD program in pulp and paper production [155]. In 1991 the Chemical engineering department was formed, and the University created a research center for chemical processes in the forest products industry (CIEPQPF). The Department of Chemical Engineering is located approximately 40 miles away from SOPORCEL's Figueira da Foz mill, and since the 1987 it has had close collaborations with industry [155].

In 1976, the School of Agronomy of the Technical University of Lisbon (ISA-UTL) created a Forestry Research Center (CEF). This center began conducting multidisciplinary research on the eucalyptus ecosystem, including hydrology, sulviculture, and plant breeding programs. The Center's initial focus on eucalyptus was partially in response to the environmental movement formed against the eucalyptization of Portugal's forestlands. As explained by a founding member of the CEF, "The main trigger for the establishment of the CEF was the environmental movement that saw eucalyptus as an exotic species" [156]. Environmentalists had concerns about the environmental impact of eucalyptus, in particular, its water consumption and its impact on local agronomy and to address these concerns CEF began working with the local industry (for more information on the origins of CEF's industrial relationships see the vignette on page 117).

THE RAIZ INSTITUTE: A HYBRID INDUSTRY-UNIVERSITY RESEARCH ORGANIZATION

In 1995, Portucel and Soporcel merged their research and development units forming an independent institute called Raiz (Instituto de Investigação da Floresta e Papel). The idea behind was to facilitate the future merger of these companies [126]. Portucel and Soporcel held 94% of the shares of this institute, and the remaining 6% belonged to the Universities of Aveiro, Coimbra, and ISA-UTL.

One initial goal for this institute was to increase the yield of the company-managed forestlands. Specific lines of research thus included the genetic improvement of trees through breeding programs, the control of pests, and the definition of fertilization standards. The Institute also conducts applied research on pulp and paper manufacturing, with specific research lines on increasing the efficiency of the manufacturing process, reducing contamination, and improving the printing quality of uncoated papers. In all these areas, Raiz has established relationships with different university partners.

A perspective on the evolution of Portucel Soporcel's university relationships is presented in Figure 32 which shows the different business lines and the number of university co-publications per line. The company has published 60 papers in open science journals, 59 of which have been written with at least one university partner. All these publications were written after the Raiz institute was created. This does not mean that the company lacked university relationships prior to the formation of the Raiz Institute, but rather highlights the academic orientation of this hybrid research organization.

As observed in Figure 32, 44% of Portucel Soporcel's publications with universities are in the area of forestry, and 39% correspond to the firm's paper and pulp operation. Since 2007, the company has diversified the scope of their research activities to include waste valorization studies, including the production of biofules, biochemical, and the exploration of byproducts from waste materials.

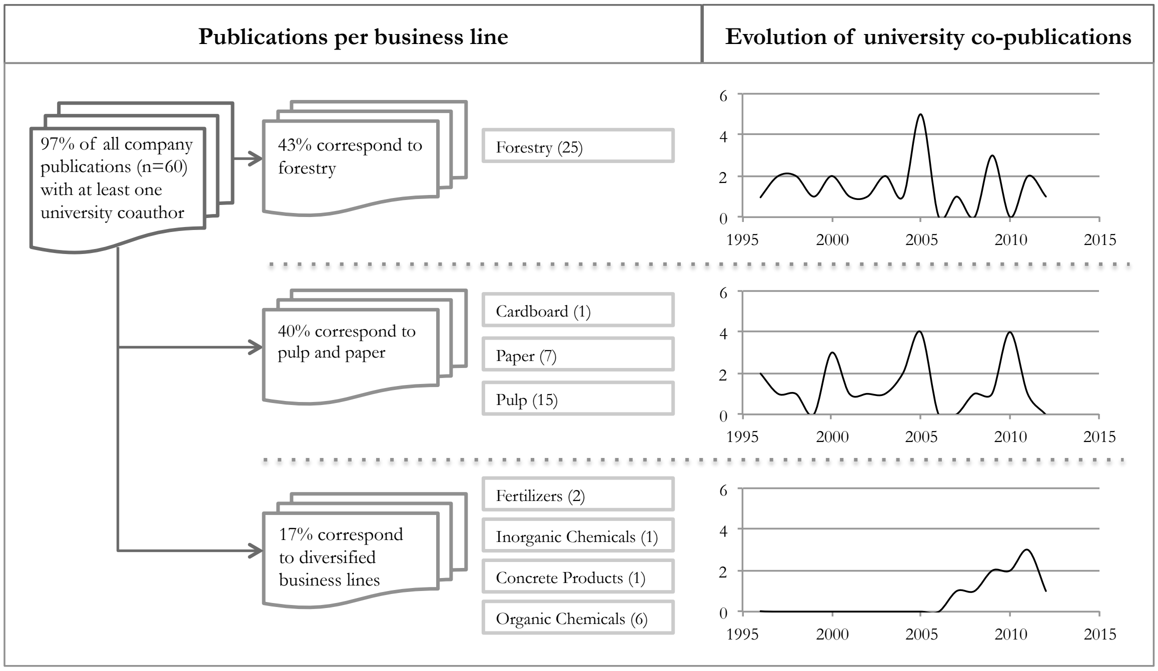


FIGURE 32: COEVOLUTION OF UNIVERSITY CO-PUBLICATIONS AND PORTUCEL SOPORCEL BUSINESS LINES

3.1. Research priorities along Portucel Soporcel's value chain

If we analyze the firm's university relationship from a value chain perspective (Figure 33), we observe that most of the collaborations have been in the areas of raw materials (i.e., forestry) and final products (i.e., paper and pulp). Little research has gone into process technologies.

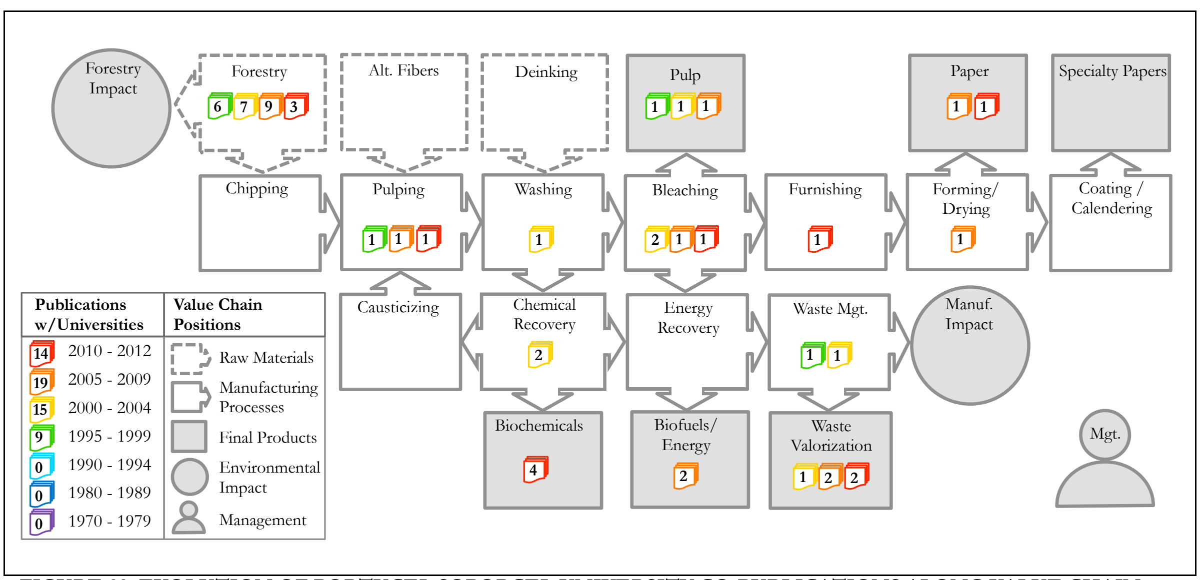


FIGURE 33: EVOLUTION OF PORTUCEL SOPORCEL UNIVERSITY CO-PUBLICATIONS ALONG VALUE CHAIN

Forestry Research Collaborations

During the 1990s, Soporcel began a program for the genetic improvement of the Eucalyptus Globulus. In 2000, the program was expanded to describe the genomic sequence of eucalyptus, in collaboration with Brazilian, and Spanish companies, and the technical assistance of North Carolina State University, IBET, ITQB, and the University of Toulouse [157]. The company also conducted studies on the characterization of the soil and climate conditions of their forestlands, in order to create tree clones tailored to the terrain conditions. In 2006 the company created a new eucalyptus clone suitable for dry or medium-dry terrain conditions [158].

In the area of pest control, the Raiz Institute conducted studies aimed at finding natural predators for the *Phoracantha Semipunctata* and the *Gonipterus Scutellatus*, two beetles endemic from Australia which feed on eucalyptus affecting its yield [157]. In 1996 the company worked with the university of Evora to find natural enemies for the *Phoracanta* beetle, and in 2009, the company collaborated Australian universities to find natural enemies for the *Gonipterus* beetle and to diversify the genetic pool of their clones to make them more resistant to this pest. The company succeeded in finding two natural enemies for the *Gonipterus* beetle and since 2010 began testing 20 different eucalyptus species to find if they are able to resist this pest [150].

In the area of forest management and fire prevention, the company has close collaborations with the University of Tras-os-Montes e Alto Douro (UTAD), in particular with prof. Paulo Fernandes [126]. In 2009 the Portucel Soporcel Group initiated collaboration (project Fire Engine) with UTAD, MIT, and ISA, with the goal of improvign the combat and prevention of fires, and developing a forest fire management system.

PULP AND PAPER RESEARCH COLLABORATIONS

In the area of pulp and paper technologies, the company has built close ties with two universities close to their northern mills: the University of Coimbra and the University of Aveiro. With the University of Coimbra, the company has worked with the Department of Chemical Engineering in the area of paper and pulp production. In 1989, Portucel established a protocol for teaching three different courses at the University of Coimbra, and began offering paid internships to chemical engineering students. In 2001, the company collaborated with researchers at the University of Coimbra in the project OPTI-Kraft aimed at improving the economic and environmental aspects of the pulping process, and in 2009 they conducted a study aimed at analyzing the ink spreading patters on uncoated papers (Project PADIS). Out of this project, Portucel Soporcel launched in 2010 a new line of papers for specially designed for inkjet printers, and they are currently testing a new surface treatment technique based on nanoparticles of styrene copolymers for producing premium papers with improved optical properties [142]. With the University of Aveiro, Portucel Soporcel has worked with the Department of Chemical Engineering on several projects aimed at improving the pulping process and fiber quality of printing papers. In 1999 they collaborated on a project for improving the bleaching process with oxygen and polyoxometalates. In 2002, they worked on project aimed at improving the yield of the eucalyptus Kraft pulping process. More recently, the company began a project called Paperbright aimed at obtaining high performance bleached pulps.

Environmental Research Collaborations

In 2004 the company began a certification program of all their forestlands through the Programme for Endorsement of Forest Certification (PEFC) and Forest Stewardship Council (FSC) norms [157]. In 2007, the company created an environmental committee to guide their actions into sustainable forestry. Five professors from the universities of Aveiro, ISA, Coimbra, Universidade Nova, and IST compose the board of this committee, which meets three times per year to assess the company's environmental performance and suggest strategic of actions.

Waste Valorization Research Collaborations

In 2006, the company began research in biofuels, including the assessment of crops with both pulping and energy potential [158]. They also started other research aimed at finding additional value in pulping waste products. In 2008, the company explored the utilization of pulping residues mixed with bituminous substances for creating a paving mix for road construction [149]. Other projects include the utilization of lime sludge for correcting the acidity of soils, and the extraction of substances from eucalyptus bark for its use in the food, cosmetics, and pharmaceutical industries [142]. All these projects have been done in collaboration with Portuguese universities.

The company has been working since 2010 on a project named Trees for Joules, which seeks to improve eucalyptus trees for energy conversion. This project is in collaboration with ISA and the universities of Paul Sabatier in France, and the Portuguese IBET institute. That same year, the company started a project with the University of Coimbra for producing biofuels from Kraft pulp residues (project BIIPP). Another new project is development of new polymer structures reinforced with cellulose fibers for eco-friendly products (project Valorcel with the university of Minho).

3.2. Geography of university partners

The maps in Figure 34, based on the company's publication records, shows that most of the company's university partners are located close to Portucel Soporcel's manufacturing centers in Portugal. The Raiz institute is the main node within this network, and professors from the Universities of Coimbra, Aveiro and ISA are the most frequent university coauthors.

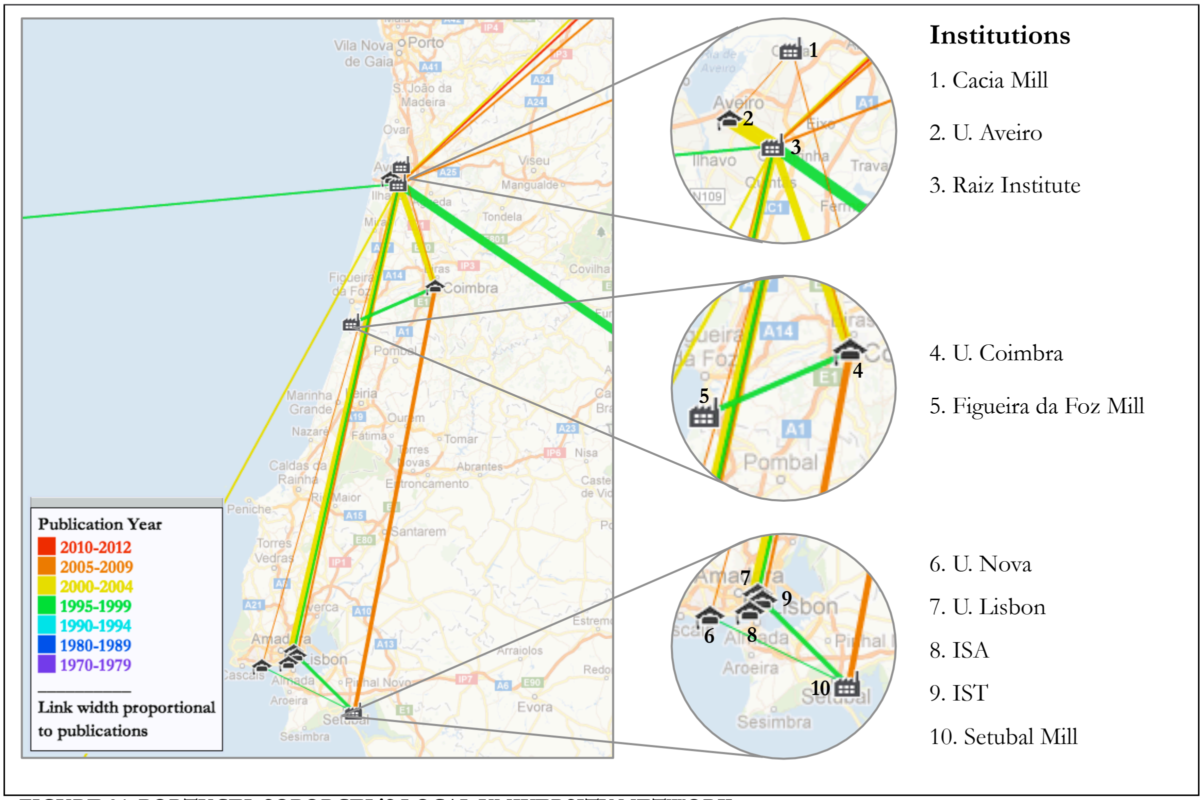


FIGURE 34: PORTUCEL SOPORCEL'S LOCAL UNIVERSITY NETWORK

At the international level, the company has established strong research collaborations with the University of Tasmania, and North Carolina State University (NCSU), among others (See Figure 35). The relationships with these international partners have been mainly in the area of forest genetics. With the University of Tasmania the company has worked on tree genetics. With NCSU, in 2004, the company started a project called GENOGLOB, to genetically improve the eucalyptus tree.

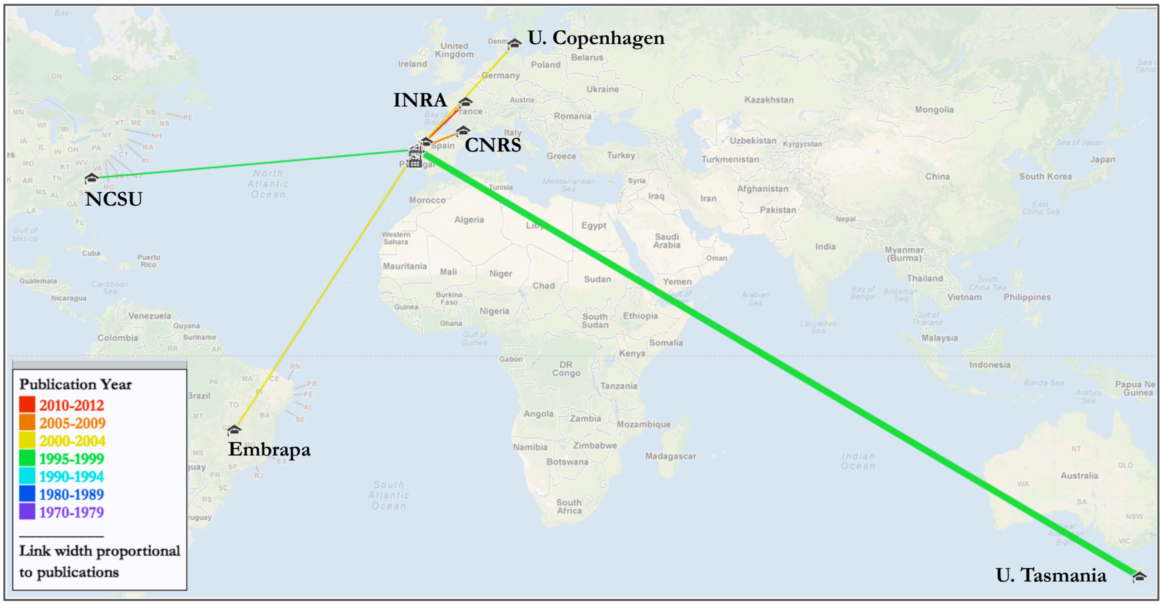


FIGURE 35: PORTUCEL SOPORCEL'S GLOBAL UNIVERSITY NETWORK

3.3. TECHNOLOGY TRANSFER THROUGH PEOPLE FLOWS

Portucel Soporcel has conducted in-house R&D since the 1950s, but only recently has the company began patenting and publishing its work in open science journals. These publications provide an opportunity for determining the people involved in R&D activities and to analyze their academic and professional careers. The names obtained through this patent and publication analysis does not constitute a representative or complete list of all company R&D personnel. For example, the Raiz Institute reports having 55 collaborators [159], yet only 22 different individuals have published or patented under Raiz or Portucel Soporcel's name. The exercise of analyzing the academic and professional trajectories of these people is useful, however, as it provides information on the trajectories of the firm's most productive researchers.

Twenty-two individuals have either patented or published at least two papers under the company's name. Analysis of professional trajectories shows that most of the twenty-two have been recruited from academia, joined the company during the 1990s, and continue working for the firm. At an aggregate level, the number of researchers peaked in 2000, and has remained stable since then (See Figure 36).

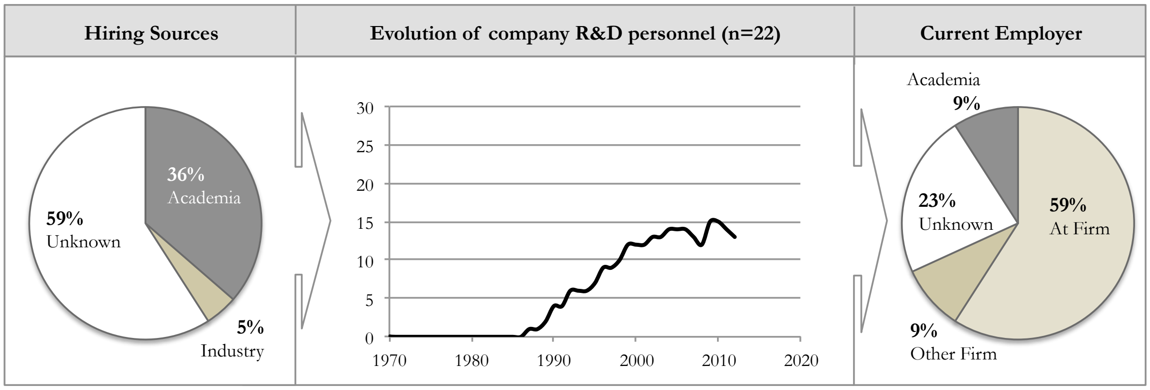


FIGURE 36: EVOLUTION OF PORTUCEL SOPORCEL R&D PERSONNEL

Analysis of the academic training of the researchers shows an overlap between the institutions attended by these people, and the university publication partners. Figure 37 shows that most of the firm's research staff have been recruited from Portuguese universities, which are also the firm's most common publication partners.

There are several dynamics that explain this trend. First, companies tend to recruit from universities that have developed expertise in knowledge areas relevant for the firm. Second, company personnel have pursued university degrees while working, and have conducted research on projects relevant for the firm. Soporcel, for example, sent a researcher to pursue her PhD at the North Carolina State University to support the company's research line in eucalyptus genetics [160]. Four research papers between NCSU faculty and Portucel Soporcel researchers have been written since then. Third, company personnel have occupied part-time faculty positions at partnering universities, and others participate in thesis committees. The on-campus presence of company personnel provides an opportunity for scouting for talent, as well as the development of research in areas relevant to the firm's knowledge base. Finally, people move with their network, and tend to recruit and seek collaboration partners within the people they already know. As explained by a senior company manager "In the middle of the 80s, we established a variety of agreements with ISA for studying eucalyptus. It was the closest at the time, and in the middle of the 80s it was the only forestry school in Portugal. Afterwards other universities started with forest sciences, but at the time ISA was practically the only one. Being the only one also meant that all the agronomist and foresters here in the company came from ISA. So we had good relationships with the people there" [160].

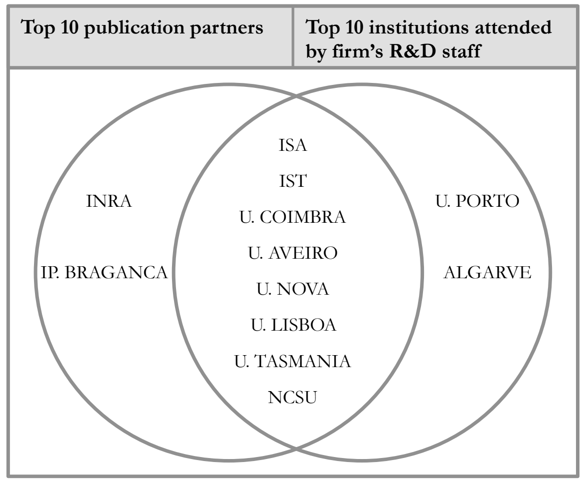


FIGURE 37: OVERLAP BETWEEN HIRING AND PUBLISHING PARTNERS

Permeable industry university boundaries and the role of technological boundary spanners

As shown in Figure 36, the people flows between industry and universities are bidirectional. Firms hire from universities, and people leave firms to join university research laboratories. Permeable industry-university boundaries facilitate the transfer of technology between these institutions. Dr. Nuno Borralho's professional career presents a good example of the permeability of these organizational boundaries and the role played by technological boundary spanners in the diffusion of technology across organizations.

Dr. Borralho received a B.Sc. in Forestry at ISA in 1986, and in 1987 began his professional career as a researcher in that institution. In 1988, he joined Celbi in charge of the company's tree breeding strategy. Celbi had been collaborating with ISA since the 1980s on a tree breeding program [156]. Between 1990 and 1991, he pursued a D.Phil. in Forest Genetics at the university of Oxford, with his dissertation on the "Genetic improvement of Eucalyptus Globulus for pulp production." He returned to Celbi after his PhD and became an invited lecturer on Quantitative Genetics and Tree Breeding at ISA until 1993.

Between 1993 and 1998, Dr. Borralho was a lecturer in the department of plant sciences at the University of Tasmania at Hobart, Australia. He continued working on tree genetics and while in Australia he forged closed relationships with Soporcel. In 1998, this company recruited Dr. Borralho to become director of the Raiz Institute. In this position, he continued collaborating with his colleagues at the University of Tasmania, coauthoring 8 papers on tree genetics between 1996 and 2009. In 2007, Dr. Borralho became an independent consultant and a research associate at ISA's Forestry Research Center (CEF). A depiction of Dr. Borralho's professional career is presented in Figure 38.

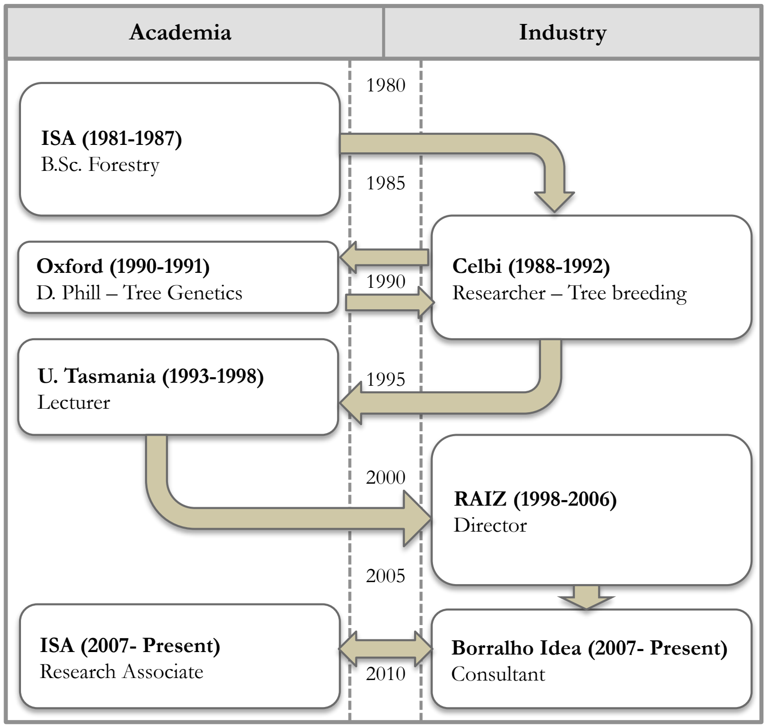


FIGURE 38: PERMEABLE INDUSTRY-UNIVERSITY BOUNDARIES

4. Case Study Discussion

The Portucel Soporcel case shows that industry-university relationships coevolve following a path dependent process. The firm's decision to concentrate on eucalyptus pulps affected its subsequent research agenda with universities and external partners and Table 11 presents a summary of how the firm's different strategic periods affected its university relationships.

During the first period, the company became a diversified producer of forest products. In the absence of local experts, the company relied on Finnish technicians for knowledge on pulping, bleaching, and packaging manufacturing technologies. The company also relied on technical assistance of Albert Reed & Co. from the UK for knowledge of paper and newsprint production [144] which the firm's technical staff adapted to the Portuguese context. Of particular importance was the adaptation of the sulfate process for producing bleached eucalyptus Kraft pulp in 1957. This innovation led to the development of a cost-competitive pulping industry in Portugal, which in turn increased pressures on the supply of raw materials.

The second period was characterized by an increased emphasis on forestry research. New competitors entered the Portuguese eucalyptus pulping market, and firms focused on increasing the yield of their forestlands. At the same time, the Portuguese higher education system experienced a period of rapid growth. New universities were created with the explicit goal of providing the qualified professionals for the local industry.

The third period was marked by the vertical integration of the Portuguese paper and pulp industry. Portucel and Soporcel merged their R&D labs in 1995 creating the Raiz Institute. Three Portuguese universities became partners in this Institute. After the integration of Portucel and Soporcel in 2001, the firm opted for having a narrow business base, and to concentrate on uncoated woodfree papers. Consequently, most of the university collaborations, as judged by publications records, focused on the early stages of the value chain. Forty-four percent of the firm's university-coauthored papers have been in the area of forestry, and only 10% of projects on final products, creating a narrow research focus on the final stages of the value chain.

TABLE 11: SUMMARY OF HOW PORTUCEL SOPORCEL'S UNIVERSITY RELATIONSHIPS COEVOLVED

University Links / Firm Strategies	Research Priorities	People Flows	Institutional Networks
Period 1: **Diversification** (1950-1974)	**Production Processes** • Kraft pulping & bleaching • Packaging manufacturing • Newsprint & papermaking	**International Experts to Portugal** • Finnish experts on pulp and packaging production • UK experts on paper & newsprint manufacture	**Equipment Suppliers** • Links with American and Northern European equipment suppliers • No links with Portuguese Academia
Period 2: **Focalization** (1975-1992)	**Forest Management** • Pest Control • Eucalyptus yield **Environmental Research** • Pollution control • Effluent treatment	**Personnel to International Institutes** • Sent personnel to Australia to diversify eucalyptus genetic pool, and find natural pest controls	**Local University Links** • Initial links with ISA, U. Coimbra and U. Aveiro
Period 3: **Integration** (1993-2003)	**Forest Genetics** • Eucalyptus Genetics **Product Quality** • Paper & Pulp properties	**Increased R&D Staff** • Recruited mostly from local university partners	**Integrated Research Institute** • Raiz institute in partnership with ISA, U. Coimbra, and U. Aveiro • Internationalization of research collaborations
Period 4: **Internationalization** (2004-Present)	**Waste Valorization** • Biofuels • Value added chemicals	**Personnel exchange expected with Mozambique** • Portuguese experts to Mozambique and/or Mozambican experts to the firm	**International University Links** • Research collaborations with Portuguese and international universities

During the fourth period, the company internationalized its manufacturing base by opening a subsidiary in Mozambique. The company has been planting and testing new eucalyptus breeds and is scheduled to open a new pulping mill in 2020. If the pattern holds, the Portucel Soporcel Group will start collaborating with forestry schools in Mozambique, and we expect to see people flows and institutional arrangements with Mozambican universities. If these universities lack experience or knowledge on eucalyptus forestry, we would expect to see the same pattern that gave origin to the Portuguese pulp industry. Portucel will attract

Portuguese or international researchers to jumpstart their forest operations in Mozambique, and the country's universities will internalize and adapt that knowledge to their own context.

The Portucel Soporcel case also illustrates how industry-university relationships are affected—directly and indirectly—by changes in the political and social environment. The Portuguese Carnation Revolution of 1974, for example, changed CPC's plans to open a mill in Angola, and the political event gave birth to Soporcel as a firm. The Carnation Revolution also led to the emancipation of the former Portuguese colonies, which in turn led to the return of several Portuguese university professors that were important in the creation of the university of Aveiro and the subsequent growth in Portugal's higher education system [153].

From a social perspective, both universities and Portucel Soporcel have changed their research agenda in response to social demands. Portuguese academia began developing knowledge on eucalyptus globulus in response to industry demand and also to the environmental movement formed against the perceived "eucalyptization" of the country [156]. Similarly, Portucel began investing in pollution and effluent treatment plants during the 1970s because of social pressures, and the University of Aveiro responded by offering courses on environmental sciences in response to this social demand. The point is that political and social events are important forces that behind the coevolution of industry-university relationships.

A final point refers to the tightly coupled nature of industry-university links. Bidirectional people flows amplify the diffusion of knowledge among partnering institutions, which causes them to create, accumulate, and disseminate knowledge on similar areas. In other words, knowledge is not only created by universities and then transferred to firms. Firms also create knowledge and then transfer it to universities.

A good example of how knowledge flowed from firms to universities is in the area of natural pest control. During the 1980s, the longhorn borer beetle (*Phoracantha Semipunctata*) infested Portugal's Eucalyptus forestlands. The larvae of this beetle make galleries on the trunk of the eucalyptus, weakening and potentially killing the trees. Since the beetle is native from Australia, it had no known predators in Portugal. At the time of infestation, Portuguese universities had no specific knowledge on how to control this beetle. In the words of a former Raiz board member "Since nobody was caring about these issues, we started studying the subject. Knowledge on Eucalyptus was not present in Europe. It was only present in Australia. We sent people and collected knowledge there. We also collected plant specimens in order to diversify the biogenetical basis of the eucalyptus in Portugal" [160]. Soporcel internalized this knowledge and later shared it with ISA and other local universities. Currenly, ISA and the University of Evora have research on natural pest control, and are working with the Portucel Soporcel Group to combat more recent eucalyptus pests such as the *Gonipterus Scutellatus*. Figure 39 presents a schematic of this bidirectional industry-university technology transfer process.

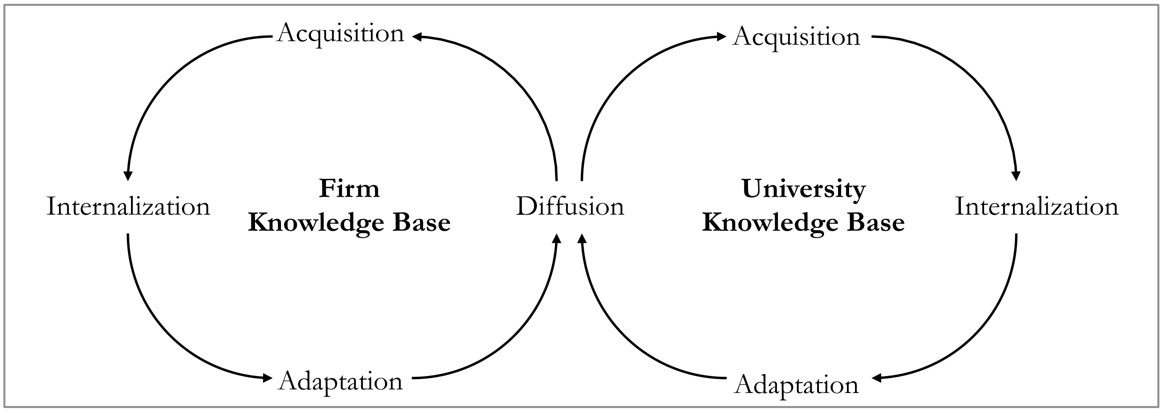


FIGURE 39: INDUSTRY-UNIVERSITY KNOWLDGE DIFUSSION PROCESS

THE INFORMAL ORIGINS OF CEF'S INDUSTRIAL RELATIONSHIPS

In 1962, Swedish company Billerud[1] opened a pulping mill in Leirosa, Portugal. During the 1960s, Celbi established several permanent plots of land to monitor the growth of eucalyptus globulus [161], and during the 1970s, Swedish researchers began developing the first forest growth models.

In 1976, the Center for Forestry Studies at the Higher Institute of Agronomy (ISA-UTL) was formed. At the time, the CEF had no formal relationships with Celbi. A CEF forestry student, however, who had some informal connections with the company, approached Celbi and asked whether he could use their data for his thesis (relatório de estágio). Celbi agreed, and a collaboration began that has lasted until today. As recalled by one of the CEF professors initially involved in this collaboration "At that time I was only a young researcher, just starting. The thesis of this student of mine was a first approach to use Celbi's data. Later on, we started a PhD student just to take advantage of Celbi's data and provide them with a model to predict the growth of the forests. From then on, we have been always working together" [156].

During the 1980s, Celbi began a tree breeding program and involved CEF researchers. Celbi and CEF applied for joint projects involving FCT (Portugal's National Science and Technology Agency), and also EU funds. In 1986, for example, Celbi and the CEF established trials aimed at determining the limits for the productivity of Eucalyptus. Celbi contributed to this collaboration by establishing the trials, and making the tree growth measurements.

Notes

[1] In 1984 Billerud became part of Stora, which later became StoraEnso.

APPENDIX III: SONAE INDUSTRIA

1. INTRODUCTION

Sonae Industria is the world's second largest manufacturer of wood based panels, including particleboard, medium density fiberboard (MDF), hardboard, oriented strand board (OSB) [162]. The company also produces decorative laminates, and chemical products (formaldehyde and formaldehyde based resins) for its application in the furniture, building, decoration, and home improvement markets.

Sonae Industria is headquartered in Maia, Portugal, and has 26 production plants in 8 different countries. The company employs 4,700 people, and in 2011 achieved a sales volume of €1.364, 70% of which came from sales in the European market [163].

Figure 40 presents a time history of Sonae Industria's sales and R&D expenditures versus time. The company has spent between 0.1% and 0.4% of its sales in R&D. The observed decline in sales since 2007 was the result of the housing market crisis, which has negatively affected the firm.

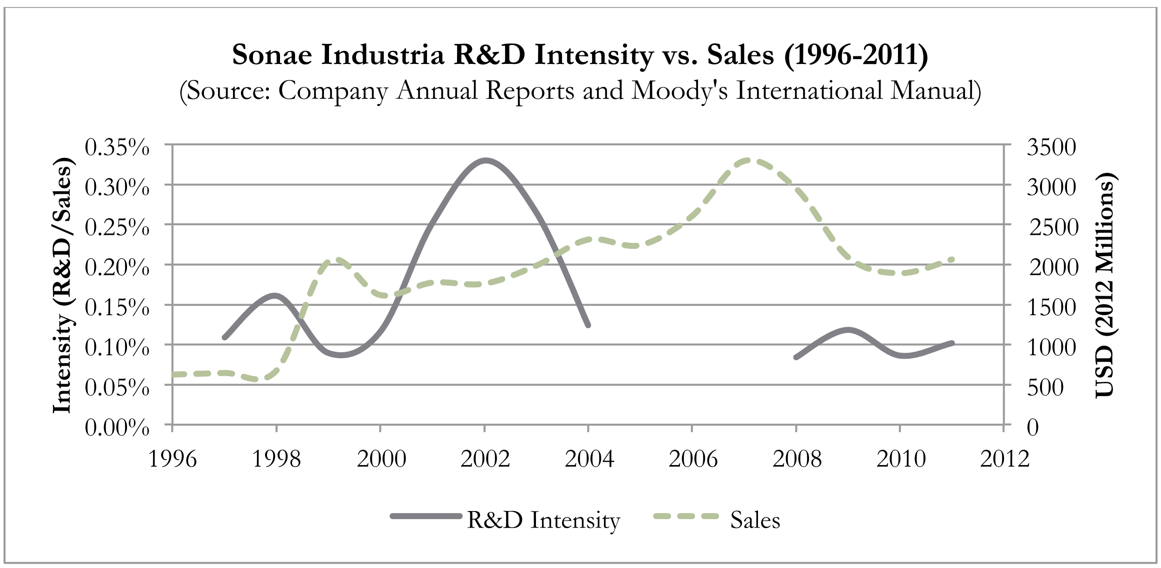


FIGURE 40: EVOLUTION OF SONAE INDUSTRIA R&D INTENSITY

This case study presents a longitudinal review of changes in (i) the company's businesses, (ii) research strategy and (iii) connections to universities and public research institutes during each strategic period of the firm.

Section 2 characterizes the different strategic periods of Sonae Industria. Section 3 describes the origins and evolution of the firm's university relationships as judged by changes in the research priorities of the firm, changes in the firm's university network, and people flows between partnering institutions. Section 4 summarizes the main findings and lessons.

2. Historical Changes in Company Strategy

Data on Sonae Industria's strategy was obtained by analyzing the company's annual reports and secondary sources of information, including journals, press articles, and company historical retrospectives. We also conducted four on-site interviews with senior managers of the firm. Based on the data, we defined 5 different strategic periods as in the left hand side of Figure 41. The right hand side of the figure shows the trajectory followed by Sonae Industria.

Strategic Periods

Period 1 (1959-1970): Focalized manufacturer of high-pressure laminates

Period 2 (1971-1982): Integration into particleboards

Period 3 (1983-1990): Diversification into retail and telecommunications

Period 4 (1991-2003): Internationalization

Period 5 (2004-onwards): Focalization into particleboards

Strategic Trajectory

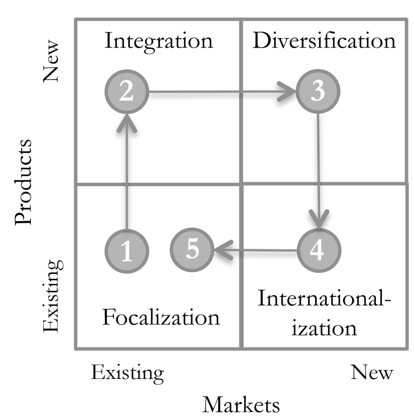


FIGURE 41: SONAE INDUSTRIA STRATEGIC PERIODS

Period 1 (1959-1970): Focalized manufacturer of high-pressure laminates

In 1959, Afonso Magalhaes founded The Sociedade Nacional de Aglomerados e Estratificados (Sonae) in Maia, Portugal. The company initially produced wood panels made from grape vine stems from the local wine industry in the Douro Valley [164]. In 1962, the company began producing high-pressure laminated products. At the time, the company had less than 60 employees. In 1965, Magalhaes hired Belmiro Azevedo, a recent chemical engineering graduate from the university of Porto, to become the company's general manager. During this first period, the company remained a focalized producer of thermo-laminated decorative products sold under the brand laminite.

Period 2 (1971-1982) Integration into Particleboards and Chemical Resins

In 1971, Sonae acquired Novopan and entered the wood particleboard market [162]. The company also started producing melamine-surfaced products for its utilization in the furniture and interior decorating industries. In 1975, the company entered the chemical industry through the production of melamine and phenolic resins. In 1982, the company extended its chemical products range by incorporating formaldehyde and urea resins, which are used in the manufacture of particleboards [164].

PERIOD 3 (1983- 1990): DIVERSIFICATION INTO RETAIL AND TELECOMMUNICATIONS

In 1983, Sonae was listed in the Lisbon Stock Exchange, and Belmiro Azevedo acquired 16% of its shares. In 1984, Afonso Magalhaes died and Azevedo took control of the company by acquiring a 35% stake in Sonae [165]. That same year, Sonae acquired Algoma and became Portugal's largest particleboard manufacturer. In 1987, the acquisitions of Siaf and Paviopan, two Portuguese wood panel manufacturers, further strengthened the Sonae's position in the local the wood panel market [162].

Azevedo wanted to make Sonae a large European company, but thought this was impossible to accomplish just relying on forest products [165]. In 1983 the company thus began diversifying into new business areas including retail, real estate, construction, telecommunications, and other non-forest industries [166].

In 1982, Azevedo created Sonae Distribucion a subsidiary company for entering the retail market through the acquisition of the Modelo supermarket chain. Sonae also formed a joint venture with French retailer Promodes to open Portugal's first hypermarket in 1985. In 1986 Sonae entered the tourism industry opening the Porto Sheraton hotel, and through the acquisition of Orbitur, a Portuguese campsite operator [164]. In 1988, Sonae Information Technology was created for investing in the IT and media sectors. In 1989, the company entered the construction business through Contacto Construçoes, and also the real estate business by opening its first shopping center. In 1989, the company acquired Radio Nova, and in 1990 they launched Publico, a nationwide daily newspaper [164].

PERIOD 4 (1991-2003): INTERNATIONALIZATION

In 1991, Sonae reorganized its business units and created Sonae Industria to consolidate all wood-based products. During this period, Sonae Industria focused on internationalizing and growing its manufacturing base, a process that had started in 1989 through the acquisition of Spanboard, a particleboard manufacturer with plants in Northern Ireland [162].

In 1993, Sonae Industrial acquired Tafisa, Spain's second largest manufacturer of wood-based derivatives. This acquisition allowed Sonae to become the largest manufacturer of wood panels in the Iberian Peninsula, controlling 30% of the market. In 1994, Sonae started a plant in Lac-Mégantic, Canada for manufacturing particleboard, and in 1998, opened a MDF (medium density fiberboard) plant in Valladolid, Spain. In 1999, Sonae opened a particleboard plant in South Africa, a MDF plant in Brazil, and a new chemical plant in Sines, Portugal, to supply resins for the Iberian plants. In 1999, Sonae acquired a sawmill in Cuellar, Spain, and another sawmill in Mozambique through the acquisition of Ifloma. In 2000, Sonae acquired an 85% stake in Glunz AG, a German manufacturer of OSB, Softboard, and plywood with operations in Germany and France. That same year, Sonae Industria acquired Sappi Novoboard, becoming South Africa's largest supplier of particleboard. After these acquisitions, Sonae industria became the world's largest producer of wood panels with more than 50 plants in over 15 countries [164].

During this period, Sonae Industria also took advantage of the privatization of several Portuguese companies acquiring in 1995 a 29% stake in Portucel, Portugal's largest pulp producer, and in 1999 an 11% of Soporcel, a large paper manufacturer. Sonae also formed a joint venture with the Spanish group Europac to acquire 65% of Gescartao, a Portuguese packaging company [164].

Period 5 (2004-Onwards) Focalization into particleboards

In 2004, Sonae Industrial divested its stake in Portucel, Soporcel, and Gescartao to concentrate on panels. In 2005, Carlos Bianchi de Aguiar became CEO. Sonae Industrial was spun-off from Sonae SGPS and was listed in the Lisbon Stock exchange. That year, the company entered a joint venture with Tarkett AG, a French manufacturer of flooring products. In 2006, the company acquired Hornitex, a German panel maker, and Darbo, a particleboard manufacturer in France[164].

In 2008, after the sub prime crisis, the company entered a restructuring phase, including closure of several plants and divesture of their Brazilian operations in 2009. On 2010, Sonae closed its plant in Duisburg, Germany, and sold another plant in Lure, France. In 2012, the company announced it would also close its UK plant in Knowlsley. Between 2008 and 2012 the company reduced 26% of its installed capacity from 10.1 to 7.5 millions of m3 [162].

3. The Origins and Coevolution of Sonae's University Relationships

The oldest university relationship we found occurred in 1986, when Sonae created a formal recruiting program and offer internships to local university students [167]. During that period the company was diversifying its industrial base and needed to recruit talent for different parts of the organization. The first university research projects emerged from these diversified business areas and not from the company's original wood panels core business. In 1991 Sonae collaborated with the University of Porto on developing sale forecasts for the company's supermarkets [168].

In 1991, Sonae Industria was formed to consolidate all the company's forest assets, and new university projects were created in support of this area. In 1998, Sonae Industria collaborated with the Instituto Pedro Nunes of the University of Coimbra on a project aimed at optimizing particleboard cutting technology (project woodpecker) and in 1999, Sonae collaborated with the Institute for Technology and Experimental Biology (IBET) on improving the growth rate of pine trees in Portugal (project Pinus) [169].

Growth in the company's R&D expenditures occurred in 2000 after the acquisition of the German firm Glunz AG (See Figure 40 in page 118). Glunz had a strong tradition in R&D and had formed multiple academic connections, in particular with the Technical University of Dresden and with the German Forest Industry Research Center (Bundesforschungsanstalt forst holzwirtschaft or BFH). After the acquisition, Glunz's R&D team became Sonae Industria's formal R&D organization.

In 1993, Sonae Industria formed Euroresinas to manage the production of resins and chemical additives used in the manufacture of laminated boards. Over time, this subsidiary established university connections aimed at optimizing the production and developing new chemical products. In 2003, Euroresinas worked with the Faculty of Engineering of the University of Porto (FEUP) on a project aimed at optimizing urea-formaldehyde resins for producing panels from different tree species (project UF Madeira), and in 2005, the company collaborated with the New University of Lisbon (U. Nova) on developing eco-friendly ready to assemble furniture [170].

Since 2006, Euroresinas has gained more organizational independence from Sonae Industria, which has facilitated the establishment of new university links. As explained by a company senior manager: "we wanted to be a little bit more independent in terms of business from Sonae Industria, and we wanted to create a business portfolio that could be self-sustained" [171]. Euroresinas thus began diversifying the types of clients and industries they serve: "we work with the Sonae Industria group, and also with the coating industry, the insulation industry, the abrasive industry, and several other small clients that produce wood manufactures that are different from Sonae Industria. This was an effort to broaden our minds and to obtain know-how from other industries into our group" [171]. Euroresinas also created an internal R&D department, composed of 4 people, in charge of developing new technologies for their chemical business and also to explore new business opportunities in different areas from Sonae Industria's traditional wood panel business.

In 2006, Euroresinas joined FEUP, the University of Aveiro and several other companies to create a polymer research network. As explained by a senior manager of Euroresinas "we started working with universities and with other companies that have the same [research] interests to create the Portuguese Polymer Competence Network. We created this association and we connected with the Universities of Porto, Coimbra, Minho, Aveiro to develop know how in this area" [171].

The Polymer Competence Network was launched in 2007 with the help of government funds. Since then this consortium of companies and universities has undertaken several joint R&D projects. Euroresinas is experimenting with the application of phase-changing materials on furniture laminates. As explained by a company manager: "phase-changing materials (PCMs) are used in the paint industry to control temperature. We took out this idea and applied it into laminates to create furniture that also serves as a passive temperature control of the environment. For example, if you have a living room with this kind of furniture, you can have the living room's temperature controlled by the furniture itself"[171].

In addition to the Polymer Network, Euroresinas has developed deep ties with the Faculty of Engineering of the University of Porto (FEUP). In 2007, Euroresinas worked with FEUP and the Polytechnic School of Viseu on a project aimed at producing wood panels from waste belonging to different tree species (project Ohpan), and in 2009 on a project aimed at developing tailor-made adhesives for manufacturing low formaldehyde emission wood panels (project E0 Formaldehyde).

On campus presence at the University of Porto

In 2012, Euroresinas decided to have an on-campus presence at FEUP. As explained by a company manager: "Before [the lab], we had the traditional approach, with an internal R&D unit that was very limited in terms of the type of project we could do. We worked with universities at a certain distance, which is also the traditional way of companies to work with universities. For example, we gave a project to the university, let them work, and at the end we would go and ask for the results. This [approach] never worked. At the end we got results that were only theoretical and we would not get anything practical to use in our industry. So we said no. This is not the way to do it, so lets try [a new approach]" [171].

The recent on-campus presence has also altered the nature of Euroresina's university relationships. As explained by a company manager "This lab is door-to-door with the Polymer Network lab and with other company labs that have common interests. We are located in the middle of the university of Porto, in a building that is called UPTEC. What is the advantage? We use equipment from the university that we didn't have access to, and we also gained access the university's students. We have a very simple lab, but the equipment is always available and we have access to technologies that we did not own before" [171].

3.1. Research priorities along Sonae Industria's value chain

We have organized Sonae Industria's university relationships from a value chain perspective, as described in Figure 42, which shows the different processes involved in the production of fiberboards. Most of Sonae Industria's university co-publications have been in the area of resin manufacturing, and have been published in recent years (2010 onwards). Most of these publications have been with researchers from the University of Porto.

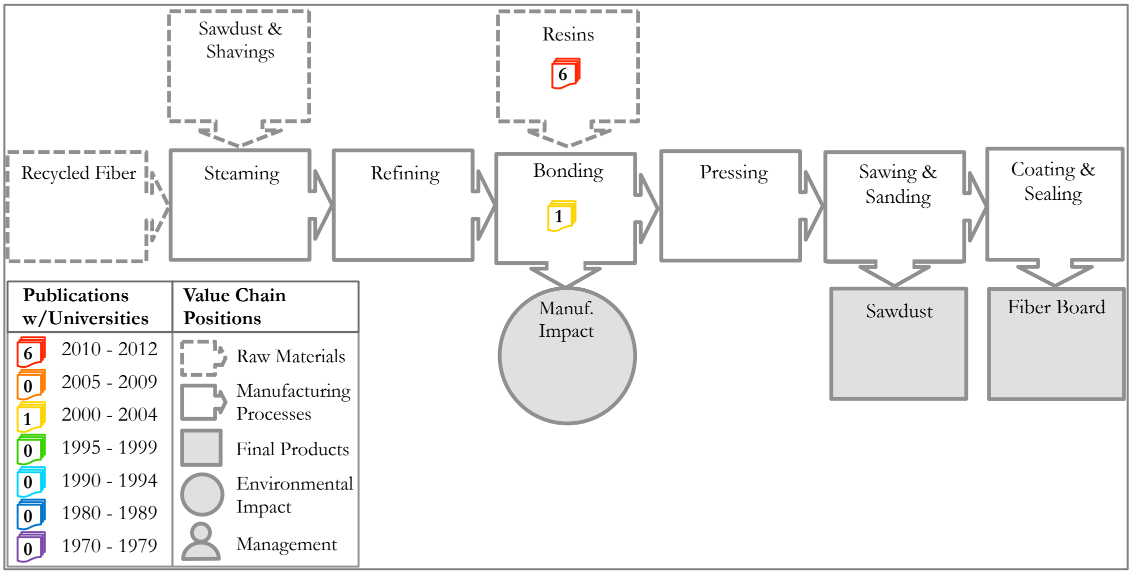


FIGURE 42: EVOLUTION OF SONAE INDUSTRIA UNIVERSITY CO-PUBLICATIONS IN FIBERBOARDS

3.2. Geography of university partners

Figure 43, based on Sonae Industria's publication records, shows the geographic distribution of the company's university network. Sonae Industria's university network has historically been concentrated in Portugal, near the company's production facilities near Porto.

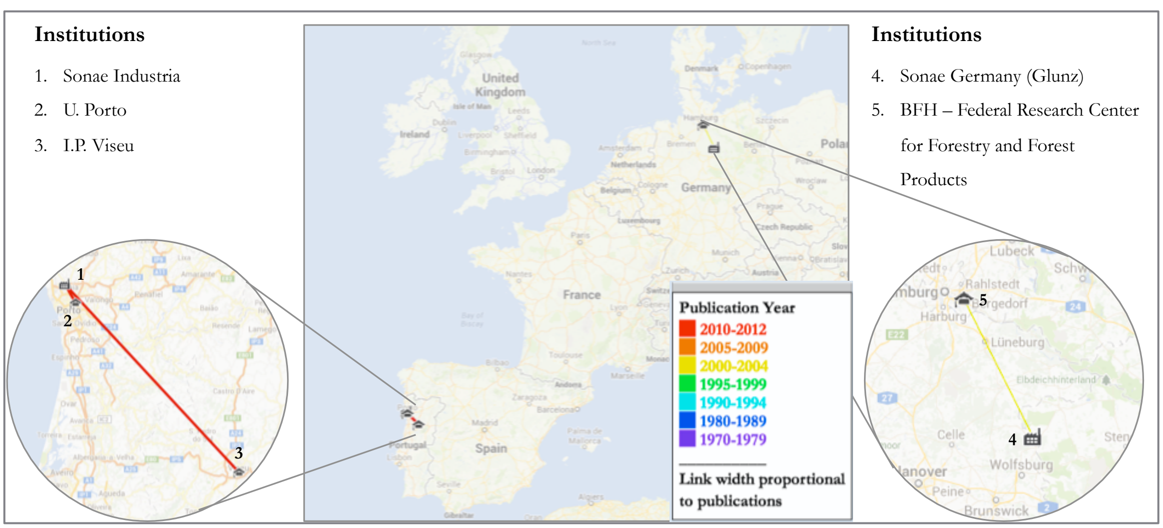


FIGURE 43: SONAE INDUSTRIA UNIVERSITY NETWORK

Sonae Industria's international university network was established as a consequence of the acquisitions the company has made outside Portugal. Figure 43 shows a geographical representation of Sonae Industria's university partners in Germany, which were established after the company acquired Glunz, a German manufacturer of fiberboards.

Interview data revealed that Sonae Industria, through its German subsidiary Glunz, has also engaged in collaborations with the University of Hamburg, the University of Dresden, the University of Göttingen, and with the Fraunhofer Institute for wood research (WKI) in Germany, and with the French institute of technology for forest-based and furniture sectors (FCBA) [171].

In 2011, Sonae Industria established a relationship with the New Zealand Crown Research Institute (Scion), to license a technology called Woodforce. This technology allows the manufacture of fiber reinforced plastic composites that can be used as a replacement of glass fiber in automobile parts [172]. The rationale for this acquisition, according to a senior company manager, was to diversify the firm's product base given the poor situation of the construction industry [173].

3.3. Technology transfer through people flows

To analyze the academic and professional trajectories of Sonae Industria's most prolific authors and inventors we used Sonae Industria's publications and patenting records. We were able to develop a list of 28 people involved in the company's R&D activities, where each individual in the list has either patented or published at least one paper under Sonae Industria's name.

Figure 44 shows the evolution of Sonae Industria's research staff. As shown in the figure, most of Sonae Industria's R&D personnel have been recruited from industry. The figure also indicates that Sonae Industria's R&D personnel peaked in 2005, after which there was a decline as a consequence of the focalization strategy of the firm. After leaving Sonae Industria, 46% of these researchers joined other firms, and one person went back to a research institution (the Technical University of Munich, Holzforschung München).

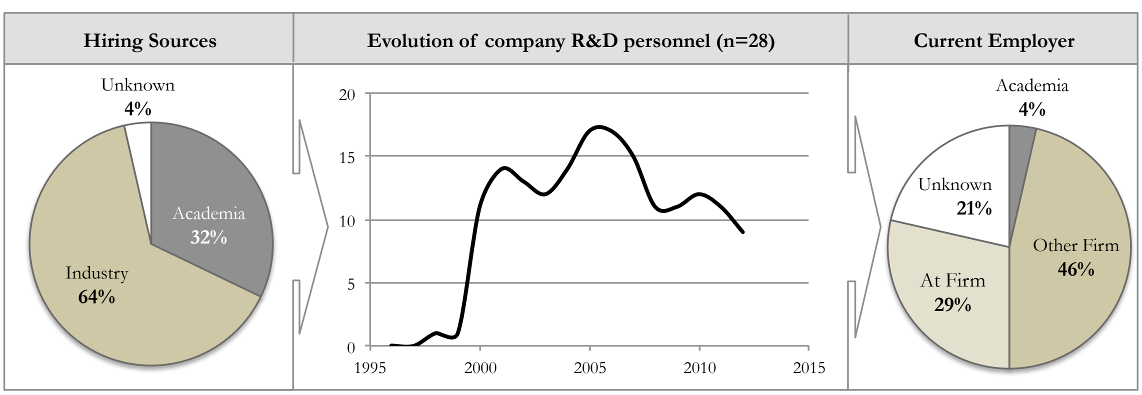


FIGURE 44: EVOLUTION OF SONAE INDUSTRIA'S R&D PERSONNEL

Analysis of the academic training of Sonae Industria's researchers shows little overlap between the academic institutions attended by these people and the company's publication partners (See Figure 45), which is a consequence of the low number of publications of the firm. Sonae Industria has only coauthored 6 articles with university researchers, and thus assessing the level of overlap with this metric is subject to small number bias. Figure 45 also shows that the German R&D staff comes from a wider range of universities than the firm's Portuguese R&D staff, who have predominantly been recruited from the University of Porto.

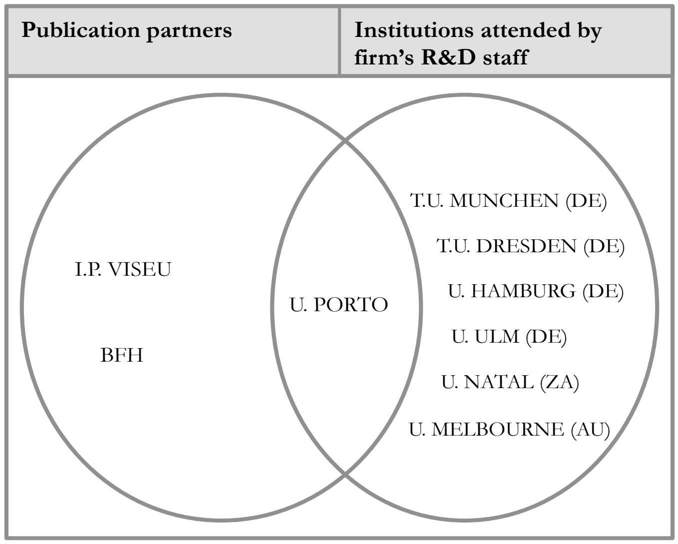


FIGURE 45: OVERLAP BETWEEN SONAE INDUSTRIA'S HIRING AND PUBLISHING PARTNERS

4. Case Study Discussion

Sonae Industria has endured several strategic changes and participated in a diverse set of industries and regions over time, giving us the opportunity to analyze how changes in Sonae Industria's strategy have affected its relationship with universities and research institutes. Table 18 presents a summary of these findings. The table only shows the last three strategic periods of the firm because we could not find any evidence of university relationships in earlier periods. The table summarizes how the firm's research priorities, people flows, and institutional networks were modified as a consequence of the observed changes in strategy.

TABLE 12: SUMMARY OF HOW SONAE INDUSTRIA'S UNIVERSITY RELATIONSHIPS COEVOLVED

University Links / Firm Strategies	Research Priorities	People Flows	Institutional Networks
Period 3: **Diversification** (1983-1990)	**Diversified businesses** • Demand models for supermarket sales	**Increased hiring of staff** • In relation to the diversified business areas	**First University links** • Recruitment based contacts and internship offerings
Period 4: **Internationalization** (1991-2003)	**Resin production** • Tailor resins to different wood products	**International R&D Lab** • Glunz's staff became Sonae Industria's R&D team	**First sponsored R&D projects** • With Portuguese universities on resin manufacturing • With German universities after acquisition of Glunz
Period 5: **Focalization** (2004-Present)	**New resins** • Low formaldehyde emissions **Process improvement** • Kaizen manufacturing	**On campus presence** • Creation of new lab at University of Porto	**Consortium-based relationships** • New projects in Portugal in the area of resins

When contrasted with the other firms in our dataset, Sonae Industria has the lowest number of university links. This is because the technology utilized in their productions processes is mature and because the company has not been vertically integrated into forestry as are some of their competitors (forestry schools are frequent partners of forest product firms).

The Sonae Industria case also illustrates the effects of internationalization on the firm's university relationships. After the acquisition of the German firm Glunz in 2000, Sonae Industria gained access to an R&D lab in the area of wood panels. Researchers at this lab had forged relationships with different universities. We thus observed the emergence of new university links between Sonae Industria and German universities (e.g. U. Hamburg, U. Dresden, U. Göttingen).

Effects of regulations on the formation of university links

A final point refers to the effects of regulations on the emergence of industry-university links. As hypothesized by Porter, environmental regulations can stimulate innovation and enhance the competitiveness of firms [174, 175] and the development of low-emission formaldehyde resins offers a good example of the formation of new university projects as part of this process.

Formaldehyde is a chemical compound commonly found in resins utilized in the manufacture of composite wood products. In 1992, formaldehyde was identified as a toxic air contaminant which could cause throat irritation, difficulty in breathing, could trigger asthma symptoms in people with asthma [176]. The California Environmental Protection Agency Air Resources Board (CARB) thus initiated a regulatory process aimed at limiting the emission standards for finished goods containing formaldehyde. In 2007, the CARB approved an airborne toxic control measure (ATCM) to reduce formaldehyde emissions contained in composite wood products sold in California [177]. In 2009, the first phase of the California Composite Wood Products Regulation (CWP Regulation) took effect imposing stringent formaldehyde emission standards for composite wood products. The regulation also aimed the import of low-cost high-emitting products containing formaldehyde.

Sonae Industria closely followed California's regulatory process. As explained by a senior manager, "when California created the norm to reduce formaldehyde emissions, some people in the industry thought this would not affect us. However, a few months later, some international furniture clients such as IKEA began requesting all products to comply with the Californian regulation. It was because of California that we began researching and developing low-emission resins" [178].

In 2009, Sonae Industria began a research project in collaboration with the University of Porto aimed at developing zero emission adhesives for composite wood products (project E-Zero Formaldehyde) [169]. As explained by a senior manager of Euroresinas, Sonae

Industria's chemical subsidiary, the results of this collaboration have been promising: "we have created resins with emissions that are lower than wood, which means that the resin itself can actually capture formaldehyde from the environment. This resin can now be used as an additive and mixed with other bulk resins to achieve the required formaldehyde emission levels" [171].

The development of the emission-capturing resin has, in turn, improved the competitiveness of Sonae Industria. As explained by a senior manager "you can currently find low-emission resins in the market, but these are expensive. However, if you figure out which is the right additive, you can buy the raw materials to produce your own low-emission resins at a cost that is ten times lower. And that's the truth; it's ten times cheaper, and thus we cannot lose this competency" [178].

In 2011, the US National Toxicology Program listed formaldehyde as known human carcinogen [179], and CARB passed a more stringent phase 2 of the CWP Regulation. As explained by a senior manager of Sonae Industria, "Chinese furniture imports into the United States have been negatively affected after the passing of the phase 2. For us, it has not been so bad, and perhaps it can even become a source of advantage as other competitors are facing increasing costs to comply with this regulation" [178].

Appendix IV: Domtar Corporation

1. Introduction

The Domtar Corporation is a North American producer and distributor of a wide variety of fiber-based products, including paper, pulp, and since 2011 adult personal care products. The company, headquartered in Montreal, has its roots in the chemical industry. Domtar owns 13 pulp and paper mills across North America, and an extensive distribution network, Ariva, to market and sale products under its own brands.

In 2011, the company achieved a sales volume of US$5.6 billions, 85% of which came from its pulp and paper operations. Domtar is the third largest market pulp producer in North America, and the seventh largest in the world. The company exports its products to nearly 50 countries and employs 9,100 people [180].

Figure 46 presents an overview of Domtar's R&D and sales expenditures over time. The company has historically spent between 0.3% and 0.5% of its sales in R&D. While it was not possible to obtain complete time series from public sources, interview with a company manager confirmed that Domtar currently spends less than 0.5% of its sales in R&D [133].

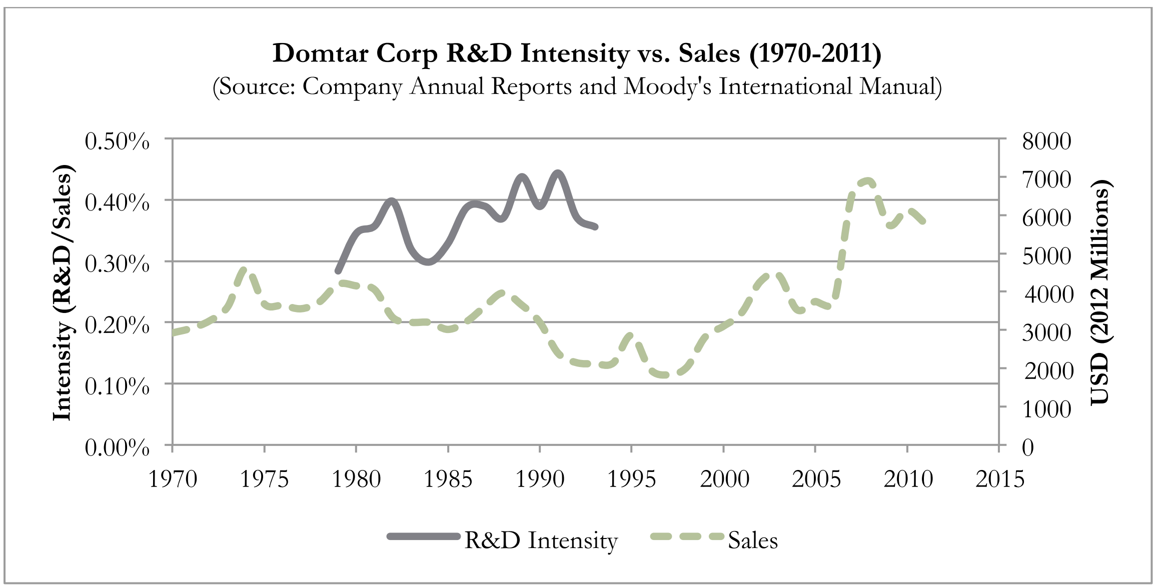


FIGURE 46: EVOLUTION OF DOMTAR'S R&D INTENSITY

This case study presents a longitudinal review of the changes in the company's business and research strategy and an overview of Domtar's connections to universities and public research institutes during each strategic period of the firm.

In section 2 we provide a characterization of the different strategies pursued by Domtar. Section 3 describes the origins and evolution of the firm's university relationships as judged by 1) changes in the research priorities of the firm; 2) changes in the network of university research partners, and 3) people flows between partnering institutions. Finally, section 4 summarizes the main findings and lessons from the case.

2. Historical Changes in Domtar's Strategy

Data on Domtar's strategy was obtained by analyzing the company's annual reports and secondary sources of information, including journals, press articles, and company historical retrospectives. We also conducted one interview with a senior manager of the firm. Based on the data, we defined 7 different strategic periods (see Figure 47), which tended to coincide with changes in the CEO of the firm.

Strategic Periods

Period 1 (1903-1956): Integration into chemical products

Period 2 (1957-1966): Diversification into construction materials, pulp & paper, and consumer products

Period 3 (1967-1973): Focalization and divesture of consumer products

Period 4 (1974-1980): Internationalization and Government control

Period 5 (1981-1989): Integration into fine papers

Period 6 (1990-1995): Focalization and divesture of chemical products

Period 7 (1996-2007): Internationalization into the US

Period 8 (2008-onwards): Diversification into personal care products

Strategic Trajectory

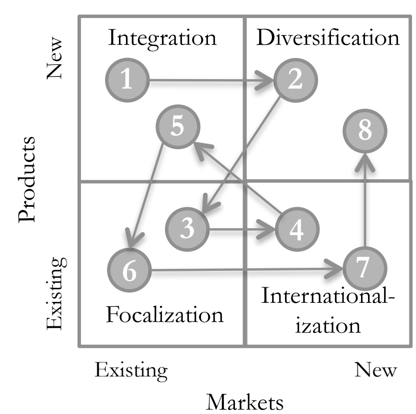


FIGURE 47: DOMTAR STRATEGIC PERIODS

Period 1 (1903- 1956): Integration into chemical products

In 1903, Dominion Tar & Chemical Co. founded a coal distillation plant in Nova Scotia, Canada. This company, whose roots trace back to 1848 in England, specialized in the production of chemical byproducts from coal distillation, which were used by the chemical, steel, and textile industries. In 1914 the company established its headquarters in Montreal, Canada, and experienced a rapid period of growth fueled by the sales of coal pitch, which was in high-demand for the construction of roads.

After WWI, the company began increasing its range of chemical products to supply the nascent pharmaceutical and plastics industries [181]. In 1929, the company was incorporated as Dominion Tar & Chemical, and made an initial public offering of shares in the Montreal and Toronto stock exchanges. The company was able to navigate through the depression thanks to its diversified chemical products portfolio [181]. Domtar's chemical portfolio was further expanded in 1937 through the acquisition of Industrial Minerals, an Alberta-based Canadian company that manufactured chemical salts.

After WWII, the Canadian industry entered a period of great prosperity, and by the end of the 1950s, Domtar was looking for new opportunities for growth. According to the company's President, the company had to opt either to specialize and grow internationally, or to diversify and grow in the Canadian market [182]. In 1957, Wilfred N. Hall became president of the company, and he opted for the second strategy: to grow preferentially in the Canadian market through diversification.

PERIOD 2 (1957- 1966): DIVERSIFICATION INTO CONSTRUCTION MATERIALS, PULP, PAPER, PACKAGING, AND CONSUMER PRODUCTS

Under Hall's presidency, the company diversified into pulp, paper, and construction materials. In 1957, the company acquired a 33% stake at Howard Smith Paper Mills, a Canadian fine paper manufacturer with facilities in Cornwall, Ontario, and Windsor, Quebec. Similarly, in 1959, the company acquired a stake in Gypsum, Lime & Alabastine Canada, a large manufacturer of gypsum wallboard for the construction industry.

During the 1960s, the company continued expanding through acquisitions. In 1961, Domtar acquired the St. Lawrence Corporation, a producer of newsprint, and Hinde & Dauch Ltd., a manufacturer of corrugated containers and merchandising displays. The company also expanded internationally, opening a plastics facility in the UK, a bleach plant in the West Indies, and acquiring 49% of Cellulosa d'Italia, an Italian paper and pulp producer in 1963 [181].

In 1965, the company changed its name to Domtar Ltd. to reflect its diversified business range, which consisted of six different units. Domtar Chemicals sold pressure treated wood products, limestone, iron, salts, coal tar, and synthetic detergents. Domtar Construction materials sold bricks, wallboard, decorative plastic laminates, industrial lumber, and precast concrete products. Domtar Consumer Products sold bleach, starch, fabric softeners, and other household items. Domtar Packaging sold grocery bags, folding cartons, corrugated boxes, and composite cans. Finally, Domtar pulp and paper sold specialty coated papers, Kraft pulps, containerboard, and wrapping materials[182]. By the end of the 60s, pulp and paper products represented more than half of Domtar's sales [183].

PERIOD 3 (1967- 1973): FOCALIZATION AND DIVESTURE OF CONSUMER PRODUCTS UNIT

In 1967, T.N. Baupre became President of Domtar, and restructured the company's business around three divisions: chemical, construction, and pulp and papers. He divested its consumer products division to Bristol-Myers, as they could not compete effectively against larger players [183]. Domtar, however, faced high production and labor costs, and during the oil crisis of the 1970s, the pulp and paper division underwent heavy losses. Baupre even evaluated withdrawing from the pulp and paper business [181].

Period 4 (1974- 1980): Internationalization and Government control

In 1974, Alex D. Hamilton became President of Domtar. He closed unprofitable paper mills, and began to internationalize the company's construction business into the United States. In the words of Hamilton "We have to broaden our interests, become as independent as we can from the ups and downs of the Canadian economy… We're looking in both Canada and the U.S."[184]. Domtar thus acquired a lime plant in Pennsylvania in 1976; a wallboard facility in California in 1978; a brick and tile plant in Mississippi in 1981; and Genstar Gypsum Products in 1987, which had several wallboard plants in the United States. By 1982, 30% of Domtar's sales came from the US [185].

Period 5 (1981-1989) Integration into fine papers

In 1981, the Government of Quebec took control of 42% of Domtar's stock after a series of hostile takeover bids. James H. Smith became president of the company. Under Smith several of Hamilton's decisions came under revision. The Government of Quebec criticized Domtar's decision to invest and seek markets outside the province and also the closure and lack of investment in the pulp and paper mills of the region [184]. To alter this situation, Smith invested 1.2 billion dollars to modernize its fine papers plant in Windsor, Quebec. This mill entered operations in 1989.

By the end of the 1980s, Domtar was a diversified conglomerate, obtaining 42% of its sales from pulp and paper, 17% from packaging, 12% from chemical, and 29% from their construction business line. Domtar was in a good financial situation and began looking for new growth opportunities. As opposed to the 1960s, this time the company concentrated on fewer global products and they divested the chemical division to focus on construction materials and paper and pulp business lines [181].

Period 6 (1990- 1995): Focalization and divesture of chemicals division

In 1989 Domtar announced the divesture of its chemical assets for CAD$ 100 million. The company also sold its oil and gas operations, the Arborite construction products division, and the chemical salts divisions. In 1990, the pulp and paper industry had one of the worst cyclical slumps in 50 years [183]. Pierre Desjardins became CEO of Domtar and intensified the divesture of the company's assets. He sold the roofing business unit, which was part of the construction materials division, and also announced the restructure and streamlining of the company's operations. In 1993 the company restructured its forestry, logging, and sawmill units, creating a separate forest products division. In 1994 the company spun off two paper mills and two saw mills to form a new company called Alliance Forest Products Inc. Despite these changes, between 1990 and 1993 Domtar operated at a loss [186].

In 1995, Stephen Larson became CEO of the company, and concentrated on paper, pulp, lumber, and packaging. On 1996 Domtar sold its Gypsum products division to Georgia

Pacific and also sold its decorative panels business unit to a private-equity fund. Later that year, Larson left Domtar and was succeeded by Raymond Royer.

PERIOD 7 (1996- 2007): SECOND WAVE OF INTERNATIONALIZATION INTO THE US

Under Royer's direction, the company initiated a series of targeted acquisitions aimed at strengthening its position in the fine papers market. In 1997, Domtar spun-off its packaging and containerboard division forming Norampac in joint venture with Cascade, another large Canadian forest products company. Domtar received CAD$300 million from this deal which were used to acquire the E.B. Eddy Company, a fine paper manufacturer of Canada. After this acquisition, Domtar became Canada's largest manufacturer of fine papers, and the seventh largest in the US.

During the early 2000s, the company began a series of targeted acquisitions into the US fine papers market. In 2000, Domtar acquired the RIS Paper Company, a Kentucky-based firm. The acquisition provided Domtar with a large distribution network for selling its products in the US market. In 2001 the company also acquired four paper mills from Georgia Pacific for CAD$2.53 billions. This large acquisition allowed Domtar to double its production capacity, becoming Canada's largest paper company, and the third largest manufacturer of uncoated papers in the US.

In 2005, the company entered another period of hardship due to increased competition, raising costs, and unfavorable exchange rates of the Canadian dollar. Royer further increased the company's presence in the US. In 2006, Domtar closed 40% of their Canadian papermaking capacity, and sold its 50% stake in Norampac to Cascades, exiting the packaging business. In 2007, the company merged with Weyerhaeuser's fine paper division creating a new entity called the Domtar Corporation. During Royer's tenure, Domtar became the largest integrated uncoated freesheet paper manufacturer in the US, and the second largest in the world.

PERIOD 8 (2008 – ONWARDS): DIVERSIFICATION INTO PERSONAL CARE PRODUCTS

In 2008 John D. Williams. Williams became CEO. Williams expected a decline in demand for uncoated freesheet papers in North America at 2-4% per year for the foreseeable future [180] and the company diversified into personal care products.

In 2010, Domtar announced the divesture of its wood business to EACOM Timber Corporation, and in 2011, the company announced the acquisition of Attends Healthcare, Inc. of Greenville, North Carolina, manufacturer of adult incontinence care products sold under the Attends brand. In 2012, the company acquired Attend's European operations for $236 million, which included a manufacturing and research and development facility in Aneby, Sweeden, and distribution centers in Scotland and Germany. Finally, Domtar also acquired EAM Corporation, a manufacturer of absorbent cores that had a research facility in Jesup, GA [187].

3. The origins and coevolution of Domtar's university relationships

While Domtar's chemical division had a long tradition in research, Domtar's knowledge of pulping and paper manufacturing came after the merger with Howard Smith Paper, and the St. Lawrence Corporation in 1961 [182]. Howard Smith Paper had developed a strong in-house research capability in pulp and paper production [188], and most of Domtar's university relationships stem from Howard Smith's researchers and technical personnel.

During the 1920s, C. Howard Smith, President and major shareholder of the Howard Smith Paper Company, decided to invest in a new alkaline pulp mill in Cornwall, Ontario, and hired George Tomlinson to review the plans of the mill [188]. Tomlinson continued working for Howard Smith paper and in 1929 became director of research of this company, conducting experiments to improve the bleaching of Kraft pulp and inventing the recovery boiler in 1929. According to a senior company executive "the Tomlinson recovery boiler is the single piece of technology that it is present in every pulp and paper mill in the world right now. This was a critically important innovation. Before the invention of Tomlinson's recovery boiler, the pulp and paper industry had no means of recovering the chemicals and latent heat that was created as a byproduct of the pulp digestion process. So the entire internal chemical recovery and internal energy recovery system is predicated on Tomlinson's invention [133]".

C. Howard Smith was also instrumental in the creation of the Pulp and Paper Research Institute of Canada (former Paprican, currently FP Innovations), and in the development of McGill University's research program in cellulose chemistry. These two institutions had close relationships with Howard Smith Paper, and later with Domtar throughout the years (see vignette on FP Innovations in page 149). C. Howard Smith convinced Dr. Harold Hibbert in 1926 to fill a newly created Chair in Cellulose and Industrial Chemistry at McGill University; Dr. Hibbert was the PhD thesis supervisor of George Tomlinson II, the son of Howard Smith Paper's research director George Tomlinson Sr.

George Tomlinson II conducted experiments on the oxidation of lignin, discovering that vanillin could be produced from spent sulfite liquor. At the time, vanillin was sold for $12,000 per ton [189], and Howard Smith Chemicals became interested in Tomlinson II's research. After graduating in 1935, Tomlinson II received a fellowship from Howard Smith Chemicals to continue his work at McGill University in order to develop an industrial process for the production of Vanillin [188]. In 1936, Tomlinson II moved to Howard Smith's Cornwall paper mill, and in 1937 the company began the commercial production of vanillin from alkaline-treated sulfite liquor. After the retirement of his father, George Tomlinson II became research director of Howard Smith Paper in 1940 [188].

During the Second World War, Tomlinson II began conducting research on phenolic resins. The supply of phenol was limited but Tomlinson II discovered he could substitute phenols with the free phenolic compounds present in alkaline pulping liquors. This invention was sold under the brand name Arborite, which is a trademark for decorative high-pressure laminates. Howard Smith Paper and later Domtar continued producing high-pressure laminates using this technology until petrochemical phenols replaced lignin phenols in the 1960s [190].

At the beginning of the 1950s, the Queen's Printer asked Howard Smith to develop a special paper for producing tabulating cards to be used in the 1952 Canadian census [189]. IBM machines processed census data by passing electrical current through holes in the cards and the paper used in the manufacturing of these cards needed to be free of electricity-conducting particles. Canadian mills, however, produced pulps with a high "dirt count" including bark particles and fly ash from coal combustion. Fly ash, in particular, was a known electricity conductor and traditional cleaning equipment was unable to remove these ashes. Tomlinson II conducted experiments utilizing liquid hydrocyclones, and found that shear and centrifugal forces allowed classifying and removing fly-ash particles and other contaminants from pulp [190]. He created a device called the Centricleaner, which allowed separating contaminant particles based on gravity and on the particle's shape depending on the dimensions of the cyclone. Centricleaners allowed Howard Smith to produce papers with less than four particles of contaminants per ton, significantly less than IBM's specifications [189].

Centricleaners became widely adopted by the industry, and continue to be used today by practically all mills producing fine papers [190]. Centricleaners not only allowed the production of fine papers, but also allowed manufacturers to increase the mix of hardwoods and to utilize the whole tree in pulp production. Until then, the use of local hardwoods was limited because of difficulties in debarking these trees. Centricleaners solved this problem by removing bark-particles after pulping, and also solved the problem of wood chip contamination, enabling manufactures to store chips outdoors [189].

During the 1950s Tomlinson II also worked on improving the pulping process. In 1958, for example, he invented the Magnefite pulping and recovery process, which allowed producing high-quality pulps through a magnesium-based sulfite process. While sulfite pulping is in decline, most of the mills still using this technology utilize Tomlinson's Magnifite technique [190].

After the merger of Howard Smith with Domtar in 1961, Tomlinson II became Director of R&D. That year Domtar built a new research center in Senneville, Quebec, staffed with 50 people, one third with PhDs [182]. The Senneville research center was located 10 miles away from Pulp and Paper Research Institute of Canada, which had moved from McGill University to a new building in Point Claire, Quebec in 1957 [191].

At Senneville, Tomlinson II continued working on improving the pulping process. In collaboration with Paprican, Tomlinson II invented in 1964 the "Alkafide" continuous digester process. This technology utilized high-sulphidity liquor to impregnate wood chips prior to cooking them to produce pulp, which allowed reducing, from 3 hours to 40 minutes, the pulping process [192]. Tomlinson II was able to validate this technology at the pilot plant scale, but the operational introduction was abandoned as Domtar faced financial difficulties and terminated the project [190].

In 1966, Domtar's research center in Senneville was expanded by 14,000 sq. feet to provide space for a metals powder pilot plant and an acoustics laboratory for construction materials division. In 1967, the company announced the production of metal powders in their plant in Pennsylvania, and in 1969 Senneville's acoustics laboratory was opened to analyze the acoustic properties of the company's floor, wall, and ceiling products [193].

During the 1970s, Domtar's research emphasis shifted towards environmental research. Tomlinson II became Vice-President of Research and Environmental Technology, a position he held until his retirement in 1977 [190]. In the area of environmental research, Domtar worked with several Canadian universities, and also with Canadian Department of Fisheries to monitor the company's impact on rivers and water basins.

Figure 48 presents a historical evolution of the company's university co-publications. Domtar as a company has published 225 articles, but only 25% of them, the lowest co-publication percentage of all the companies in our dataset, have been written in collaboration with a university or public research laboratory.

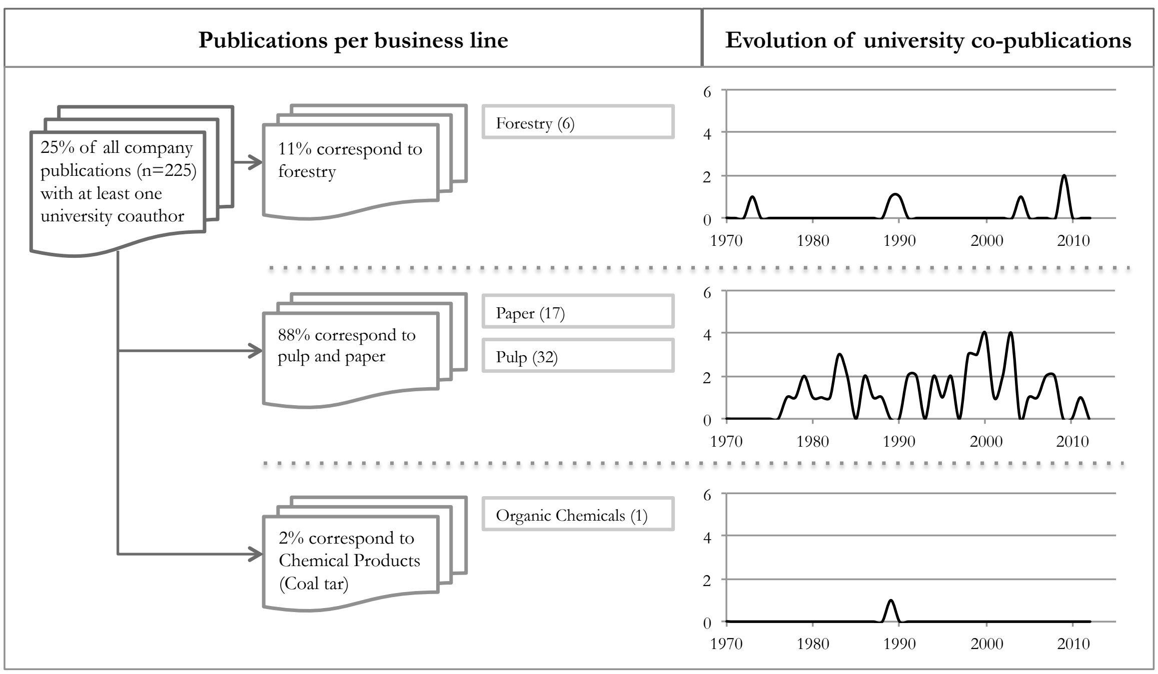


FIGURE 48: COEVOLUTION OF UNIVERSITY CO-PUBLICATIONS AND DOMTAR'S BUSINESS LINES

Domtar's publications with universities are concentrated in the areas of pulp and paper technologies. There is only one paper written with a university in the area of chemicals, and no papers in the area of construction materials. Although this does not mean that Domtar has not conducted research in these areas. According to the ISI Web of Knowledge database, there are more than 10 papers written by the company on gypsum wallboards and on carbon tars and pitches. The absence of university co-publications in these areas suggests that universities have played a minor role.

Decline of in-house R&D and the closure of Domtar's research center

The recession of the early 1980s hit the Canadian forest products industry hard. Between 1980 and 1984 the largest Canadian pulp and paper companies, including Domtar, reduced their R&D investments and R&D personnel [194]. As shown in Figure 49 and Figure 50, there has been a steady decline in Domtar's publication and patenting activities since the 1980s.

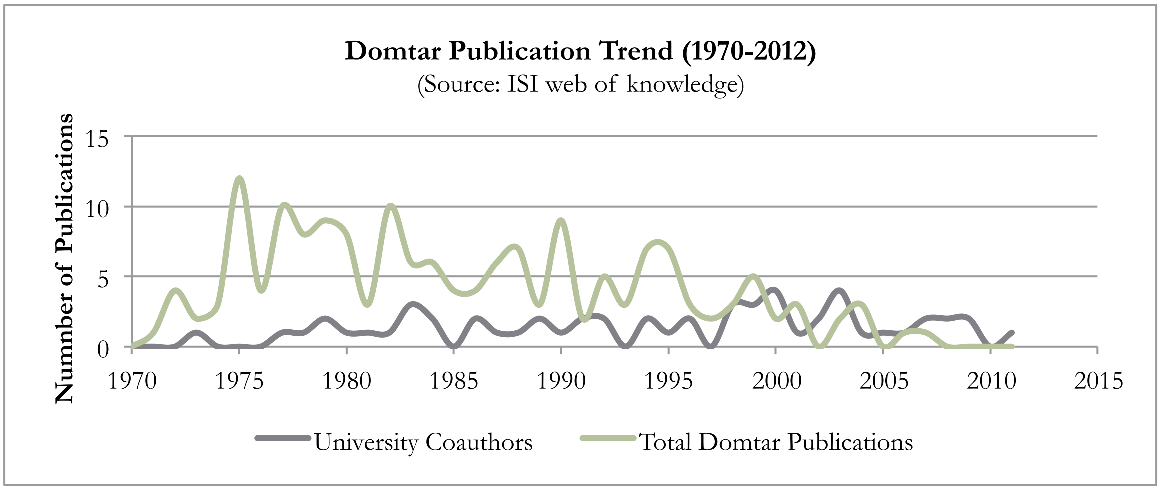


FIGURE 49: DOMTAR'S PUBLICATION TREND

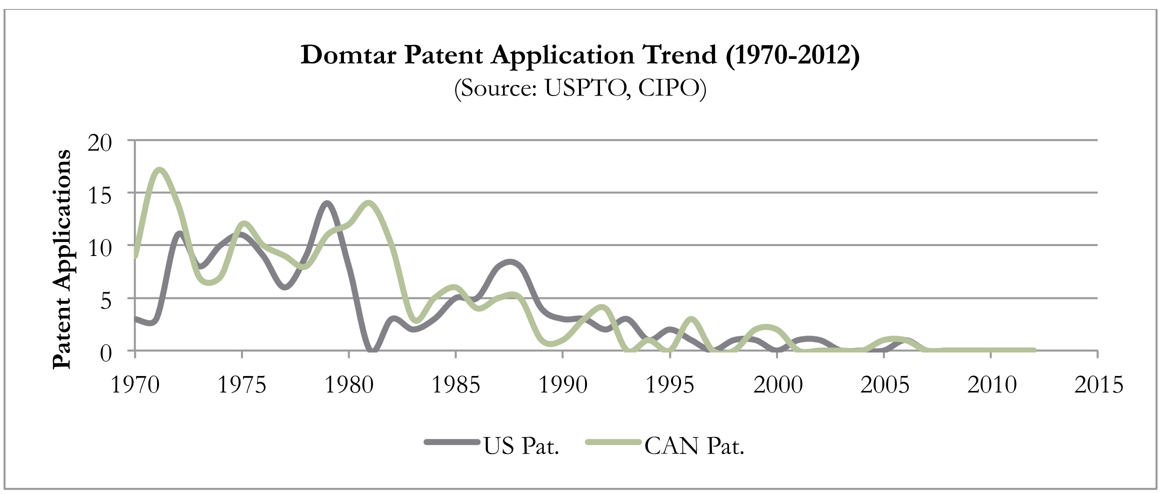


FIGURE 50: DOMTAR'S PATENTING TREND

In the mid 1980s, the Canadian forest products industry had a recovery. Domtar's Senneville research center staff peaked in 1988 with 135 collaborators and a research budget of CAD $11 millions [195]. However, in 1989 Domtar divested its chemical division, which led to a reduction of 40 positions in Senneville's R&D center. During the 1990s, Domtar continued reducing personnel as part of a company-wide downsizing effort [196]. In 1990, the Senneville staff was reduced to 72 people, and in 1992, Domtar's R&D budget was reduced to 7 millions. In 1996 Domtar divested the construction materials division, and ceased to conduct research in this area. Finally, in 2000 Domtar closed the Senneville research complex. According to Domtar's Vice President for research at the time, Robert Eamer, R&D at Domtar had become isolated from the company's business units, and the company's shareholders were dissatisfied with the research performance of the firm [197]. The decision was to move Senneville's R&D staff back to the mills and head office in Montreal.

The closure of Domtar's Senneville research center was also part of a larger trend within the Canadian forest products industry. According to a senior company executive, not only Domtar, but "a very long list of research facilities got closed in a span of about 5 years right about that time" [133]. One reason was the economic difficulties faced by the Canadian pulp and paper industry in the early 2000s. "As I recall, and the industry of course is very cyclical, those were difficult times in the US and Canada because we just came out of a pretty significant expansion in the capacity. There were a lot of new projects that put new capacity in pulp and paper, and there were also a lot of expenditures incurred to address environmental issues that really came to in the 1990s. Then the market hit a soft spot and it became exceedingly difficult to maintain those labs" [133]. A second reason was the overall performance and contribution of these labs to the company's bottom line. According to a Domtar senior executive, there was an industry-wide assessment on what was each company's return for their investment in research and development "If you look at how much R&D is costing you and after 20 or 30 years you look back and see what it has contributed to your top and bottom line and then you look forward and ask if it is a good use of your resources, and everybody at the same time decided it wasn't" [133].

INFORMAL TECHNOLOGY GROUP AND CONSORTIA-BASED UNIVERSITY RELATIONS

After the closure of the Senneville research Center, Domtar's research priorities shifted towards development. According to Eamer, "We should call it technology development, not research" (quoted in [197]). Domtar's decision to concentrate on operations and executions had several repercussions for the company's university relationships. According to a senior Domtar executive "the idea, and I think we did a good job, was to have a laser like focus on execution. And so, intermediate to long-term research became a secondary priority at best" [133]. Universities were thus in charge of conducting the more exploratory, long term research for the company. In 2000, for example, Domtar joined the Chair of Environmental Design Engineering at the Polytechnic Institute of Montreal [198]. Between 2004 and 2007 Domtar was member of a research consortium at the University of Toronto's pulp and paper center aimed at increasing energy and chemical recovery efficiency in the Kraft process. In 2007, Domtar also became part of the Bioactive Paper Network of McMaster University. Domtar also continued being a member of Paprican, and McGill's University industrial research center after the closure of Senneville.

The consortia-based collaborative research model, however, was not sustainable, and forest products companies in Canada and the US began moving away from across-the-board research programs [197]. As explained by a Domtar executive "One of the roles of institutions such as FP Innovation was to act as a liaison between the industry and the academic circles. That element of the equation is wrong. The research institutions survive longer than the actual product research labs that were owned by the industry players. They (Paprican) also underwent transformation, had to reinvent themselves because a lot of those collaborative research models collapsed" [133]. Domtar thus changed its research strategy and emphasized internal R&D.

RENEWED EMPHASIS ON IN-HOUSE R&D

After the closure of the Senneville research center, Domtar retained a small technology group, but there was no R&D organization per se. This situation changed, however, in 2008 when Domtar rebuilt its internal R&D group and hired a new director of R&D for the company.

After the formation of the new R&D group, Domtar began a series of collaborations aimed at establishing a bio-refinery program. In 2009 Domtar established a joint venture with FP Innovations to build and operate a commercial-scale nanocrystalline cellulose plant in Domtar's Windsor mill in Quebec (Project CelluForce). Nanocrystalline structures, which are stronger than steel, give trees their rigidity. They have several applications as a lightweight, durable material [199]. The CelluForce demonstration plant opened in 2012 producing 1 ton of nanocrystalline cellulose per day [200]. In 2011, Domtar began a project to remove lignin from black liquor utilizing Metso's Lignoboost technology. This project was done in collaboration with the US Forest Products Laboratory, the North Carolina State University, and the Biofuels Center of North Carolina [201]. In 2012 Domtar started a project with the Battelle Memorial Institute and with the Centre for Research and Innovation in the Bio-economy (CRIBE) to develop a fast pyrolysis system to transform wood waste into liquid fuels at Domtar's plant in Dryden, Ontario [202].

3.1. RESEARCH PRIORITIES ALONG DOMTAR'S VALUE CHAIN

From a value chain perspective, Figure 51 shows that most university collaborations have been in the area of waste management, environmental impact, and pulping technologies.

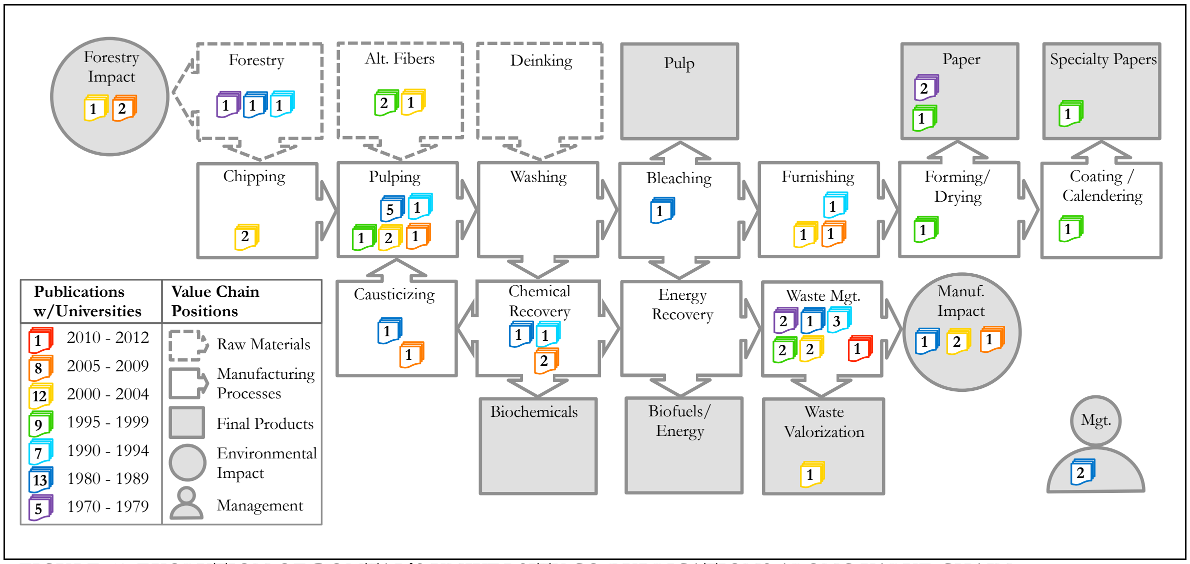


FIGURE 51: EVOLUTION OF DOMTAR'S UNIVERSITY CO-PUBLICATIONS ALONG VALUE CHAIN

WASTE MANAGEMENT COLLABORATIONS

In the area of waste management, Domtar has conducted research on controlling odors from pulp waste treatment ponds, biodegradation of spent pulping liquors, and effluent sludge treatment. In these research areas, the company has worked with local universities and Canadian government agencies including the University of Quebec, the University of Calgary, the University of Western Ontario, Queens University, Environment Canada, and the Canadian Department of Fisheries.

ENVIRONMENTAL IMPACT COLLABORATIONS

On the environmental side, Domtar has worked with research institutions in assessing the impact of the company's forest management practices on wildlife (e.g. red-shouldered hawks, Canada Warbler), and also on the impact of the company's manufacturing operations on rivers and streams (e.g. fishes, fresh water mussels). Partners in these projects have been FP Innovations, and the Canadian Government Agencies (e.g. Canadian Forest Service, Environment Canada, Ontario Ministry of Natural Resources, etc.).

PULPING COLLABORATIONS

Since the 1980s, Domtar has been collaborating with Paprican in ultra-high-yield pulping. This technology, also known as steam explosion pulping (SEP), utilizes vapor to heat chips at high temperatures, followed by explosive decompression to cause the chip's fibers to soften. During the 1990s, this technology became an alternative to traditional CMP (chemical-mechanical pulp) and CTMP (chemical-thermo-mechanical pulp) pulping processes as it allowed reducing the amount of energy required to refine fibers [203]. Related studies on improving the refinement process were also conducted by Domtar and Paprican to enhance the design of the refiner plate, and to better control the chip refiner operation.

A different pulping technology also pursued by Domtar in collaboration with Paprican is the pulp yield enhancement by chemical means. During the 1990s, Paprican developed a process for cooking hardwoods with anthraquinone and polysulphide liquors, to increase Domtar's pulp yield by 3% [204].

3.2. GEOGRAPHY OF UNIVERSITY PARTNERS

Figure 52, based on the company's publication records, shows the geographic distribution of Domtar's university partners. Historically, Domtar's university network has been concentrated in Canada, and in particular near Montreal. Domtar's former Senneville research center, Domtar's head quarters, McGill University, Ecole Polytechnique, and FP Innovation's (former Paprican) are all located within a 10-mile radius. Domtar's former Senneville research center was the main node within this network, and researchers from FP innovations are the most common publication coauthors. After the closure of the Senneville research center, Domtar's mills became more active in publications, in particular, Domtar's Cornwall and Espanola Mills in Ontario.

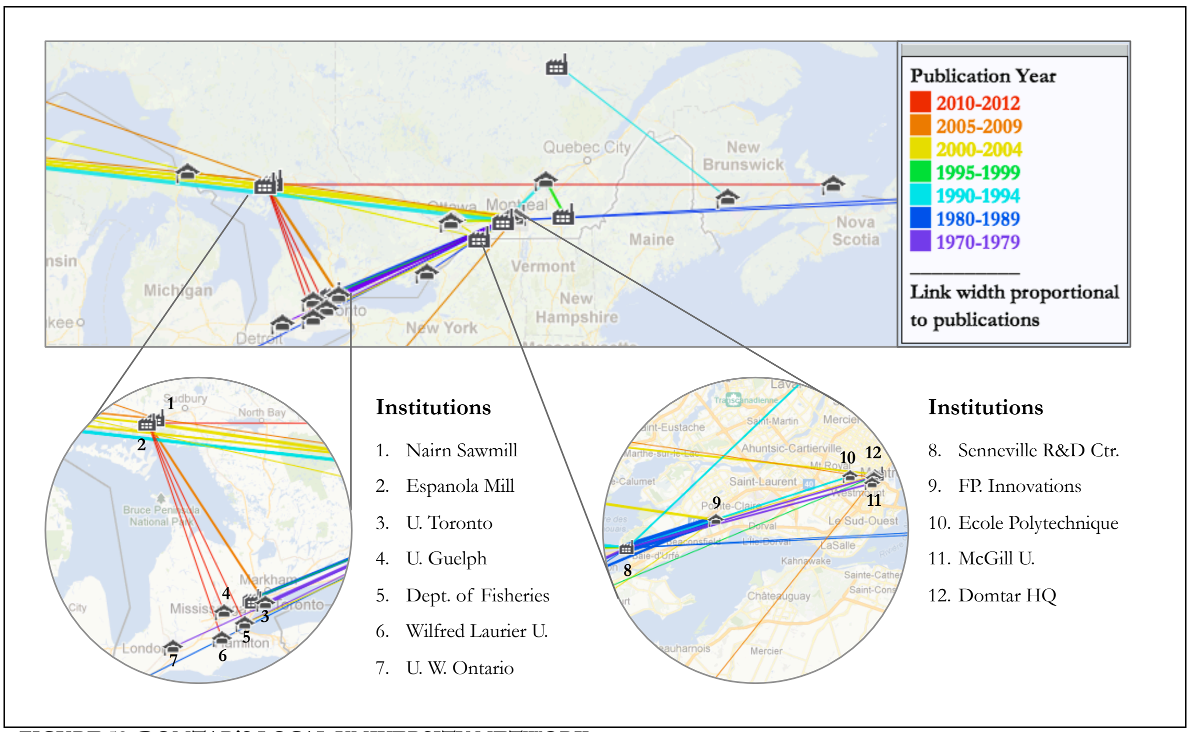


FIGURE 52: DOMTAR'S LOCAL UNIVERSITY NETWORK

Domtar's international university network is smaller than its Canadian university network. The company has coauthored only three papers with international partners. As explained by a company executive, one reason that Domtar's university network has been predominantly Canadian, is that "Domtar was a household name in Canada, but had absolutely no presence in distribution or sales in the United States" [133]. The internationalization into the US, through the acquisitions of Georgia Pacific assets in 2001 and the merger with Weyerhaeuser's fine paper division in 2007, is changing this trend. "This was a very major change; this idea to go international from a Canadian perspective, going to the US was a big deal. The US acquisitions had profound impact on the company's relationships with research institutions and with its own research programs" [2]. Since 2010 Domtar has been collaborating with several US partners including the Batelle Memorial Institute, the US Forest Products Laboratory, and North Carolina State University, as discussed in Section 3.

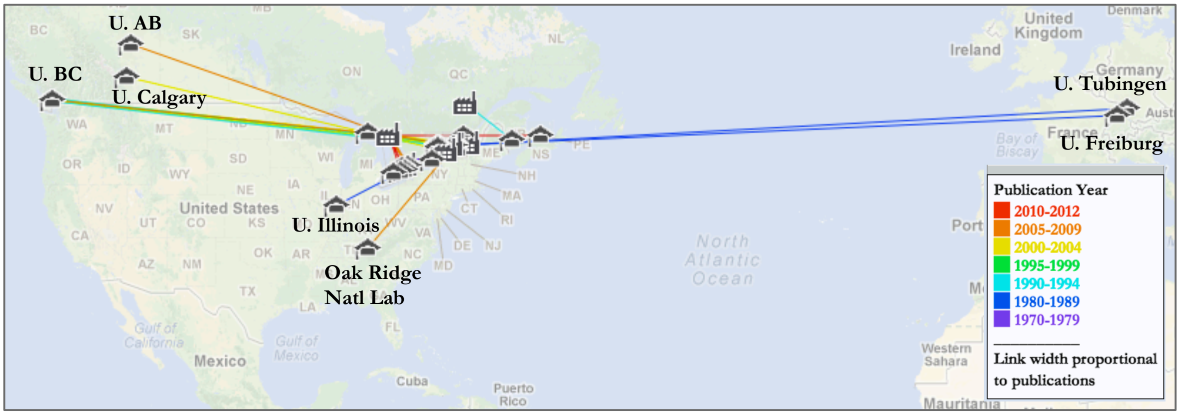


FIGURE 53: DOMTAR'S GLOBAL UNIVERSITY NETWORK

3.3. Technology transfer through people flows

To analyze the academic and professional trajectories of Domtar's most prolific authors and inventors we used Domtar's publications and patenting records to develop a list of 81 people involved in the company's R&D activities. Each of the names in this list have either patented or published at least two papers under Domtar's name.

Analysis of the professional trajectories shows that most of Domtar's R&D personnel have been recruited directly from academic or research institutions, particularly from McGill University, the University of Toronto, and Paprican (FP Innovations). As observed in Figure 54, Domtar's R&D personnel peaked at the end of the 1980s, after which there was a steady decline in the number of people working in R&D. After the closure of the Senneville research center in 2000, most of Domtar's research personnel were relocated to the company's mills or central headquarters, although a few took early retirements or left the company to pursue jobs closer to their homes [197]. After leaving Domtar, 39% of the researchers joined other firms, and 14% went back to research institutions, mainly Paprican (FP Innovations).

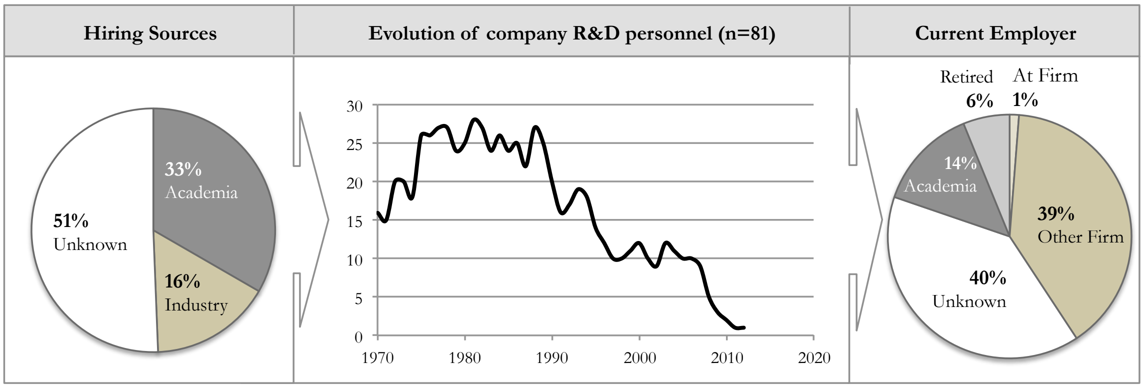


FIGURE 54: EVOLUTION OF DOMTAR'S R&D PERSONNEL

Analysis of the academic training of Domtar's researchers shows an overlap between the academic institutions attended by these people and the company's publication partners (See Figure 55). FP Innovations has participated in almost 40% of Domtar's publications and has helped directly and indirectly in the training of several of the company's personnel. A least 5% of Domtar's researchers in the sample have been recruited directly from FP Innovations, and several others have benefited from the academic training received at the Universities associated with FP Innovations. For example, several FP Innovation researchers have educational joint appointments with McGill departments [205], and FP Innovations has funded academic chairs at McGill University, the University of British Columbia, and at the Ecole Polytechnique of Montreal.

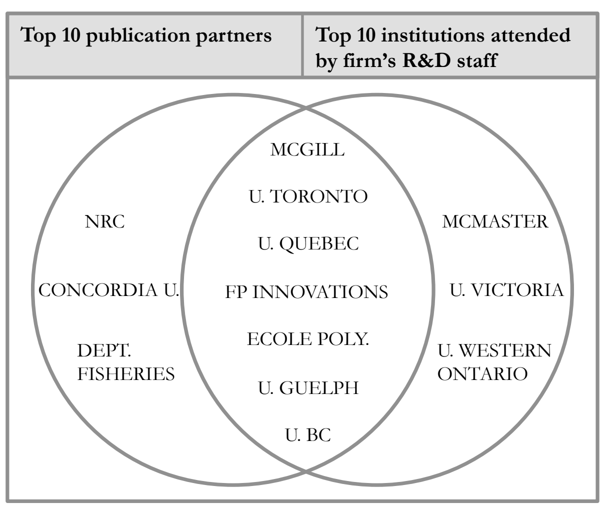


FIGURE 55: OVERLAP BETWEEN DOMTAR'S HIRING AND PUBLISHING PARTNERS

4. CASE STUDY DISCUSSION

Domtar has endured several strategic changes and participated in a diverse mix of industries over time, giving an opportunity to analyze how changes in corporate strategy have affected its relationship with universities and research institutes. Table 13 presents a summary of these findings.

TABLE 13: SUMMARY OF HOW DOMTAR'S UNIVERSITY RELATIONSHIPS COEVOLVED

UNIVERSITY LINKS / FIRM STRATEGIES	RESEARCH PRIORITIES	PEOPLE FLOWS	INSTITUTIONAL NETWORKS
PERIOD 1: **INTEGRATION** (1903-1956)	**Production Processes** • Recovery Boiler (1920s) • Vanillin (1930s) • Arborite phenolic resins (1940s)	**First R&D Center** • Howard smith begins conduction R&D in 1920s • Recruiting of McGill students (Tomlinson II)	**Creation of Paprican** • C. Howard Smith instrumental in the creation of Paprican • First collaborations with McGill University (Vanillin production)
PERIOD 2: **DIVERSIFICATION** (1957-1966)	**Pulping technologies** • Black liquor oxidation, Centricleaners, Magnefite pulping, ClO2 bleaching **Chemicals** • Metal powder pilot plant **Construction Materials** • Acoustic properties	**New Senneville R&D Ctr.** • Merged R&D personnel of Howard Smith Papers, St. Lawrence Co., and Domtar • R&D Ctr. staffed with 50 people, 1/3 with PhDs	**Growth of Paprican** • New research building in Poite Claire, close to Domtar's Senneville R&D Center • Collaborations in pulping technologies with Paprican (Alkafide project)
PERIOD 3: **FOCALIZATION** (1967-1974)	**Pulping technologies** • Fluidized bed reactors **Forestry equipment** • Roadside chipper	**Local university recruiting** • Recruited PhDs from U. of Toronto, McGill, U. Quebec, McMaster, and also from Paprican	**Local University Network** • U. of Toronto Chemical Dept. • McGill University • Paprican
PERIOD 4: **INTERNATIONAL-IZATION** (1975-1980)	**Environmental Impact** • Effluent and emissions treatment **Chemicals** • Resins, tar pitches	**Senneville R&D Ctr Growth** • Growth in R&D staff at the end of 1970s.	**First Int. collaborations** • U. Freiburg & U. Tubingen, Germany • Virginia Tech, US – Forest Products
PERIOD 5: **INTEGRATION** (1981-1989)	**Alternative pulping** • Steam explosion pulping **Alternative fibers** • New tree species	**Senneville R&D Ctr Peaked** • 135 people in 1988	**New projects at local Univs.** • Same university partners: McGill, U. Toronto, Concordia Univ, Paprican
PERIOD 6: **FOCALIZATION** (1990-1995)	**Sustainable Forestry** • Soil nutrition • Harvesting techniques	**Decline in R&D staff** • Loss of 40 positions after divesture of Chemicals Div. • Further cuts after divesture of Construction Materials.	**Consortia research networks** • With Canadian university partners: McGill, U. BC, E. Polytechnique, U. Quebec, Paprican
PERIOD 6: **INTERNATIONAL-IZATION** (1996-2007)	**Operations management** • "Laser-like" focus on operations and execution	**Closure of R&D Center** • Transfer of R&D staff to mills and Corp. HQ. • Further decline in R&D staff	**Funding of University Chairs** • Sustainable Forestry – U. Quebec (1998) • Supply Chain – E. Polytechnique (2000), U. Laval (2007)
PERIOD 7: **DIVERSIFICATION** (2008-ONWARDS)	**Bio Refinery** • Lignin, biofuels, Nano-crystalline cellulose **Personal Care** • Disposable diapers	**Rebuilt R&D organization** • Hired people to join internal R&D • Incorporated R&D personnel of Attends personal care	**Merger of Canadian Res. Ctr.** • Paprican, Forintek, Feric, and the Canadian Wood Fibre Centre form FP Innovations **New links with US institutions** • NCSU, US FPL

During Period 1, Domtar was a chemical company that specialized in coal distillation. While it had an internal R&D lab, there is no evidence that the researchers at this lab had strong university relationships. Domtar developed strong university connections after the acquisition of Howard Smith Papers in 1957. Prior to this acquisition, Howard Smith Papers had played a relevant role in the creation of Paprican, the Canadian Pulp and Paper Institute, and in the development of the Cellulose and Industrial Chemistry Chair at McGill University.

The second period was characterized by the diversification of Domtar's business lines. Through acquisitions, Domtar entered the pulp and paper, construction materials, consumer products, and packaging industries. Domtar merged its research laboratory with Howard Smith Papers and St. Lawrence Corporation's labs, creating a large research complex at Senneville, Quebec, located close to Paprican's new Pointe-Claire research center and also to McGill University in Montreal. Domtar has hold close relationships with these two research institutions ever since.

The third period was marked by the divesture of Domtar's consumer products division to Bristol-Myers and the reorganization around three businesses areas: pulp and paper, chemicals, and construction materials. Domtar began staffing the Senneville research center with local university graduates, and began a small number of collaborations in pulp and paper technologies with Paprican, the University of Toronto, and McGill University.

The fourth period was marked by the internationalization of Domtar's construction materials division into the US. The 1973 oil crisis left Domtar's pulp and paper mills with high energy costs, and the company closed several mills in Canada. The Company's R&D Center grew in size, and the first international university collaborations started.

The fifth period was characterized by the Government control of the company. Domtar's research priorities shifted towards environmental research, and energy efficient pulping technologies (e.g. steam explosion pulping). The Senneville R&D center continued to grow and Domtar increased the number of projects with universities mainly in Canada.

The sixth period was characterized by the divesture of Domtar's chemical and construction materials divisions with repercussions for the company's research center, which reduced its staff by half. In terms of Domtar's university relationships, while there was a reduction in the number of company publications, there was no observed a decline in the number of publications with universities perhaps because Domtar has the lowest university co-publication rate compared to the other firms in our sample. Only 56 of the company's 225 publications have been written with a university partner. Further, in the area of chemicals and construction materials, Domtar had coauthored only one paper with a university partner. Thus, no significant university relationships were lost after divesture of these divisions.

The seventh period was characterized by economic difficulties for the Canadian pulp and paper industry. Domtar decided to internationalize and grow into the US through a series of large acquisitions in the pulp and paper market. During this period, the company closed its

Senneville research center following an industry-wide closure trend. Domtar changed its research priorities towards operations and executions, and began moving away from consortia-based research alliances.

Period 8 is marked by diversification into personal care products through acquisitions. Domtar also rebuilt its internal R&D organization, and after the acquisitions of Attends and EAM Corporation, the company now has three new R&D centers located in Greenville, NC, Jesup, GA, and Anneby, Sweden. After the expansion into the US Domtar began collaborating with new research institutions and US universities.

THE MEDIATING ROLE OF EQUIPMENT MANUFACTURERS IN TECHNOLOGY DIFFUSION

The Domtar case illustrates the role of equipment manufacturers in the development and diffusion of technology. Domtar researchers have developed several important technologies for the pulp and paper industry, but the company has commercialized few of these inventions. Tomlinson's recovery boiler, for example, was licensed to the Babcock and Wilcox Company, an engineering company specialized in boilers [133]. Bauer, a US manufacturer of hydro cyclones, marketed the Centricleaners designed by Domtar to remove pulp impurities. The same is true for some of the projects developed by Domtar in collaboration with Paprican. The Paprilox system, for example, was initially tested and validated at Domtar's Espanola mill in 1999, however Paprican licensed this technology to Noram Engineering, a Canadian-based engineering company.

As explained by a Domtar executive who used to work for an equipment manufacturer prior to joining the firm, during the 1940s and 1950s most of the pulp and paper companies were innovators. However, the companies that ended up commercializing the technologies were the equipment manufacturers. "The people who had the technology are the equipment vendors, and that is not an accident, it is because some very fundamental reasons that it should work that way. It is not that the equipment manufacturers are smarter than the folks who are operating at the mills, is that (equipment manufacturers) are exposed to a much broader spectrum of conditions whereas an operating company and the folks in a given mill they just see the same thing all the time"[133]. In other words, since equipment manufacturers are exposed to a broader scope of needs and conditions, they are able to develop the capabilities and experience necessary to serve the pulp and paper industry at a world basis. "Currently, most of the innovations in process and manufacturing technologies for the pulp and paper industry are coming out of machinery vendors"[133].

BIDIRECTIONAL KNOWLEDGE FLOWS IN THE DEVELOPMENT OF A TECHNOLOGY

A related point refers to the role of universities in the development of a technology. There is constant iteration between universities and firms for developing and transferring new technologies. Domtar's current research projects in the conversion biomass into value-added chemicals (i.e., bio-refinery) and the development of Domtar's Nanocrystalline cellulose plant are two examples of bidirectional knowledge flows.

The idea that companies can obtain value-added chemicals from its pulping operations is not new. Domtar, for example, began producing phenolic resins from lignin during the 1940s. During the late 1960s, however, Domtar stopped utilizing this technology as phenols from petrochemicals sources became cheaper [190]. Universities, however, continued conducting research on the production of lignin from pulping liquors, and in the 1990s a group of researchers from Chalmers University working in collaboration with Innventia developed a cost-effective process for producing lignin out of black liquors, which they named Lignoboost. The technology was developed as part of a research project funded by Swedish Energy Agency, and several forest products companies including Weyerhaeuser and Stora Enso [206]. After passing pilot tests in 2006, this technology was licensed in 2008 to Metso, a Finnish equipment manufacturer. In 2011 Domtar selected this technology to produce lignin at the company Plymouth mill in North Carolina. As summarized by a Domtar executive "So we were doing this in the 1960s, and the reason it stopped is because the economics of it didn't make any sense. In that time, oil was rather cheap and phenol was easier to combine, and it turned out to be easier to work with than the lignin precipitate from black liquor… So now we are sort of reinventing the wheel" [133].

A second example of the iteration between universities and firms for developing a technology occurred in the area of nanocrystalline cellulose. Nanocrystallyne cellulose structures (NCCs) were first observed by Bengt Rånby in 1949, then a researcher at the Institute of Physical Chemistry of the University of Uppsala, Sweden [207]. In 1957, Rånby began working for the American Viscose Corporation, a US manufacturer of rayon and other cellulose-based chemicals. Rånby continued working on NCCs in collaboration with Robert Marchessault [208], a PhD graduate from McGill University, who had previously spent a year as a postdoctoral fellow at the University of Uppsala in 1955 [209].

In 1962 the American Viscose Corporation was sold to the FMC Corporation, and both Rånby and Marchessault moved to the State University of New York. In 1969 Marchessault returned to Canada and joined the University of Montreal. In 1979, Marchessault was recruited by the Xerox Research Center of Canada, where he served as Vice President of research, and continued conducting research on cellulose and crystalline structures. In 1990, Marchessault returned to McGill University, where he began collaborating with Prof. Derek Gray, studying the iridescent properties of NCCs [210]. Dr. Gray, who was a research scientist at FP Innovation (former Paprican), spent the next years refining the methods for extracting Nanocrystals from wood pulp. In 2012, Domtar and FP Innovations opened the world's first commercial scale NCC plant in Windsor, Canada. Figure 56 summarizes the different institutions, people, and development paths followed by NCCs.

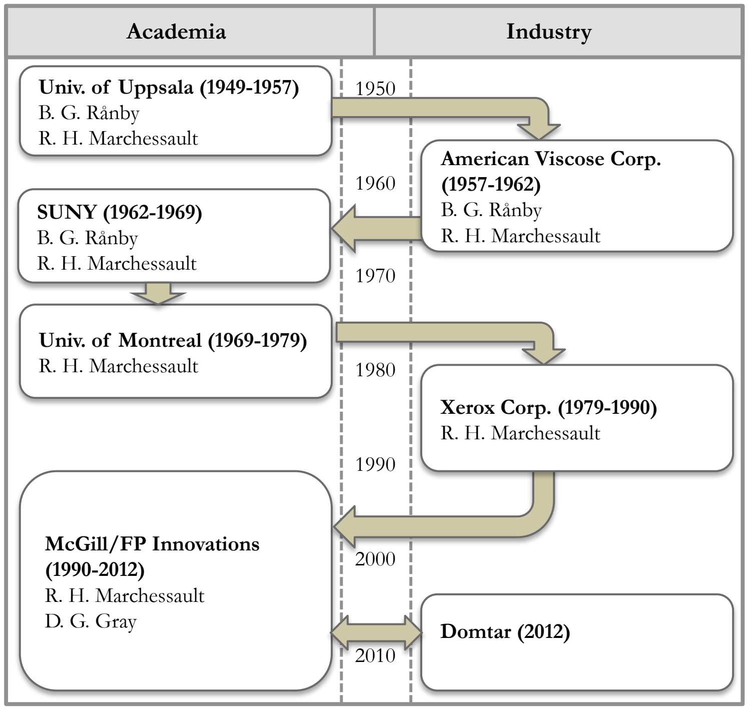


FIGURE 56: BIDIRECTIONAL KNOWLEDGE FLOWS IN THE DEVELOPMENT OF NCCS

THE TIGHTLY COUPLED NATURE OF INDUSTRY-UNIVERSITY LINKS

A final point refers to how changes in Domtar's strategy affected university research agendas. The industry-wide closure of the industrial R&D labs had several consequences for Paprican and Domtar's university partners. According to a Domtar executive, after the closure of most of the industry's corporate R&D labs there was a reorganization, on a global scale. All of the national research institutions that were servicing the industry, "also underwent transformation, had to reinvent themselves because a lot of those collaborative research models collapsed" [133]. For Paprican, in particular, these were difficult times. In 2004, it began a restructuring phase and several employees left the Institute [211]. In 2007, Paprican merged with Forintek, the Forest Engineering Research Institute of Canada (Feric), and the Canadian Wood Fibre Centre forming FP Innovations. Only recently FP Innovations has regained profitability. The point is that if industry loses interest and stops supporting university research, the knowledge and technical capabilities developed by the region's research institutions can be eroded.

FP Innovations as a hybrid industry-university research organization

The Underwood-Simmons act eliminated tariffs imposed to Canadian newsprint entering the United States, and the Canadian pulp and paper industry saw a period of rapid growth. The Canadian Forestry Association began lobbying for the creation of a Canadian Forest Products Laboratory (CFPL) and in 1913 convinced the Canadian Department of Interior to create this institution [212].

The CFPL was initially located at the McGill University Campus in Montreal. At the time, McGill had a research line in forest products and industry had donated pulp digesters for students to conduct pilot tests [213]. The CFPL's first research lines were on wood preservation, wood distillation, timber physics, and pulp and paper technologies [212]. The first director of the CFPL was a McGill Alumni from the Chemical Department, and during the 1920s several FPL staff gave lectures to McGill Students [213].

During the 1920s, however, the Canadian Pulp and Paper Association (CPPA) felt that the CFPL's research line in pulp and paper was underfunded, and began lobbying for additional government funds [194]. In parallel, the CPPA and McGill University reached an agreement in 1925 to jointly fund a chair in the Chemical Engineering department. Half of the funds came from the industry members of the CPPA, and the other half came from a 200,000-dollar donation made by the widow of a paper industrialist (E.B. Eddy) to McGill University. C. Howard Smith, who was president of the CPPA, convinced Harold Hibbert, an assistant professor of chemistry at Yale, to fill the Eddy Chair in Cellulose and Industrial Chemistry [214].

In 1926 the CPPA, the Canadian Government, and McGill University reached an agreement for the creation of the Canadian Pulp and Paper Research Institute (Paprican). The CPPA committed to the construction of a new building at McGill University, and the Canadian Government agreed to merge the Pulp and Paper Division of the CFPL with this new institute. The first stone of Paprican's new building was laid in 1927 and Prof. Hibbert's research laboratory was transferred to this new research institute [214].

During the 1950s, Paprican grew in size, and in 1957 the Canadian Government agreed to fund a new building in Point Claire, PQ. During the 1960s, this lab continued growing and during the 1970s the Canadian Government opened an affiliate lab at the University of British Columbia, Vancouver. At the beginning of the 1990s, Paprican peaked with 375 employees and a research budget of CAD 31 millions [191].

In the early 2000s, Paprican's member companies pressed for a reorganization of this Institute and the number of employees was reduced to 276 in 2004 [211]. In 2007 Paprican merged with three other research organizations Feric, Forintek, and the Canadian Wood Fibre Centre to create FP Innovations. Currently, FP Innovations has 550 employees across Canada, and a research budget of CAD 97 millions [215].

Appendix V: International Paper

1. Introduction

International Paper (I-P) is the world's largest paper and packaging firm. It was founded in 1898 as a result of the merger of 17 mills from the US northeastern region. The company has 31 pulp, paper and packaging mills, 208 converting plants, 20 recycling plants operating in North and South America, Europe, and Asia [216].

On 2011, International Paper generated US$26 billions in sales—twice as large as its closest competitor—from four main business units: papers, industrial packaging, consumer packaging, and their business-to-business distribution system [216]. The company is headquartered in Memphis, TN, and has approximately 70,000 employees worldwide.

Figure 57 presents an overview of I-P's sales and R&D expenditures versus time. The company has a long heritage of R&D expenditures, reaching approximately 1% of their sales in the early 1980s. Recently, however, the company has been reducing R&D and is currently the firm with the lowest R&D intensity of our sample, investing approximately 0.05% of its sales in R&D.

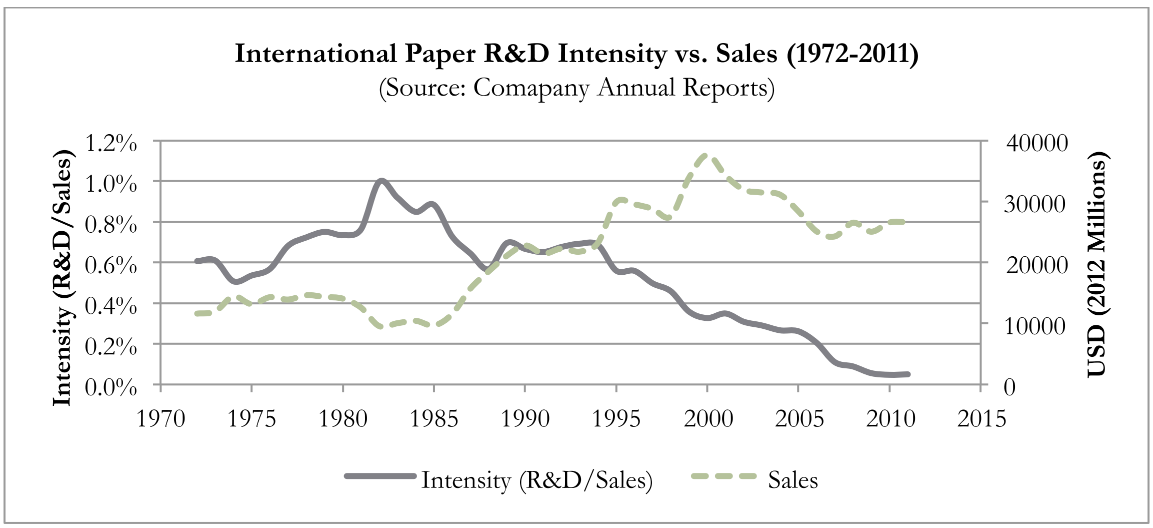


FIGURE 57: EVOLUTION OF INTERNATIONAL PAPER R&D INTENSITY

This case study presents a longitudinal review of changes in (i) the company's businesses, (ii) research strategy and (iii) connections to universities and public research institutes during each strategic period of the firm.

Section 2 characterizes the different strategic periods of I-P. Section 3 describes the origins and evolution of the firm's university relationships as judged by changes in the research priorities of the firm, changes in the firm's university network, and people flows between partnering institutions. Section 4 summarizes the main findings and lessons.

2. HISTORICAL CHANGES IN COMPANY STRATEGY

Data on I-P's strategy was obtained by analyzing the company's annual reports and secondary sources of information, including journals, press articles, and company historical retrospectives. We also conducted interviews with a current and a former senior R&D manager of the firm. From the data, we defined 11 different strategic as in the left hand side of Figure 58, which coincided with changes in the CEO of the firm. The right hand side of the figure shows the trajectory followed by International Paper.

STRATEGIC PERIODS

Period 1 (1898-1912): Integration into sulfite pulps

Period 2 (1913-1923): Internationalization into Canada

Period 3 (1924-1935): Diversification into electric power

Period 4 (1936-1942): Integration into packaging

Period 5 (1943-1951): Diversification into chemicals

Period 6 (1952-1965): Integration into consumer packaging, printing, and construction materials

Period 7 (1966-1969): Unrelated diversification

Period 8 (1970-1983): Focalization

Period 9 (1984-1999): Internationalization (Europe, Asia)

Period 10 (2000-2005): Focalization

Period 11 (2006-Onwards): Internationalization into BRIC economies

STRATEGIC TRAJECTORY

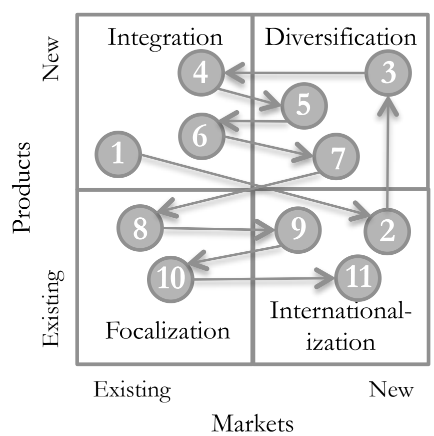


FIGURE 58: INTERNATIONAL PAPER STRATEGIC PERIODS

PERIOD 1 (1898–1912): VERTICAL INTEGRATION INTO SULFITE PULPS

International Paper (I-P) was founded in Albany, NY in 1898, after 17 pulp and paper companies from the Northeast region decided to merge, controlling almost 60% of the US newsprint market [217]. During the first period, I-P acquired different patents and obtained a technological monopoly on sulfite pulping [218]. Sulfite pulp was stronger than the prevalent groundwood pulp, which produced a low quality yellowish paper [219]. Papermakers, however, found that by combining sulfite pulp and groundwood pulp, they were able to obtain a cheap good-quality white paper, which was in increased demand for newsprint and books [218]. During this period, I-P increased its production capacity of sulfite pulp from 490 tons/day in 1898 to 1,000 tons/day in 1912, and it licensed its technology to more than 200 paper manufacturers [218].

Newspapers, however, resisted this patent monopoly and lobbied for eliminating Canadian newsprint import tariffs [220]. I-P, foreseeing tariffs reductions, vertically integrated increasing its timberland holdings to 1,2 million in 1908, and acquiring the Turner Falls Machinery Company of MA to increase their capabilities in papermaking machines [218].

In 1909, I-P's sulfite digester patents expired, and the government announced a reduction in Canadian newsprint tariffs, prompting the company to revise its strategy. In 1911, the company announced it would move its newsprint production to Canada, and in 1912 that it would shift its US production towards specialty papers [218]. Finally, the Underwood-Simmons tariff act of 1913 confirmed I-P's prediction by eliminating tariffs on Canadian newsprint imports.

Period 2 (1913-1923): Internationalization into Canada and Southern US

In 1913, Philip T. Dodge became President of International Paper. The influx of Canadian newsprint into the US market had negatively affected the company's newsprint market share, which was reduced from 60% to 26% [221]. In 1915, the company announced it would stop building newsprint mills in the US, and that it would start erecting them in Canada [222]. In 1919 they started the construction of a newsprint mill in Three Rivers, Quebec, and in 1925 they announced the construction of another sulfite mill in Gatineau River. That same year, I-P announced the acquisition of the Riordon Company of Canada, which included a Rayon-producing sulfite mill in Temiskaming, Quebec, a paper mill in Ticonderoga, New York, and a newsprint mill in Hawkesbury, Ontario [223].

From a technological perspective, this period was marked by the emergence of Kraft (Sulfate) pulping in the US. This technology was created in Germany during the 1880s, and it produced a strong brown pulp—Kraft means strong in German—suitable for wrapping paper, bags, and containerboards. New advancements in chlorine bleaching opened this process to the production of white papers. The invention of the recovery boiler during the 1930s lowered the cost of this process as it allowed the reutilization of Kraft pulping chemicals. Kraft pulping also opened the pulp and paper industry for the southern US States, as resinous species could be used as feedstock for pulp production. The first US Kraft pulp mill opened in North Carolina in 1909, and several others were soon built [224]. The South offered low-cost timberlands, warm temperatures that allowed year-round operations, and flat lands that facilitated the exploitation of timberlands by conventional trucks, as opposed to waterways or rails in the north.

International Paper acquired its first sulfate pulp mill at Van Buren, Maine in 1920, and in 1925 they expanded into the south by acquiring the Bastrop Pulp and Paper Company and the Louisiana Pulp and Paper Company. In 1926 they started building a new mill in Camden, Arkansas, and established the Southern International Paper Company as a subsidiary of I-P. During period 2, the company also increased its timberland holdings in the south to supply the raw materials for the new mills, and they formed Arizona Chemical, a joint venture with the American Cyanamid Company to produce sodium sulfate for the Kraft pulping process.

PERIOD 3 (1924-1935): DIVERSIFICATION INTO ELECTRIC POWER

In 1924, Archibald Graustein was elected president of I-P and moved to fully exploit I-P's water resources for the production of electricity [225]. I-P opened a hydroelectric plant at Sherman Island, NY, and a few years later they built three large hydroelectric plants on the Gatineau River near Ottawa. In 1925 I-P acquired a substantial interest in the New England Power Association, and by 1929, 54% of I-P's revenues came from the sale of electric power. That same year, the International Paper and Power Company was formed to manage all electric assets. This subsidiary was short lived, as in 1935 the Public Utility Holdings Act forced the divesture of I-P's power generation assets.

During this period, I-P also started moving up the value chain into specialty papers and other pulp-converted products. In 1927, the company acquired the George and Sherrard Company of Wellsburg, West Virginia, which manufactured bags for the flour, cement, and fertilizer industries. In 1928 I-P secured a contract from the US government to produce stamped envelopes and newspaper wrappers for the Post Office Department, and acquired an envelope converting plant in Dayton, Ohio. In 1928, I-P acquired a controlling stake in the Continental Paper and Bag Company, and in 1931 acquired the Seminole Paper Corporation, a producer of toilet tissue.

In Canada, I-P began diversifing into wood building materials and hygiene products. In 1927, I-P had created the International Fibre Company in Midland, Ontario to produce insulating building boards and in 1939, I-P formed a joint venture with the Canadian Masonite Corporation to build a mill in Gatineau, Quebec for the manufacture of hardboard [226]. I-P also started producing sanitary pads and facial tissue in Canada in 1931 [227].

Finally, the Southern International Paper began a period of capacity expansion through the construction of new pulp mills in Mobile, AL (1928), Panama City, FL (1931), and Georgetown, SC (1937), which allowed increasing the I-P's production output (See Figure 59). I-P also began acquiring timberlands to secure the supply of raw materials to these mills. By 1948 the company had over 21,000 square miles of forest in the US and Canada, a forested area equivalent to the states of Vermont, Massachusetts and Rhode Island [221].

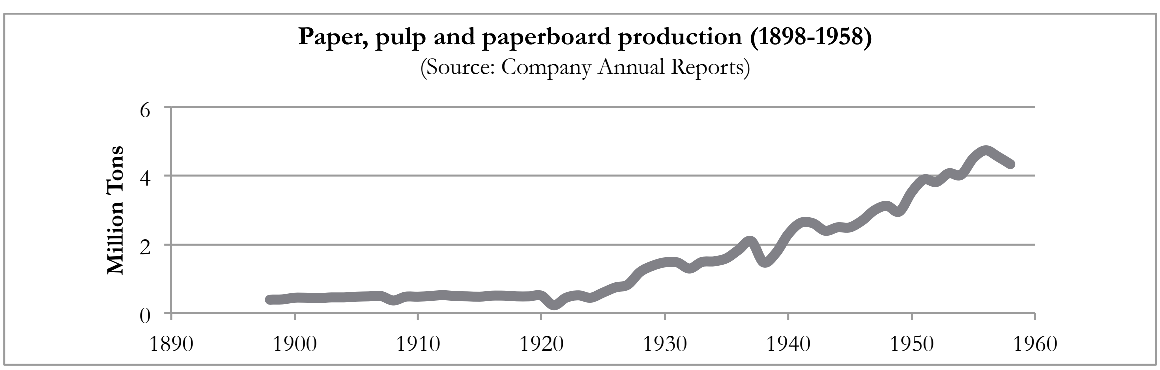


FIGURE 59: INTERNATIONAL PAPER PRODUCTION OUTPUT (1898-1958)

PERIOD 4 (1936-1942): INTEGRATION INTO PACKAGING

In 1936 Richard Cullen became president of the company, and expanded into corrugated shipping containers through acquisition of the Agar Manufacturing Corporation, which owned several shipping container plants in New York, Massachusetts, Illinois, and Kansas [226].

During World War II, I-P shifted its production to support the war effort. In 1942, I-P designed a new shipping container, the V-1, made of five layers of moisture-proof Kraft board laminated with a non-water soluble adhesive, which was used for transporting supplies to the troops in the fighting fronts. The Canadian mills also produced nitro-cellulose for explosives, rayon yarns for parachutes, and converted waste paper for the production of mortar shells [228].

PERIOD 5 (1943-1951): DIVERSIFICATION INTO CHEMICALS

In 1943, John Hinman became President of International Paper and began diversifying into specialty chemicals and other byproducts of their pulping operations. In 1948 I-P built a dissolving pulp plant in Natchez, Mississippi, which produced rayon for tire cords. By 1959, these rayon cords had become the standard equipment for the tires of passenger cars manufactured in the US and Canada [229]. In 1954, they acquired Canadian Commercial Alcohols Limited, which produced alcohol from sulfite liquor sugars. This company also produced magnesia insulating materials and gasoline conditioners [230]. I-P's Arizona Chemical Company began producing fatty acids, rosin, turpentine, and tall oil, which are chemical byproducts of the sulfate pulping process. I-P also started producing plywood from hardwood resources not suitable for pulping [221].

During this period, I-P continued expanding in packaging. In 1946 the company built a corrugated container plant in Springhill, Louisiana, and acquired the Sharff-Koken Manufacturing Company of St. Louis, Missouri, which manufactured corrugated fiber shipping containers [231]. During the 1950s, the company added several other shipping container facilities in the US and Canada (through the acquisition of Canadian Hygrade Container limited in 1955) [232]. I-P also began producing liquid packages through the acquisition of the Single Service Company in 1946, and through the construction in 1952 of a milk container plant in Youngtown Ohio, and in Minneapolis, Minnesota, in 1954.

PERIOD 6 (1952-1965): INTEGRATION INTO CONSUMER PACKAGES, PRINTING AND CONSTRUCTION MATERIALS

In 1952, I-P created the office of the Chairman of the Board, and the position of Chief Executive Officer. John Hinman became Chairman, and Richard C. Doane CEO of I-P. During this period, the company integrated into the consumer packaging, mass printing, and construction material industries.

In the 1930s, technological improvements in Kraft bleaching, paper coating, and the development of special inks and rotogravure color printing created an increasing demand for new packages and specialty papers. The creation of Xerography during the 1950s, and computer printers in the 1960s, created a whole new market for office specialty papers. I-P, however, was a latecomer to these markets and in order to build the related capabilities the company started a series of strategic acquisitions. In 1957, the company acquired the A.M. Collins Company of Philadelphia, a specialty coated papers manufacturer and began developing new synthetic resins and plastic coatings for its use in paper and paperboard [233].

In 1958, I-P acquired Lord of Baltimore Press, which produced folding cartons and labels used in different household products. This acquisition provided I-P with the technical knowhow for producing new grades of paperboard for the consumer goods packaging business [234]. In 1960, I-P acquired a plant from Murson Label Co. for manufacturing labels for canned goods, and they created a Graphic Arts laboratory with a fully equipped printing plant in Mobile, Alabama. In addition, in 1963, I-P created a Creative Marketing Center in NY, which included a simulated supermarket where consumer packages could be evaluated and tested. A second marketing center was built in 1964 in San Francisco to serve the western market. In 1966 I-P created the division of consumer packaging to consolidate these acquisitions.

In 1956, the company announced the acquisition of the Long-Bell Lumber Corporation of Washington. This acquisition allowed I-P to penetrate the Western market and to strengthen the construction materials division through the manufacture of wood products, including veneer, plywood and processed wood (posts, poles, windows, cabinets, doors, and flooring). The Federal Trade Commission objected arguing that the acquisition violated the anti-trust legislation. The dispute was finally settled in 1957 and while this acquisition was allowed, but I-P's management then moved cautiously with any diversification outside pulp and paper [235].

During the 1960s, specialty papers for xerography, thermo-fax, and computer printers became one of the fastest growing markets for I-P [236]. In 1965, the company built a new mill in Jay, Maine, for manufacturing carbonized paper for computer printing. They also started retrofitting some old mills, adding coating machines for the production of specialty papers. In 1961, for example, they installed the first commercial-scale polyethylene extrusion coater in the Niagara Falls Mill.

During this period, I-P extended its presence in the corrugated shipping container business in the US also started an international expansion building new manufacturing plants in Europe and Latin America. In 1959, I-P acquired manufacturing facilities in Germany, The Netherlands, Belgium, Luxemburg, France, Italy, and Venezuela. I-P also acquired an interest in Cargal Limited, an Israeli shipping container company. During the 1960s, I-P added new international containerboard subsidiaries in Spain, France, Puerto Rico, Colombia, Ecuador, the French West Indies, and the Canary Islands [235].

PERIOD 7 (1966-1969): UNRELATED DIVERSIFICATION

In 1966 Edward Hinman was elected president of I-P. Since the 1950s the company had a zero debt policy, which made it a potential target for a hostile takeover and Hinman started to diversify into other industries [235]. In 1967, the company started producing all-plastic containers in Litchfield, IL. In 1968, after years of research, the company announced the creation of Confil, a non-woven fabric made out rayon and nylon. To market this product, the company acquired Davol Inc., a manufacturer and seller of surgical, infant care, and home health items. That same year, the company entered the real estate business through acquisition of the American Central Corporation of Lansing, Michigan and in 1969, I-P acquired the Donald L. Bren Company of Los Angeles, which developed residential housing projects.

PERIOD 8 (1970-1983): FOCALIZATION AND OPERATIONS STREAMLINING

I-P's diversification strategy came under revision during the 1970s after a recession in the pulp and paper market produced a 30% loss in the company's earnings. Frederick Kappel, former chairman of AT&T took over as company president in 1970, and started a restructure and streamlining program that divested non-strategic assets and closed unprofitable mills. In 1972 I-P sold the Donald L. Bren Company and closed unprofitable mills in Pennsylvania, New York, Maine, and Florida, and international plants in Italy, and Puerto Rico. In 1976, I-P divested the American Central Corporation (acquired in 1968), and consolidated the southern Kraft Division and Northern Division into five business units: white papers, consumer packaging, industrial packaging, wood products, and specialty packaging [235].

During the 1970s, the pulp and paper industry became under tight scrutiny after the passing of Clean Air Act and the Clean Water Act. I-P made efforts to reduce its water and energy consumption, and to reduce air contamination and in 1974, the company appropriated $254 millions to combat air and water pollution at their mills.

The Oil Crisis of the 1970s also had consequences for I-P. To explore and exploit its energy reserves, I-P acquired in 1974 the General Crude Oil Company. I-P estimated there were 300 million barrels of oil underneath their timberlands [237].

During the 1980s, the company divested its health care subsidiary, and announced a company-wide revision of all their mills. Inefficient facilities were phased out and some facilities were retrofitted to increase their productivity. In 1981, I-P announced a 6 billion-investment plan to increase mill productivity. To finance these investments, the company divested its Canadian operations and sold the General Crude Oil Company. In 1985 I-P announced it would withdrawal from its historical newsprint business, retrofitting its Mobile mill for the production of white papers.

PERIOD 9 (1984-1999): INTERNATIONALIZATION INTO EUROPE AND THE PACIFIC RIM

In 1984, John A. Georges became President and CEO of the company. During the mid 80s I-P began a series of targeted acquisitions aimed at diversifying into specialty products to balance its business portfolio. In 1986 I-P acquired Hammermill Paper, a manufacturer of specialty papers. This acquisition provided I-P with a distribution network of more than 200 facilities in the US. The distribution network was soon expanded through acquisitions that included Saalfeld Paper Co. in 1988, Reliable Paper Co. in 1989, Dixon Paper in 1990, Wayne Paper in 1991, Western Paper in 1992, Ingram and JP Papers in 1993, Ogi/Kif Paper in 1994, and Carpenter and Seaman-Patrick Papers in 1995. By the end of 1996, I-P's distribution business accounted for 22% of the sales [238].

In 1985, I-P took full ownership of Arizona Chemical, and acquired two additional chemical producers, Bergvik Kemi of Sweeden in 1988, and Forchem of Finland in 1996. I-P also expanded into other cellulose derivatives including photographic films in 1987, and non-woven fabrics. To strengthen its position in the wood products business, I-P acquired the Masonite Corporation in 1988, and acquired in 1995 a majority shareholder status in Carter Holt Harvey, a New Zealand forest products company with strong presence in Australia and Chile. Additional expansions into the Pacific Rim included two packaging plants in Taiwan and Korea in 1985.

In the European market, I-P made several acquisitions including Aussedat Rey, a French producer of office papers and decorative panels, and Zanders Finepapiere AG, a coated papers manufacturer of Germany. In 1992, I-P announced the acquisition of Zwidzyn Cellulose, Poland's largest white paper manufacturer.

In the US, I-P announced in 1996 the acquisition of the Federal Paper Company for 3.5 billion dollars. This large and diversified forest products company had a strong presence in the bleached paperboard market. In 1999, I-P acquired the Union Camp Corporation for almost 8 billion dollars. This US manufacturer had strengths in uncoated paper and containerboard, and also possessed a large distribution. In 2000 I-P acquired the Champion International Corporation for 7.4 billion dollars. This company had operations in the US, Canada, and Brazil, which expanded I-Ps timberland holdings to almost 19 million acres worldwide[239].

At the end of this period, I-P had quadrupled its sales volume relative to that in 1980, achieving US$20 billion in sales. In addition to pulp, paper and packaging, the company also achieved a balanced business portfolio composed of wood products, specialty panels, nonwoven products, imaging products, specialty chemicals, and more than 300 distribution centers located primarily in the US (See Figure 60).

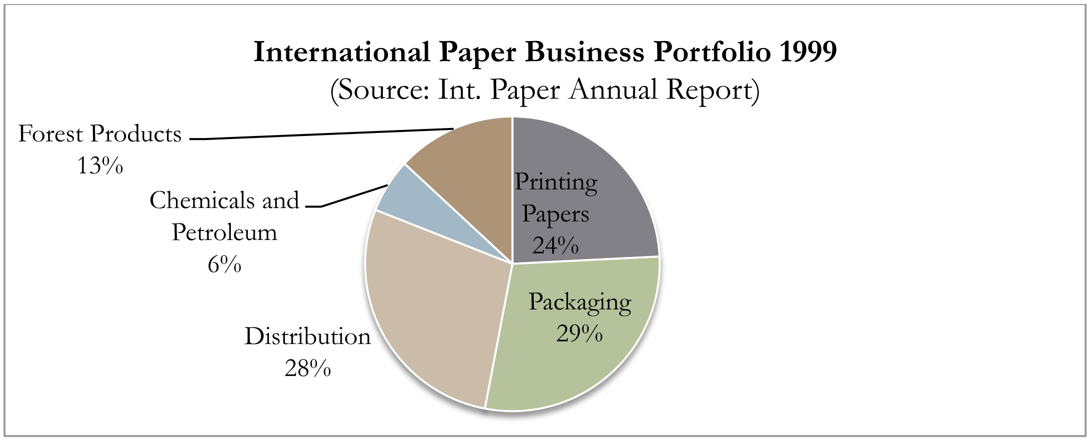


FIGURE 60: INTERNATIONAL PAPER BUSINESS PORTFOLIO IN 1996

PERIOD 10 (2000-2005): FOCALIZATION AND GEOGRAPHICAL CONTRACTION

In 2000, I-P announced a 5 billion dollar divesture plan. In 2001, the company divested its oil and gas holdings, the Masonite Corporation, and Zanders Fine Papers of Germany. The rate of divestures increased after I-P marked a net loss of $800 million dollars in 2002. John Faraci became the new CEO and announced he would further narrow I-P's business base focusing only on uncoated papers and packaging [130]. In 2002, I-P divested the Cellulose Chemicals, the decorative panels unit, and the oriented strand board facilities. Plans were also made to divest I-Ps coated and specialty papers, the beverage packaging business, its wood products business, and almost all of their US timberlands. In 2003 I-P had 19 million acres worldwide. By 2008, I-P only had 450,000 acres, most of them in Brazil [132]. Other divestures included I-P's Carter Holt Harvey participation in 2005, and the Arizona Chemical Company in 2007.

PERIOD 11 (2006-TODAY): INTERNATIONALIZATION INTO BRIC ECONOMIES

In 2005, facing mature markets in North America, the company expanded into China, Russia, Brazil, and India (BRIC economies). In 2006, I-P acquired licenses to exploit 500,000 acres of timberlands in Russia. I-P also entered into a joint venture with the Sun Paper Company to open new mills and paper converting plants in China. In 2007 I-P started a joint venture with Ilim Holding SA, a Russian pulp and packaging board company, and in 2010, I-P acquired SCA's packaging division in Asia, with facilities in China, Singapore, Malaysia, and Indonesia. Finally, I-P acquired in 2011 a 75% stake in Anhdra papers, an integrated paper manufacturer of India.

In the US, I-P acquired in 2006 Weyerhaeuser's industrial packaging business for $6 billion dollars. This included several containerboard, packaging, and recycling plants in the US. In 2011, I-P acquired Temple-Inland, a large corrugated packaging and building products company.

3. The Origins and Coevolution of I-P's University Relationship

The origins and evolution of I-P's university relationships have a close relationship with the formation of the company's research laboratories. In 1901, I-P opened a Central Tests Bureau in Glens Falls, NY. The purpose of the facility was to test the quality of the pulp and paper produced by the different mills, and to test the different raw materials utilized in the pulping and papermaking process. A few years later, small Fourdrinier machines were added to this facility to run pilot tests on papermaking and on the performance of new types of pulp. In the forestry side, in 1909 International Paper opened its first tree nursery located in Vermont. At the same time, the first forestry schools were being formed in the US.

During the 1920s, the Tests Bureau grew in size by hiring chemists and engineers to conduct studies on boiler efficiency, and process improvement [240]. In 1925, I-P obtained a second R&D lab in Hawkesbury, Ontario, after the acquisition of the Canadian Riordon Company. The laboratory concentrated on sulfite pulp research, and on the development of rayon fibers. During the 1920s and 1930s, International Paper developed its internal research capacity by recruiting European Professors. In 1926, Canadian International Paper hired Dr. Emil Heuser, former professor of Cellulose Chemistry at the Technical University of Darmstadt (TUD) and Dr. Georg Jayme from TUD to conduct research on dissolving pulps and rayon at the Hawkesbury research lab [108].

The transition of the Central Tests Bureau to a formal research lab began in the late 1920s. In 1929 Dr. John Campbell became I-P's first director of research and in 1930 the Tests Bureau was renamed as the Glens Falls Research Laboratory [235]. The laboratory conducted research on groundwood paper including newsprint, board, Kraft pulp, and fine papers [241]. During the Great Depression research staff was reduced, and the laboratory focused on operational problems rather than fundamental research [235].

In 1938, the Canadian International Paper recruited Dr. Herman Mark, professor from the University of Vienna, to help the Hawkesbury lab reorganize its research on cellulose acetate and cellophane. In 1941, the company hired a recent chemical engineering graduate from the University of Toronto, Dr. Howard Rapson, to find a substitute to war-restricted chlorine for bleaching pulp [242]. During the 1940s, the Hawkesbury lab developed the chlorine dioxide bleaching process that revolutionized the pulp and paper industry (See vignette on this technology in page 171).

In 1946, I-P opened a third R&D lab in Mobile, Alabama, to conduct research in support of their southern operations. Initial research lines focused on developing new pulp and paper grades manufactured from softwoods and hardwoods native to the south [243]. During the 1940s, International Paper started sponsoring university research projects in environmental research. The company funded, for example, a research project aimed at analyzing the effects of the Bastrop, Louisiana Mill effluents on cow drinking water, and on human health [235].

COMPANY R&D LABS BUILT LOCAL UNIVERSITY CONNECTIONS

The formation of the three R&D laboratories in Glens Falls, Hawkesbury, and Mobile gave I-P broad exposure to different university centers. After WWII these laboratories grew in size and began diversifying their research lines and university connections. The Glens Falls laboratory reached more than 50 people, working on short and long-term research projects, after the war.

In 1947, Canadian International Paper was concerned with the supply of local hardwoods to produce dissolving pulp at the Hawkesbury mill. To promote the cultivation of timber as a crop, the company created the Harrington Farm Project to provide technical assistance and a demonstration forest to local landowners. The farm was equipped with a laboratory for conducting studies on forest management in cooperation with the Canadian Forest service [244]. In addition, the company made contributions to support the forestry schools at MacDonald College, Laval University, and the New Brunswick University [245].

Canadian International Paper also worked in collaboration with the Dominion Entomological Laboratory on pest control. In 1949, a budworm infestation was threatening the supply of spruce to the company's Dalhousie Mill in New Brunswick, Canada. To solve this problem, I-P worked in collaboration with the Canadian Government to air spray more than 200,000 gallons of DDT over the infected area killing, according to the entomologists, 99.8% of the budworms [246]. During the 1950s this program was expanded to other provinces, spraying over 9.3 million acres in Canada by 1958 [234].

In 1948, the Hawkesbury laboratory was incorporated as the Industrial Cellulose Research Limited (ICR), and became an affiliate company of Canadian International Paper. At the time, the laboratory had become one of the leading research centers in cellulose and dissolving grade pulp, and was equipped with pilot plants to make rayon, transparent cellulose films and other specialty products [247]. During the 1950s, the Hawkesbury lab conducted studies for utilizing lignin from waste sulfite liquors in the manufacturing of adhesives, resins, and laminates [232]. The lab had good collaborations with the chemical department of the University of Toronto, which was started in 1953 by Howard Rapson a former Hawkesbury lab director.

The Mobile research lab, which was renamed the Erling Riis Research Laboratory, worked in close collaboration with Hawkesbury lab to develop new pulping techniques to increase the utilization of different wood species. During the 1950s, for example, Erling Riis developed a prehydrolized Kraft dissolving pulp, which allowed the Natchez, Mississippi mill to produce tire rayon cords from southern hardwoods [230].

In 1957, the Erling Riis lab incorporated a pilot plant for developing coated papers, and in 1960 a graphic arts lab with a fully equipped printing press. During the 1960s, the Earling Riis lab also opened a research line on new packaging technologies. In 1963, the lab acquired a spiral-wound-can label machine, and also conducted research aimed at developing a foillaminated carton for syrup containers [235]. At the end of the 1960s, the Erling Riis lab developed Acetakraft, a cellulose fiber used in textiles and cigarette filters [248].

New Sothern Forestry Research Station

In 1950, International Paper established nurseries in the southern states to ensure the supply of raw materials to the company's mills [249]. In 1952, the company intensified its research on seed quality to create a genetic pool from which to breed new seeds. In 1956, the company cooperated with the University of Florida, and the North Carolina State University to create seed orchards for producing a superior stock of trees. The company also worked in collaboration with the forestry schools at the North Carolina State University and Yale University to determine the hereditability of tree fiber characteristics. For these purposes, in the 1960s the company established a Fellowship for pursuing graduate studies at Yale's Wood Technology Laboratory [250].

To increase the yield of the company's forestlands, in 1957 I-P opened a forest research station in Bainbridge, Georgia. Specific research lines included pest control, tree diseases, fertilizers, the definition of planting specifications and timber harvesting techniques [251]. During the 1960s, the Bainbridge forest station began a genetic tree improvement program in collaboration with the Mobile research lab and several university centers [233]. In 1968, the first generation of genetically improved trees was planted with a faster growth rate, straighter trunks, and smaller crowns, and the potential to reduce the harvesting cycle from 40-50 years to 25 years [252].

During the 1960s, I-P southern timberlands became infected by the root-rotting disease, which caused high mortality in pine plantations. To solve this problem, I-P worked in cooperation with the US Forest Service and several forestry schools. As a result of this collaboration, the Bainbridge research station discovered that applying borax to the tree stump immediately after it was cut could stop the infection. In addition, they also found that marigold and other plants had the properties of fixing nitrogen into the soil, thus inhibiting the growth of the root-rot fungus. After this discovery, the company began planting marigolds as an inter-rotation crop [250].

During the 1960s, International Paper conduced studies with Duke University for reclaiming swamp areas in the South Carolina coast and joined other forest products companies to conduct research on local softwoods, including slash pine in collaboration with the University of Florida, loblolly and pond pine in collaboration with the North Carolina State University, and long-leaf pine in collaboration with Texas A&M and the Texas Forest Service [251].

International Paper also conducted research on machinery for harvesting and delimbing trees. During the 1960s, Thomas Busch, head of mechanical logging research developed a mechanical harvester called the *buschcombine*. This machine cut, delimbed, and sectioned logs for their transportation from the timberlands to the mills. In Canada, where the terrain is more rugged, IP joined other paper companies and equipment manufactures to develop mechanical harvesting machines. Between 1960 and 1971, I-P jointly sponsored the Logging Research Associates program, which developed the Arbomatik, a mechanical logging machine, and the LoggAll, a wheeled skidder for transporting the logs [250].

CENTRALIZATION OF RESEACH AT STERLING FOREST, NY

In 1966, International Paper announced the creation of a Corporate Research Center in Sterling Forests, NY [253]. This research center opened in 1968, and in 1969 International Paper closed the Glens Falls laboratory and to transfer the staff to Sterling Forests. During the 1970s, the Corporate Research Center incorporated a pilot pulping plant, and a second pilot plant to conduct research on non-woven fabrics for their medical devices business unit [237]. The center also conducted research on paper coating, and viscose rayon in collaboration with the Hawkesbury lab.

During the 1970s, environmental research became a priority for International Paper and both the Sterling Forests and the Erling Riis research laboratories conducted research to control the problem of air and water discharges [254]. These laboratories maintained close contacts with universities and specialized industry groups to develop advance concepts in pollution control [255].

During the 1980s, the Sterling Forests Corporate Research Center conducted research on packaging technologies and helped with the transition from acid to alkaline papermaking, and to improve paper de-inking techniques [235]. During the first half of the 1980s, however, there was a decline in International Paper's research activities, as measured by the firm's R&D investments as shown in Figure 61. In 1981, I-P sold its Canadian operations to Canadian Pacific Limited, and the Hawkesbury laboratory became an independent company.

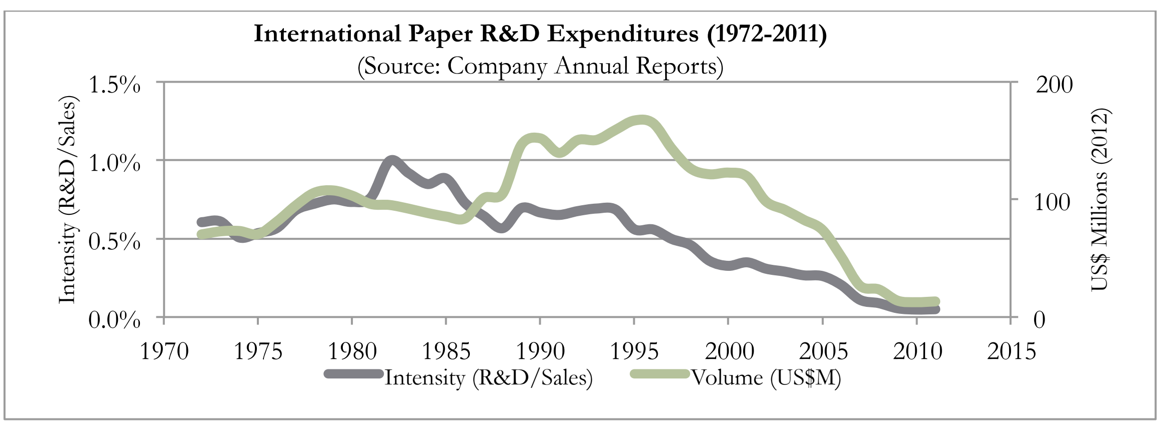


FIGURE 61: EVOLUTION OF INTERNATIONAL PAPER R&D EXPENDITURES

Figure 62 shows the different industrial sectors in which the company has been active and the number of university articles within each sector. As shown in the figure, most of the firm's university co-publications have been in the area of forestry (48%). During the second half of the 1980s, we observe in the figure an increase in the number of publications on diversified business lines as a result of the firm's diversification strategy.

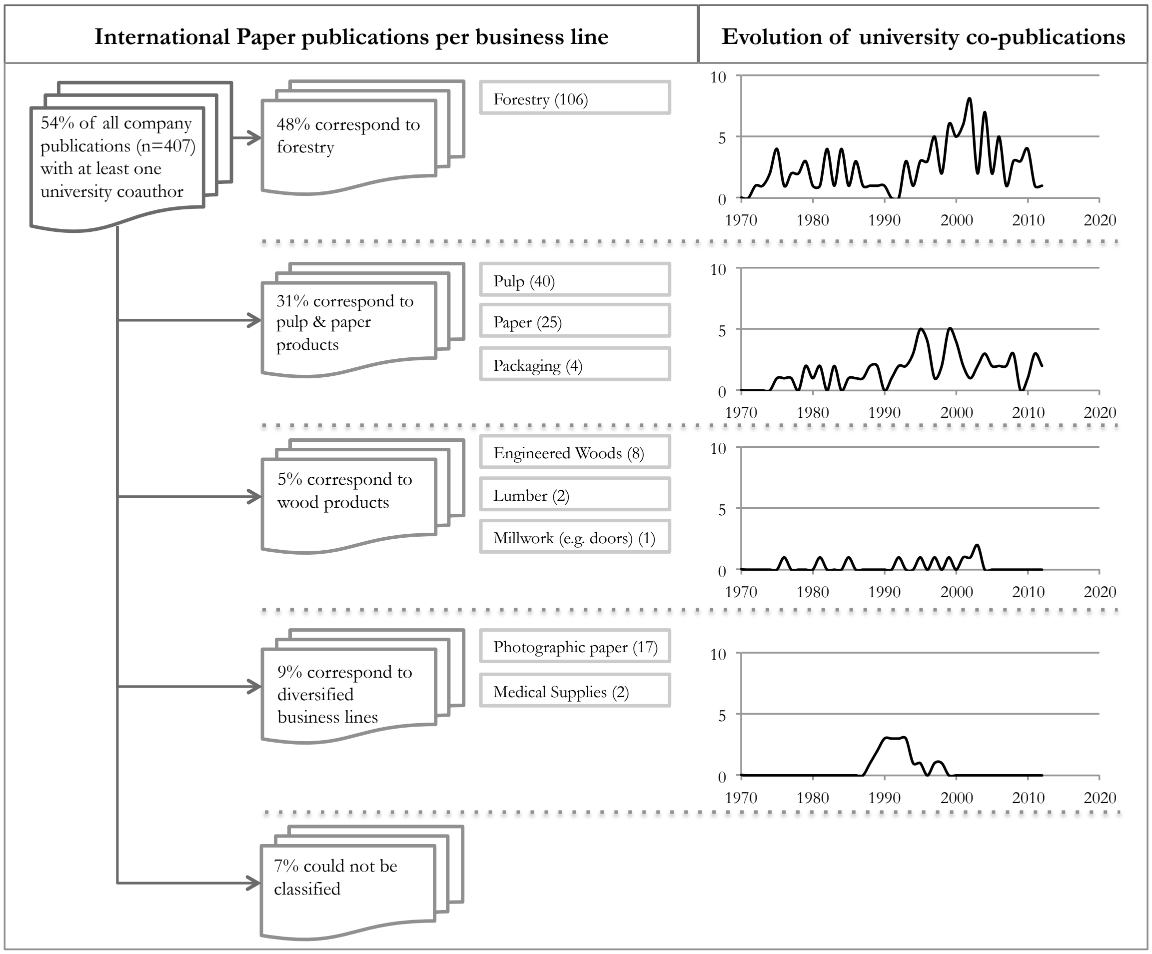


FIGURE 62: COEVOLUTION OF UNIVERSITY CO-PUBLICATIONS AND I-P'S BUSINESS LINES

INTERNATIONALIZATION OF R&D CENTERS

After several acquisitions, during the second half of the 1980s and 1990s International Paper achieved not only a diversified business base but also a diversified technology base in the areas of paper, pulping, forestry, specialty products, imaging, and packaging technologies. As a consequence, the company increased the levels of R&D expenditures (see Figure 61) and acquired different R&D laboratories in the US, Europe and New Zealand.

In 1986, I-P acquired a new paper research lab in Erie, Pennsylvania with the acquisition of the Hammermill Company. In 1987, I-P acquired Anitec Image Technology Corp, a producer of photographic papers and films for the graphics art industry. This company had research labs in Binghamton, NY. In 1988, with the acquisition of the Masonite Corporation, I-P also acquired a research lab in West Chicago that conducted research on composite wood products. In 1989, the company acquired the Ilford Group from Ciba-Geigy, a British producer of photographic paper. This company had a research laboratory in

Mobberley, England, and also in Fribourg, Switzerland. In 1990, the company acquired the graphics business of Cookson Group PLC, a British company that produces lithographic printing plates, pressroom chemicals, and plate-processing equipment. This company came with research laboratories in Morley, England, and in Munich, Germany. Similarly, in 1989 when the company entered the decorative papers business through the acquisition of French Aussedat Rey, they also acquired new research labs in Saint-Priest and Annecy, France. Finally, when the company acquired Carter Holt Harvey in 1995, they also obtained a Forest biotechnology center in New Zealand.

FOCALIZATION AND DECLINE IN R&D

In 1996, International Paper decided to narrow its business base with consequences for their R&D laboratories. That year, the company consolidated six research laboratories into a new Technology Center in Loveland, Cincinnati, that focused printing, packaging, and coating technologies [235]. The Erling Riis laboratory was closed in 1997, and the lab's research staff was transferred to the Corporate Research Center at Sterling Forest, NY, and to the Technology Center in Loveland, Ohio.

During the following years, several other laboratories were closed or sold as part of the company's divesture program. In 1997, the company exited the non-woven market and sold the specialty fibers lab in South Walpole, MA. In 1998, I-P sold its imaging business unit to Kodak, including its US and European labs. In 2001, with the divesture of the Masonite Corporation, the company also sold its West Chicago Lab. In 2004, when the company sold its stake in Carter Holt Harvey, it also lost its biotechnology center in New Zealand. That same year, the company closed its research laboratory in Sterling Forest, NY. In 2007, with the divesture of the Arizona Chemical Company, the I-P sold its chemical research lab in Savannah, Georgia. That same year, and with the sale of several of its timberlands, I-P spun-off its tree nurseries and forest research labs to ArborGen, a forest biotechnology firm in which I-P still holds an interest.

Figure 63 shows how the firm's focalization strategy affected the number of publications with universities and research institutes. As shown in the figure, while co-publications with universities became more common, the overall volume of publications declined steadily since 2000.

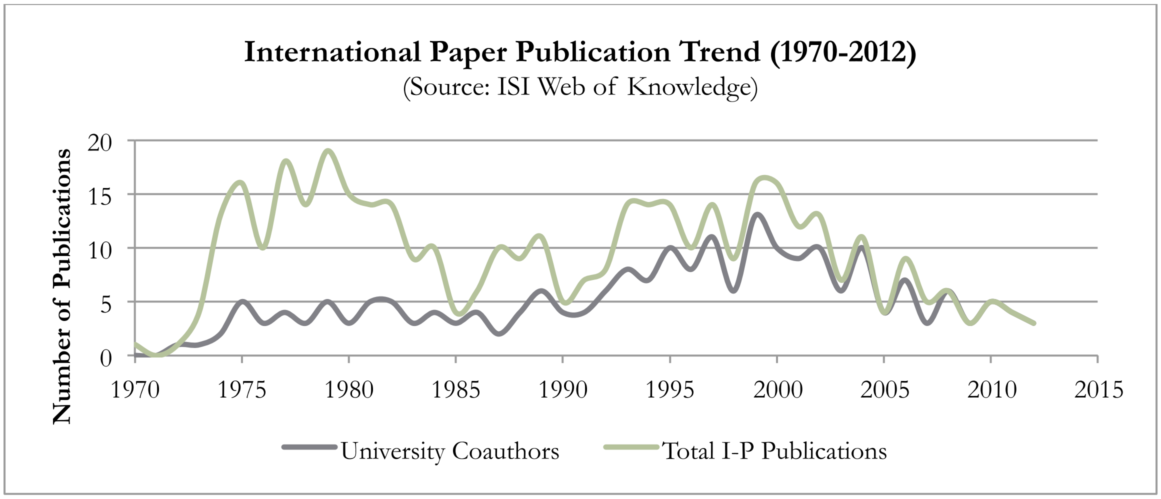


FIGURE 63: INTERNATIONAL PAPER PUBLICATION TREND

3.1. Research priorities along I-P's value chain

We have organized I-P's university relationships from a value chain perspective, distinguishing between forestry and pulp and paper university collaborations. Figure 64 shows the different processes involved in the forestry value chain. As shown in the figure, most of I-P's university co-publications in forestry have been in the area of yield management (e.g. growing, fertilizer usage) and the environmental impact of the firm's forestry operations.

In the area of forest management, I-P's most common university partners have been North Carolina State University, the US Forest Service, Auburn University, the University of Florida, and Virginia Tech. All these institutions have held close relationships with International Paper's Bainbridge Forestry Research Station.

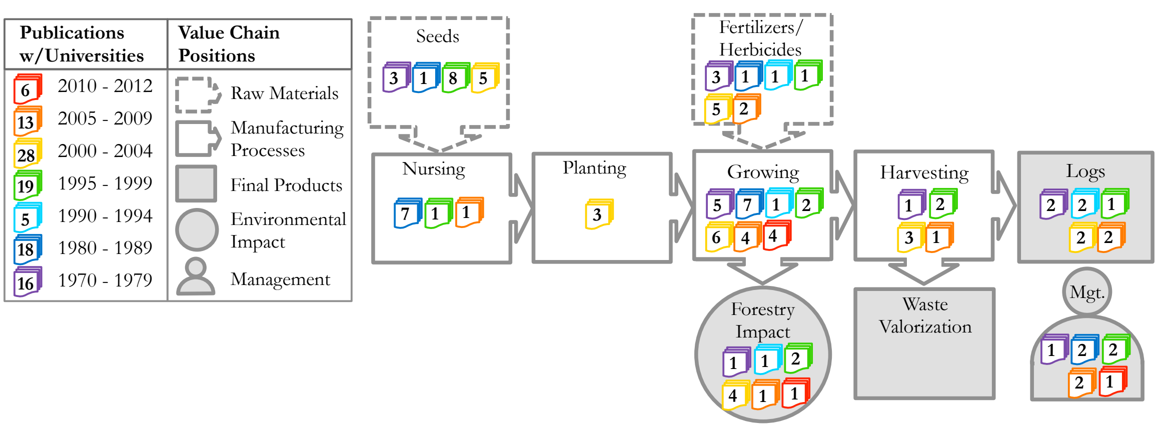


FIGURE 64: EVOLUTION OF I-P'S UNIVERSITY CO-PUBLICATIONS IN FORESTRY

In the area of environmental impact of the forestry operations, during the 1990s International Paper worked in collaboration with Clemson University, North Carolina State, and the University of Georgia Savannah River Ecology Lab, to evaluate the company's forest management practices in order to protect sensitive forest ecosystems [256].

Figure 65, shows the different processes involved in pulp and paper production. From organizing I-P's different co-publications according to these different segments, it is seen that most of the firm's university interactions have been concentrated on paper production and on improving the chemical recovery cycle of the firm's pulping operations.

In the area of pulp and paper production, International Paper's most common university partners have been Georgia Institute of Technology, Ohio State University, SUNY College of Environmental Science and Forestry, Abo Akademi of Finland, and University of Toronto in Canada.

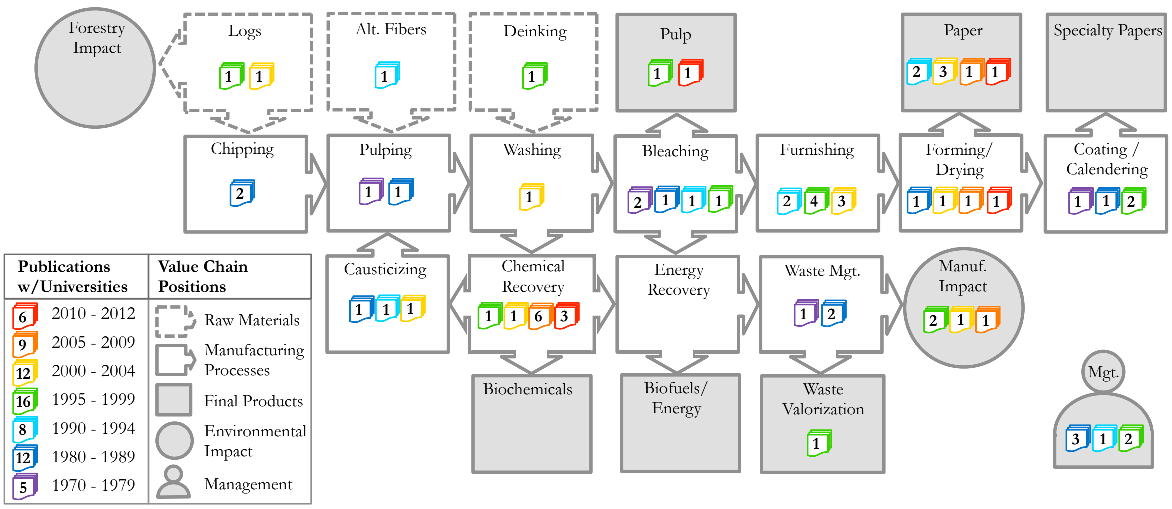


FIGURE 65: EVOLUTION OF I-P'S UNIVERSITY CO-PUBLICATIONS IN PULP AND PAPER

3.2. Geography of university partners

Figure 66, based on I-P's publication records, shows the geographic distribution of the company's local university network. I-P's university network has historically been in the US, where we can observe different hubs corresponding to the different R&D labs of the firm. I-P's most common university partners have been North Carolina State University, Virginia Tech, University of Florida, Auburn University, Ohio State University, Purdue University, University of Georgia, SUNY, and Georgia Tech.

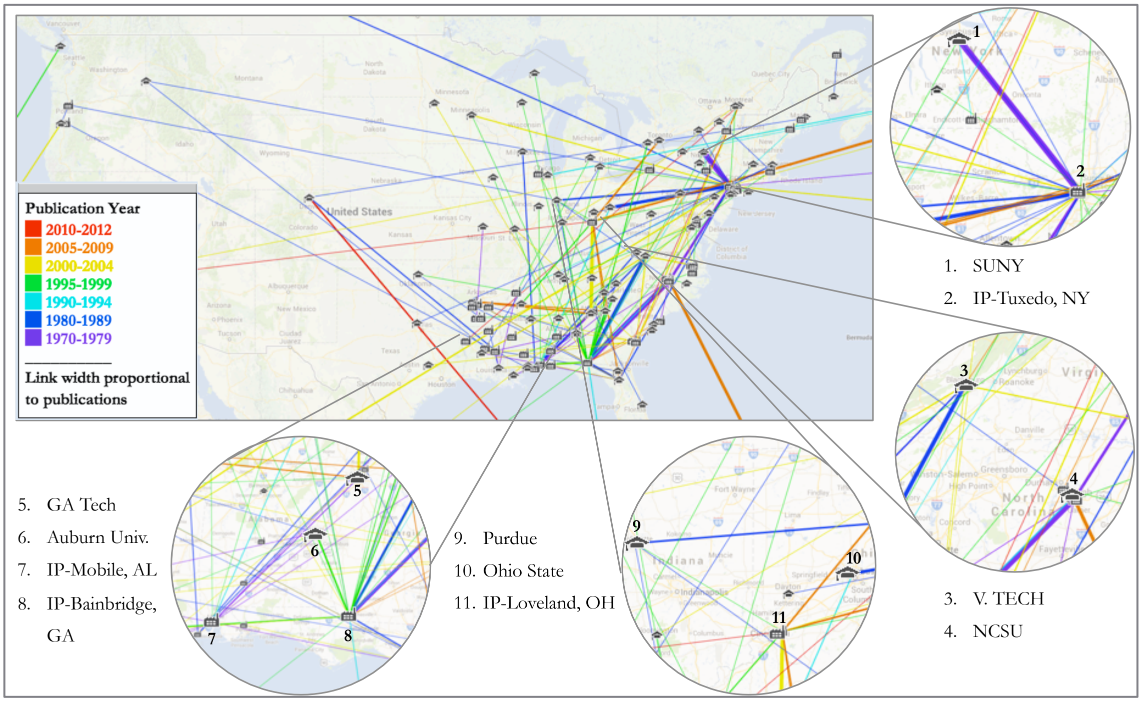


FIGURE 66: I-P'S NORTH AMERICAN UNIVERSITY NETWORK

Figure 67 shows the expansion of I-P's international network of university partners as a result of the firm's internationalization strategy. Most of these international university collaborations were inherited after I-P's acquisitions and mergers of international firms.

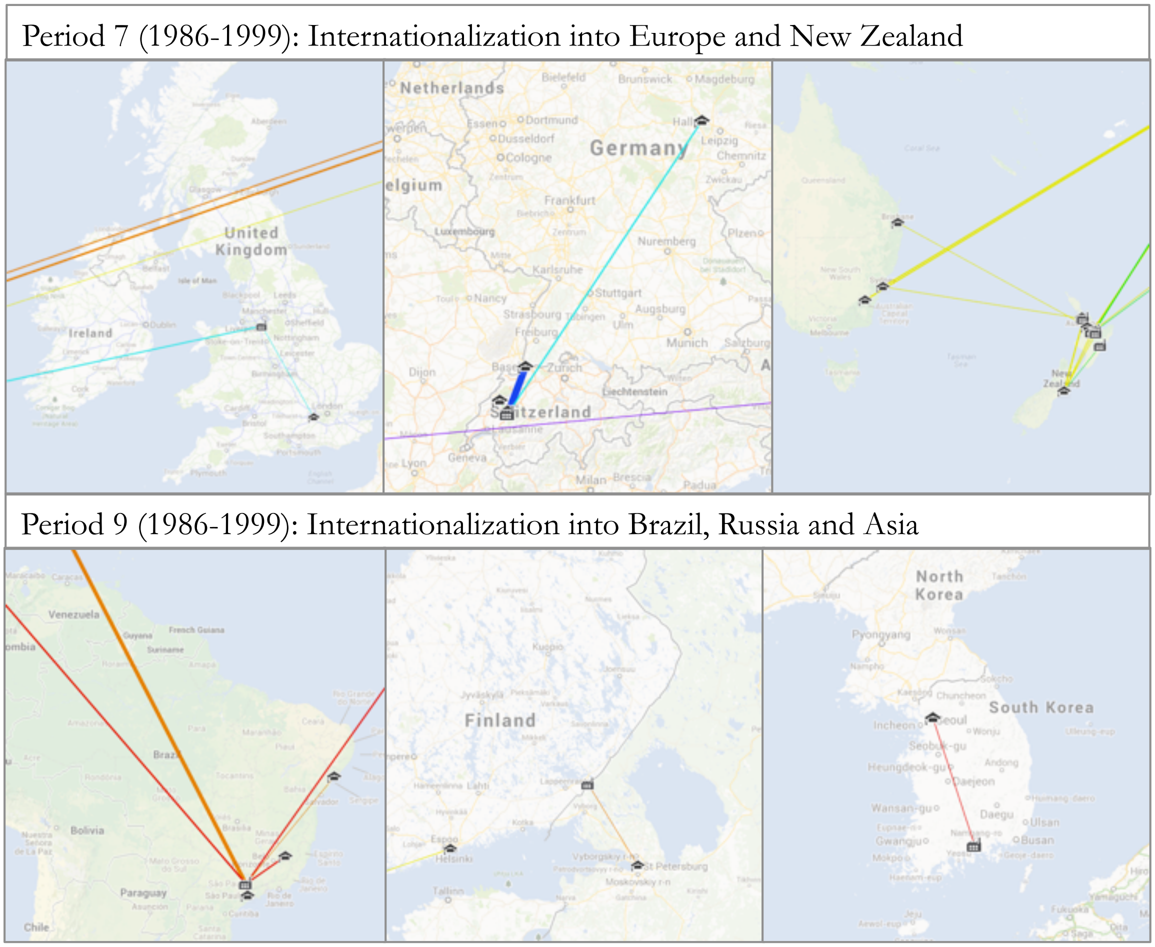


FIGURE 67: INTERNATIONALIZATION OF I-P'S UNIVERSITY PARTNERS

3.3. TECHNOLOGY TRANSFER THROUGH PEOPLE FLOWS

To analyze the academic and professional trajectories of International Paper's most prolific authors and inventors we used I-P's publications and patenting records to develop a list of 120 people involved in the company's R&D activities. Each individual in the list has either patented or published at least two papers from I-P's name.

Figure 68 shows the evolution of I-P's research staff. The figure indicates that most of I-P's R&D personnel were recruited directly from academia. The figure also shows that I-P's R&D personnel peaked in the early 1990s. After leaving I-P, 39% of these researchers joined other firms, and 15% went back to research institutions, including North Carolina State University, Institute of Paper Science, and the US Forest Service.

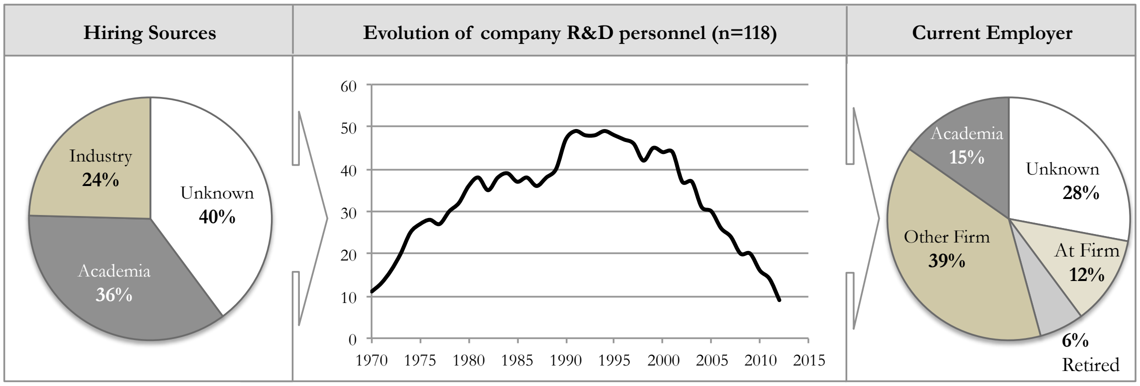


FIGURE 68: EVOLUTION OF I-P'S R&D PERSONNEL

Analysis of the academic training of I-P's researchers shows an overlap between the academic institutions attended by these people and the company's publication partners (See Figure 69). The most common university attended by the firm's R&D personnel has been SUNY, followed by North Carolina State University, Georgia Tech, Virginia Tech, and the University of Georgia. This overlap is indicative that firms recruit from universities that have developed expertise in knowledge areas relevant for the firm, and that when people move across organizations they move with their networks.

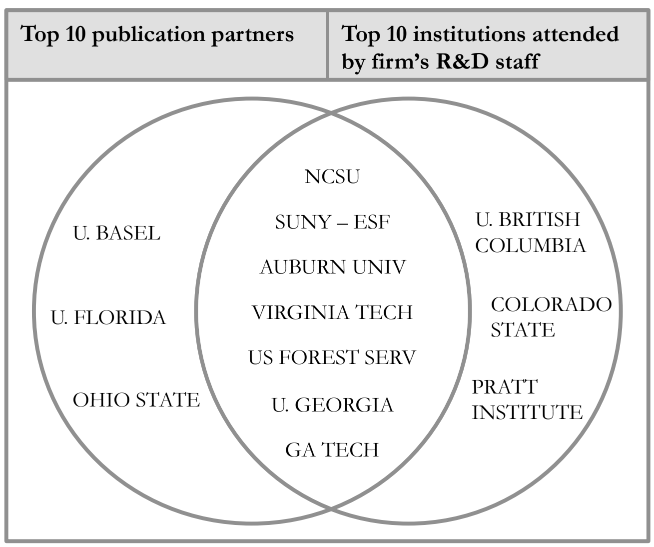


FIGURE 69: OVERLAP BETWEEN I-P'S HIRING AND PUBLISHING PARTNERS

4. Case Study Discussion

International Paper has endured several strategic changes and participated in a diverse set of industries and regions over time. This provides an opportunity to analyze how changes in I-P's strategy have affected its relationship with universities and research institutes. Table 18 presents a summary of these findings. The table shows the different strategic periods of the firm, and how I-P's research priorities, people flows, and institutional networks were modified as a consequence of the changes in the firm's strategy.

TABLE 14: SUMMARY OF HOW INTERNAITONAL PAPER'S UNIVERSITY RELATIONSHIPS COEVOLVED

University Links / Firm Strategies	Research Priorities	People Flows	Institutional Networks
Period 1: **Integration** (1898-1912)	**Quality tests** • Test quality of pulp, paper and raw materials	**First Central Test Bureau** • Glens Falls Est. 1901 **First Forest Nursery** • Est. in Vermont, 1909	**Formation of forestry schools** • Cornell (1898), Yale (1900), SUNY (1913)
Period 2: **Internationalization** (1913-1923)	**Production processes** • Process improvement • Boiler efficiency	**Growth of Test Bureau** • I-P hired European chemists from Germany, Austria	**International recruitment** • Links with European universities for recruitment
Period 3: **Diversification** (1924-1935)	**Cost control** • Little basic research • Focus on improving pulping processes	**New R&D Centers** • Test Bureau renamed Glens Falls R&D Laboratory • New R&D Lab in Hawkesbury, Canada	**Founding of new univ. labs** • Reduction in R&D staff after Great Depression. • Diaspora of I-P researchers jumpstarted university labs
Period 4: **Integration** (1936-1942)	**Pulping Chemicals** • Chlorine dioxide bleaching	**Growth in R&D** • Glens Falls staff grew to 40 • Hawkesbury lab hires from Chemists from Toronto U.	**First sponsored R&D projects** • On environmental research with US universities
Period 5: **Diversification** (1943-1951)	**Cellulose byproducts** • Rayon and dissolving grade pulps **Forestry Improvement** • Seed quality	**New Tree Nurseries** • To supply trees in the southern states and Canada	**International collaborations** • With forestry schools in connection to Canadian forestry operations
Period 6: **Integration** (1952-1965)	**Packaging Research** • Graphic arts and consumer packages **Forestry yield** • Pest control, fertilizers	**New Forestry R&D Center** • Located in Bainbridge, GA **Growth of R&D Centers** • Intensified recruitment at local universities	**Forestry collaborations** • Seed quality with NCSU, Yale, U. Florida
Period 7: **Diversification** (1966-1969)	**Forest Management** • Tree breeding program • Harvesting machines **Synthetic fibers** • Textiles, cellulose fibers	**New Corporate R&D Ctr.** • Located in Sterling Forests, NY • Closure of Glens Falls	**Pulp and paper collaborations** • Fellowship programs with local universities on pulp and paper
Period 8: **Focalization** (1970-1983)	**Process improvement** • Deinking, alkaline pulps **Pollution control** • Effluent and emissions control	**Reduction in R&D** • Divesture of Hawkesbury R&D Lab (Canada)	**Local University links** • On pollution control with universities close to mills • On forestry management with universities close to forestlands
Period 9: **Internationalization** (1984-1999)	**Imaging Science** • Photographic papers **Construction Materials** • Plywood, fiberboard **Medical Supplies** • Nonwoven fabrics	**International R&D Labs** • New R&D labs after acquisitions in the US, UK, FR, CH, DE, NZ • Closure of Mobile Lab and new Tech. Ctr. in Ohio	**Int. University collaborations** • In connection with new R&D Centers (US, UK, FR, CH, NZ, DE)
Period 10: **Focalization** (2000-2005)	**Forest Management** • Harvesting techniques, environmental impact	**Decline in R&D Staff** • Closure of Sterling Forests R&D Center • Divesture of NZ operations	**Reduced international links** • Reduction of international collaborators after divestures
Period 11: **Internationalization** (2006-Onwards)	**Eucalyptus Trees** • Growth and yield management of forests • Environmental impact	**Decline in US forestry staff** • Closure of Bainbridge Forestry R&D Lab (GA)	**New links in Brazil** • With universities on eucalyptus forestry

THE DEVELOPMENT OF THE CHLORINE DIOXIDE BLEACHING PROCESS

During WWII, chlorine became a restricted chemical because of the war effort. I-P's Hawkesbury research lab tasked Dr. Howard Rapson, a recent graduate from the University of Toronto, to find a substitute for chlorine. After testing different chemical agents, Dr. Rapson found that chlorine dioxide was able to bleach pulps and to provide the desired brightness. He also found this chemical could reduce the pulp's resin content, which enabled the pulping of Canadian pines.

The discovery of chlorine dioxide revolutionized the pulp and paper industry as it allowed the development of a brighter paper and the bleaching of Kraft pulps. The use of chlorine affected the strength of bleached Kraft paper but when bleached with chlorine dioxide, its strength remained the same. In 1946, the first chlorine dioxide bleaching process was installed in the Kipawa Mill, in Quebec [257].

In 1953, Dr. Rapson returned to the University of Toronto and joined the chemical engineering department [257]. At this university, he helped in the training of several students who continued perfecting his dioxine bleaching method. In collaboration with Douglas Reeve, a PhD student at the University of Toronto, Dr. Rapson invented the Rapson-Reeve effluent-free bleached Kraft pulp mill concept, in which the mill's effluent passes through a chemical recovery system that virtually eliminates dioxins from the pulping mill's effluents. Since the 1990s, this technology has become the dominant bleaching method used in the paper and pulp industry worldwide.

BIDIRECTIONAL FLOW OF RESEARCHERS

The case of Dr. Rapson also illustrates that researchers trained in industry have been important for the development of university research. Other researchers that left the International Paper Company have also joined universities and public research laboratories.

In 1936, Dr. Georg Jayme left the Hawkesbury research lab to become professor at the Institute of Cellulose Chemistry of the Technical University of Darmstadt. In 1938, Dr. Emil Heuser left Hawkesbury to become professor at the Institute of Paper Chemistry at the Lawrence College in Appleton, Wisconsin. In 1940, Dr. Herman Mark left I-P to become professor at the Polytechnic Institute of Brooklyn, NY, where he founded the Polymer Research Institute in 1946. Dr. Rapson formed the pulp and paper research laboratory at the Chemical Engineering department of the University of Toronto in 1953 [257].

Analysis of the company's R&D personnel showed that approximately 15% of International Paper's research staff has left the company to join universities (see Figure 68 in Section 3.3). Recent examples include Dr. Richard Phillips who joined the Department of Wood and Paper Science at NCSU after retiring as Vice President of R&D of International Paper, and Dr. Norman Marsolan who became director of the Institute of Paper Science at Georgia Tech after being director of R&D of International Paper. Both NCSU and Georgia Tech continue to be important research partners for International Paper.

APPENDIX VI: WEYERHAEUSER

1. INTRODUCTION

The Weyerhaeuser Company is a diversified forest products company, and one of the largest private owners of softwood timberlands in the US. The company was founded in 1900, and currently manages 20.3 million acres of forestlands, exporting their products to 11 countries. In 2011, Weyerhaeuser generated US$ 6.2 billions in sales from five business units: timberlands, wood products, cellulose fibers, real estate, and consulting services. The company is headquartered in Federal Way, WA and has approximately 12,800 employees worldwide [258].

Figure 70 presents an overview of Weyerhaeuser's Sales and R&D expenditures over time. The company has had a strong in-house R&D capability but since 1980 has gradually reduced its R&D expenditures to about US$ 30 millions in 2011 [258].

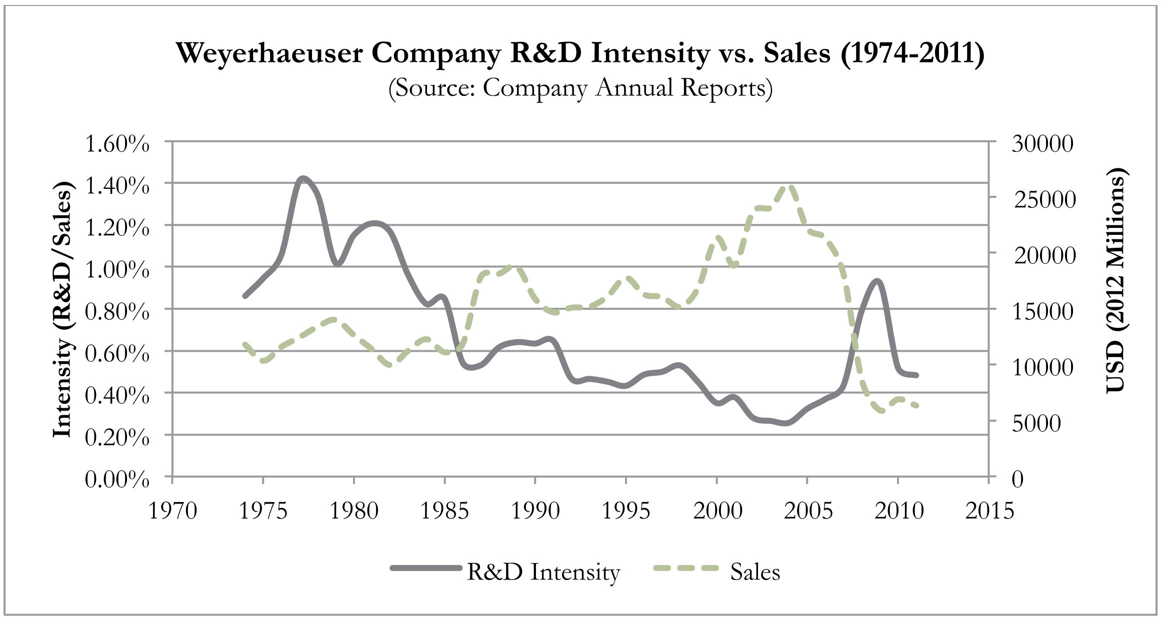


FIGURE 70: EVOLUTION OF WEYERHAEUSER R&D INTENSITY

This case study provides a longitudinal perspective on the changes in Weyerhaeuser's strategy, including the technological and environmental factors behind these changes and the consequences they had on the company's research.

In section 2, we provide a characterization of the different strategies pursued by Weyerhaeuser. Section 3 describes the origins and evolution of the firm's university relationships as judged by 1) changes in the research priorities of the firm; 2) changes in the network of university research partners, and 3) people flows between partnering institutions. Section 4 summarizes the main findings and lessons.

2. Historical Changes in Company Strategy

Data on Weyerhaeuser was obtained by analyzing the company's annual reports and secondary sources of information including journals, press articles, and company historical retrospectives. We also conducted two on-site interviews with senior managers of the firm. From this data, we defined 7 different strategic periods (see Figure 71, which tended to coincide with changes in the presidency of the firm.

Strategic periods

Period 1 (1900-1928): Integration into sawmilling

Period 2 (1929-1955): Diversification into pulp, paper, packaging and engineered woods

Period 3 (1956-1965): Integration into fine papers and liquid packaging

Period 4 (1966-1987): Diversification into non-forest products

Period 5 (1988-1998): Focalization and divesture of non-forest products

Period 6 (1999-2005): Integration into Engineered woods

Period 7 (2006-onwards): Focalization and narrowing business base

Strategic trajectory

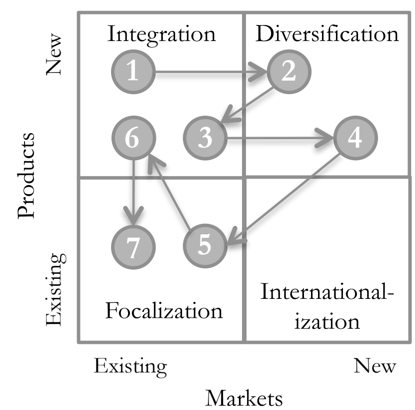


FIGURE 71: WEYERHAEUSER STRATEGIC PERIODS

Period 1 (1900-1927): Integration into Sawmilling

In 1900, Frederick Weyerhaeuser, a German immigrant, acquired 900,000 acres of timberland in Washington State from the Northern Pacific Railway Co., and created the Weyerhaeuser Timber Company. The Company initially focused on acquiring new land and selling standing timber to local sawmills. However, the Yacolt fire of 1902 pushed Weyerhaeuser into the logging business and the company opened a sawmill in Everett, WA to utilize trees downed by the fire. In 1914, Frederick Weyerhaeuser died and his eldest son John P. Weyerhaeuser took over the company.

The completion of the Panama Canal in 1914 opened new markets for Weyerhaeuser in the eastern states. To serve these markets, the Company built the first US electric lumber mill in Everett, and they acquired two merchant ships that became available after WWI. This allowed Weyerhaeuser to export Douglas fir to the east, and to enter the shipping transportation business through creation of the Weyerhaeuser Steamship Co.

As trees were logged-off, Weyerhaeuser had to decide what to do with the land. Industry practice was to sell the land after the trees had been harvested, because paying land taxes and waiting for natural regeneration was not economic. The company had been exploring the possibility of growing timber as a crop since 1904 and lobbied to change property taxes on timberlands, and this was achieved with the passing of the Clarke-McNary Act of 1924.

Between 1928 and 1929, Weyerhaeuser opened four new sawmills in the northwest region. By the end of the 1920s, the company was the largest private timberland owner in the United States.

PERIOD 2 (1928-1955): DIVERSIFICATION INTO PULP, PAPER, PACKAGING AND ENGINEERED WOODS

In 1928, F. S. Bell became President of Weyerhaeuser. The economic depression of 1929 prompted the company to diversify into pulp and paper. Taking advantage of their large hemlock reserves, Weyerhaeuser opened a bleached sulfite pulp mill in Longview in 1931.

In 1934, Frederick E. Weyerhaeuser, son of the founder of the company became president of the firm and continued the diversification. In 1936 Weyerhaeuser opened a second sulfite pulp mill, and in 1947 the company's first plywood mill opened in Longview, WA. In 1940, the company acquired the Washington Veneer Company. In 1949 the company started producing Kraft paperboard, and containerboard for packaging. By 1954, the company was producing rayon, cellophane, corrugated board, containerboard, and bleached Kraft paperboard [259]. Between 1952 and 1962, Weyerhaeuser's line of pulp grades grew from 7 to 30 [260].

In 1947, John P. Weyerhaeuser Jr. became president, marking the transition to the third generation controlling the firm. John P. continued with diversification. After WWII, the US housing market saw a rapid expansion, and the company increased the diversity of their construction material products. During the 1950s, Weyerhaeuser expanded into the engineered woods market by building a particleboard plant at North Bend in 1955, and by producing hardboard panels from alder and maple trees. In 1960, Weyerhaeuser acquired the Roddis Plywood Company to enter the architectural doors market.

PERIOD 3 (1956-1965): INTEGRATION INTO FINE PAPERS AND LIQUID PACKAGES

In 1956, John P. Weyerhaeuser Jr. died and his cousin Frederick K. Weyerhaeuser took over the company. During this period, the firm began acquiring lands in the southern states. In 1956 Weyerhaeuser bought 90,000 acres of timberland in Mississippi and Alabama and in 1959 they acquired 460,000 acres in North Carolina, Virginia, and Maryland.

Weyerhaeuser also continued expanding into packaging and paper products through the acquisitions of the Kieckhefer Container Company and the Eddy Paper Company in 1957. In 1960, after years of research in plastics and paperboard, they launched a disposable milk container, entering the food packaging business. In 1961 they entered the fine paper market. This broad product diversification prompted the company to drop the word "timber" from its corporate name in 1959, and in 1961, the company announced they had the "Nations most diversified line of forest products" [260], comprised of more than five thousand items [261].

In 1960, Norton Clapp became the first president from outside the family. Clapp prepared the company to become public in 1963. During his tenure, the company continued expanding geographically, both in the US and abroad.

On Columbus Day, 1962, Typhoon Frieda with winds up to 150 miles per hour destroyed billions of Northwest timber and Weyerhaeuser started a logging effort to recover downed trees. Because the domestic market could not absorb this oversupply, the company looked at the Japanese market, which at the time faced a shortage of softwood lumber. This episode marked the international expansion of Weyerhaeuser. The company opened international offices in Japan (1963), France (1964), and Belgium (1965). That same year, their first Canadian mill for producing bleached Kraft pulp was opened in Kamloops, BC. In 1969 Weyerhaeuser was granted 250,000 acres of timber in Indonesia, and they also expanded their operations in the US through acquisitions in Idaho, and in Arkansas, where they acquired 1.8 million acres of timberlands [262].

PERIOD 4 (1966-1987): DIVERSIFICATION INTO NON-FOREST PRODUCTS

In 1966, George H. Weyerhaeuser became president. During the 70s, a transition began in the paper business unit. Weyerhaeuser had been traditionally a specialty paper producer, yet in 1968 the emphasis began to change towards high-volume commodity-grade papers [263]. In 1973 the company announced it would enter the newsprint business [264], and in 1979 it created the North Pacific Paper Corporation, a joint venture with the Jujo paper company of Japan.

As a consequence of the oil crisis during the 1970s, the company explored other business lines in addition to forest products. Weyerhaeuser conducted geological studies for exploring new business opportunities from sand, gravel, phosphates and uranium. The company entered the commercial recreation business by developing a ski resort, and by leasing hunting privileges in Mississippi. The firm also conducted experiments to find additional land uses including growing soybeans and cotton [127].

In 1969, Weyerhaeuser entered the shelter business, and in 1970, they created the Weyerhaeuser Real Estate Company, a mortgage company, and entered the insurance business. In 1971 the company diversified into personal care products by producing disposable diapers. In 1974 George Weyerhaeuser formed a diversified business unit to accommodate new projects in personal care, food, and gardening. The company's diversification into non-forest businesses continued in 1979 when they entered the aquaculture business through salmon ranching and shrimp growing. In 1980 they started selling garden and floral products for landscaping, and in 1982 they started producing hydroponic lettuces. During the first half of the 1980s, much of the company's growth, and a significant portion of the earnings came from these non-traditional businesses [265].

PERIOD 5 (1988-1998): FOCALIZATION AND DIVESTURE OF NON-FOREST BUSINESSES

In 1988, Jack Creighton became president and restructured the company moving to a narrower business base: "we are divesting those businesses, product lines, or units which either do not have a chance of becoming competitive leaders, or which are potentially more valuable to others than to us"[266]. This meant divesture of several business lines. In 1988, they exited the food products business. In 1989, they sold the health and beauty aids business and the garden supplies businesses. During the 1990s, the economic downturn intensified the company's divestures. In 1991, they sold the molded products business unit and the diaper business unit. In 1992, they closed 50 plants, cut R&D expenditures by 25%, and concentrated back on land, timber, wood, and paper products [267].

With earnings from the divestures, the company strengthened its core business by overhauling old mills, and acquiring new timberlands. In 1992 they acquired Procter and Gamble's mills and timberlands in Georgia and they acquired new lands in South Dakota, Mississippi, and Louisiana in 1995. In 1996 they sold their Ponderosa pine timberlands in Oregon to concentrate on Douglas fir. In 1997, they exited the mortgage business and sold their Canadian chemical business.

During the 1990s, Weyerhaeuser faced increased competition from Nordic and Southern hemisphere manufacturers. In 1993 the Swedish and Finnish governments devaluated their currencies, which allowed Nordic producers of paper and pulp to become cost competitive in the US market. New entrants from the southern hemisphere also came into competition. Paper and cellulose exporters from Brazil, Australia, Chile, New Zealand, Indonesia and Malaysia had a price advantage, because they utilized hardwoods that grow twice as fast as the northern hemisphere softwoods. This eroded the company's core capability, its ability to manage and increase the yield of forestlands. The company responded by acquiring timberlands in New Zealand and in Uruguay in 1997, arguing that through this expansion "we'll benefit from rotations of 15 to 20 years, less than half as long as North American Rotations"[268].

PERIOD 6 (1999-2005): INTEGRATION INTO ENGINEERED WOODS

In 1999, Steven Rogel became president of the firm and began a series of large acquisitions. That year MacMillian Bloedel and TJ International were acquired to strengthen their position in engineered woods. The biggest acquisition came in 2001, when they took over Willamette industries, allowing them to become world leaders in paper, pulp, and structural panels, and the third largest timberland owner in America. In 2004, the company achieved record sales of US$21.4 billion.

PERIOD 7 (2006-ONWARDS): FOCALIZATION AND NARROWING FOREST BUSINESS BASE

Since 2005, several trends have affected Weyerhaeuser's competitive position. In the paper and pulp business lines, the company faced increased competition from low-cost manufacturers in South America, and also a reduction in the demand for white paper in the North American market. Coupled with an unfavorable exchange rate of the Canadian dollar this prompted the company to exit the fine paper business and sell its assets to Domtar in 2006, and to close the paper mill in Dryden, Ontario only seven years after its acquisition. The company reduced the paper grade pulp exposure in North America and shifted the product-development strategy away from low-value paper grade towards higher-return products in specialty markets [269].

The mortgage crisis that led to the collapse of the US housing market in 2007 had profound consequences for Weyerhaeuser. Sales decreased from 21 billion in 2004 to 5.5 billion in 2009. According to a senior company executive "this was a near death experience. We lost 80% of our market demand" [270]. The company responded by further narrowing its business base. In 2008, they sold their containerboard, packaging, and recycling business lines to International Paper. In 2009 they sold the Trus Joist commercial division (acquired in 1999), and in 2011 they sold their hardwood business unit, and the Westwood shipping lines [258]. The company also contracted geographically, selling their timberlands in New Zealand and closing their Australian operations.

Dan Fulton took over as CEO in 2008, highlighting the potential in non-tree assets, such as mineral rights, water, and geothermal energy. The company currently is exploring with AltaRock the possibility of producing electric power from the company's geothermal resources. They started a joint venture with Chevron in 2008 to produce ethanol from non-food lignocellulosic feedstock. They are looking for opportunities arising from an international interest in climate change and sustainability, including green building technologies, carbon sequestration programs, and the creation of cellulose-based biodegradable plastics.

3. THE ORIGINS AND COEVOLUTION OF WEYERHAEUSER'S UNIVERSITY RELATIONSHIPS

Weyerhaeuser's first university relationship was in 1917. The lumber industry at the time faced increased competition from non-wood materials that were substituting for forest products. Barbed wire was replacing the old log fence; stone and cement were replacing wooden bridges; paper cartons were replacing wooden boxes; concrete, glass, iron, and steel had taken the city office building market. The use of non-wood roofing had increased eleven times between 1905 and 1914, and the US per capita consumption of softwoods declined from 381 to 215 board feet between 1904 and 1929 [261]. Frederick Weyerhaeuser recognized this threat: "we have lost the wooden fence and sidewalk business… we are loosing the packing box business—and this is a large part of our sales—and we are threatened with other substitutes of wood so that our market is being more and more restricted." [261]. Within this context, the company created a By-Products Committee in 1917 to find additional uses for wood waste.

Weyerhaeuser's By-Products Committee traveled to Madison, Wisconsin to meet researchers at the Burgess laboratory, an institution created by Professor Charles Frederick Burgess of the University of Wisconsin. This laboratory had been experimenting with wood products, and the committee felt "it was worth gambling $25,000" to find additional uses for wood [261]. Initial research projects included wood fireproofing techniques, creation of wood briquettes for locomotive use, finding new chemicals from wood, and the creation of cattle food from larch. Research conducted at this lab led to the creation of a new insulation material called Balsam-wool in 1921, and a new wallboard material called Nu-wood in 1927[261].

ORIGINS OF WEYERHAEUSER FORESTRY R&D

In 1924 Weyerhaeuser hired the first full-time forester to survey lands for future production [271]. Since then, the company's core capability has evolved around the capacity to grow timber as a crop. In 1934, Weyerhaeuser started a forest management plan for increasing the yield of their forestlands, and in 1941 they opened the first US certified Tree Farm for producing seedlings near Montesano, WA.

In 1942, Weyerhaeuser opened a forestry research department to conduct research on seeding survival and growth rates. In 1951, Weyerhaeuser hired their first full-time forest soil researcher and in 1952 the first entomologist [271]. In 1950, the department had 55 foresters, and in 1955 Weyerhaeuser enlarged this research center hiring technical personnel for "long-range basic research"[259]. By 1957, the forestry department had 170 full-time researchers [261], and it conducted research on extending the life of old growth timber reserves, limiting the damage of seeds and seedlings by wildlife, combating insects and other pests, and conducting studies to improve the growth and yield of timberlands, including genetic and fertilizer studies to speed-up timber growth. By the end of the 1950s, Weyerhaeuser had the largest non-government research laboratory in the forestry industry [261],

Weyerhaeuser's most important development in the area of forestry was the creation of the High Yield Forest program, in 1967. This program promoted reforestation within one year of harvesting, the utilization of soil fertilizers, the thinning of the trees, and the genetic improvement of seeds. This intensive forest management program allowed reducing harvesting time from 60 to 43 years [272].

The development of the High Yield Program was based on science conducted at Weyerhaeuser's Forestry Research Department, and there is little evidence that the academic community was directly involved in the initial phases of this program. According to the director of environmental science, the academic community did not believe in

Weyerhaeuser's intensive forestry management practices and thus during the late 1960s the company created a "travelling program" to visit forestry schools in the US to present the results of their program [272].

Origins and growth of pulp and paper R&D

In 1933, Weyerhaeuser opened a research laboratory to conduct research on pulp and paper technologies, including acid and alkaline pulping, bleaching technologies and continuous pulping processes [271]. The laboratory was staffed with 10 researchers who worked on the development of a magnesium oxide (MgO) recovery plant in 1948, allowing the company to recover sulfite waste-liquor and to obtain specialty chemicals such as lignin, tannin, and vanillin. The laboratory also conducted research on bleached sulfite pulp for producing photographic paper, rayon, and cellophane [271].

At the end of the 1940s, the pulp and paper industry in the US faced a shortage of technical personnel [220]. To stimulate the formation of new graduates, Weyerhaeuser created a foundation in 1948, which began offering graduate fellowships in the areas of forestry, chemistry, and industrial relations at six universities in the US: Yale University, U. of Washington, Oregon State, U. of Wisconsin, U. Chicago, and North Carolina State [261]. Universities responded to this shortage of personnel by establishing pulp and paper foundations. In 1968, for example, the University of Washington established a paper and pulp foundation and Weyerhaeuser has been an active member of this foundation until today.

As Weyerhaeuser expanded during the 1960s, the company also acquired new research labs in paper manufacturing. In 1963, for example, Weyerhaeuser acquired Crocker, Burbank & Co, a specialty paper manufacturer of Fitchburg, MA. This acquisition came with a fully equipped paper research lab in this location.

In 1967, Weyerhaeuser's pulp research laboratory established a relationship with the university of Washington to work on new processes for eliminating Kraft mill odor [273]. The collaboration with the University of Washington intensified during the 1970s with increased environmental pressure on the US paper and pulp Industry. New pieces of legislation including the creation of the Environmental Protection Agency (EPA), the clean air act (1970) and the clean water act (1972) imposed new environmental standards, and several of Weyerhaeuser's mills were renovated or closed.

Origins and growth of Weyerhaeuser's wood products research

In 1960, Weyerhaeuser opened a research laboratory in Seattle for research on construction materials. This laboratory launched three new chemically derived products in 1962: WEF (Weyerhaeuser Extracted Fibers), Wey-Chem (Chemical extractives), and Firwax (a hard, dense wax) [260]. In 1963, Weyerhaeuser acquired Martin Marietta's Adhesives and Chemical Division and reorganized the construction materials laboratory into three research departments: polymer research, pioneering research, and construction research.

The polymer research department, staffed with 30 researchers from Martin Marietta, conducted research on aldehyde condensation, resorcinol, melamine, and urea-based adhesives, all chemicals employed in the production of engineered woods such as panels. The department also conducted studies on paper stiffening, paper impregnation, epoxy resins, hot melt plastics, thermoplastic extrusion, and plastic bonded molds, which were used in laminated wood products [274].

The pioneering research department conducted fundamental research on the physical and chemical properties of forest derived materials, and thus this work was further away from commercial application. Research areas included value added chemicals such as lignin, anatomical and physical characterization of wood, and development of mechanisms for improving wood impregnation and surface treatment techniques [275]. The construction research department conducted research on paints, wood finishes and chemical modifiers for extending the life of wood. By 1966 the laboratory had 55 researchers, including 17 chemists [275].

ORIGINS AND GROWTH OF DIVERSIFIED PRODUCTS RESEARCH

In 1941, Weyerhaeuser established a development department to find new applications, and to increase the utilization of wood [271]. In 1942, the department conducted research to extract cork from the bark of the Douglas fir, a product in shortage during WWII. Eventually, the research led to the discovery of fibers and compounds valuable for making plastics, glue, and other industrial uses [276]. In 1943 the department conducted research on phenolic resins, which were used for manufacturing exterior plywood. To utilize the bark of the tree, the Company built in 1946 a pilot plant to produce Silvacon, a corklike granule used in flooring and acoustical tile. In 1949, they launched Silvawool, a hose insulation material made out of wood fiber, and in 1950, they started developing the first moldable fibers under the name of Silvaloy. That same year, the department was renamed the Special Products Division, which contributed new products including asphalt roofing, flooring, fertilizers, and chemicals.

During the 1950s, Weyerhaeuser saw a wave of product substitution that pushed them to diversify the product range. As stated in the company's 1954 annual report: "Increasing competition puts a premium on research and development to improve existing products and methods, and to find new uses for wood which will lead to more complete and profitable utilization of the forest crop" [259]. As a result, Weyerhaeuser intensified its research and development activities, not only at its own laboratories, but also with outside laboratories and research agencies [259].

CENTRALIZATION OF RESEARCH AND DEVELOPMENT LABORATORIES

At the end of the 1960s, Weyerhaeuser had a research staff of over 500 people and had expertise in 20 areas of technology including chemistry, entomology, mathematics, engineering, microbiology, plant genetics, and plastics and polymers, among others [277]. In

1974, the company consolidated its R&D centers, creating the new Weyerhaeuser Technology Center (WTC) near its headquarters in Federal Way, WA. This building had capacity for 1000 personnel and was designed for 50% expansion in the number of researchers [278]. Research was organized around six areas including land and timber, raw materials, wood products, fiber products, technical service, and planning and engineering. In 1974, the company opened a Southern forestry research department in Hot Springs, AR, and a tropical research department in Indonesia in 1975.

Figure 72 presents an historical evolution of Weyerhaeuser's university co-publications. Company personnel have written 507 articles between 1970 and 2012 with a university coauthor, more than twice the number of articles of the next company in our dataset. As in Figure 72, 68% of these articles have been in forestry research, followed by pulp and paper research (18% of articles), and wood products research (10% of articles).

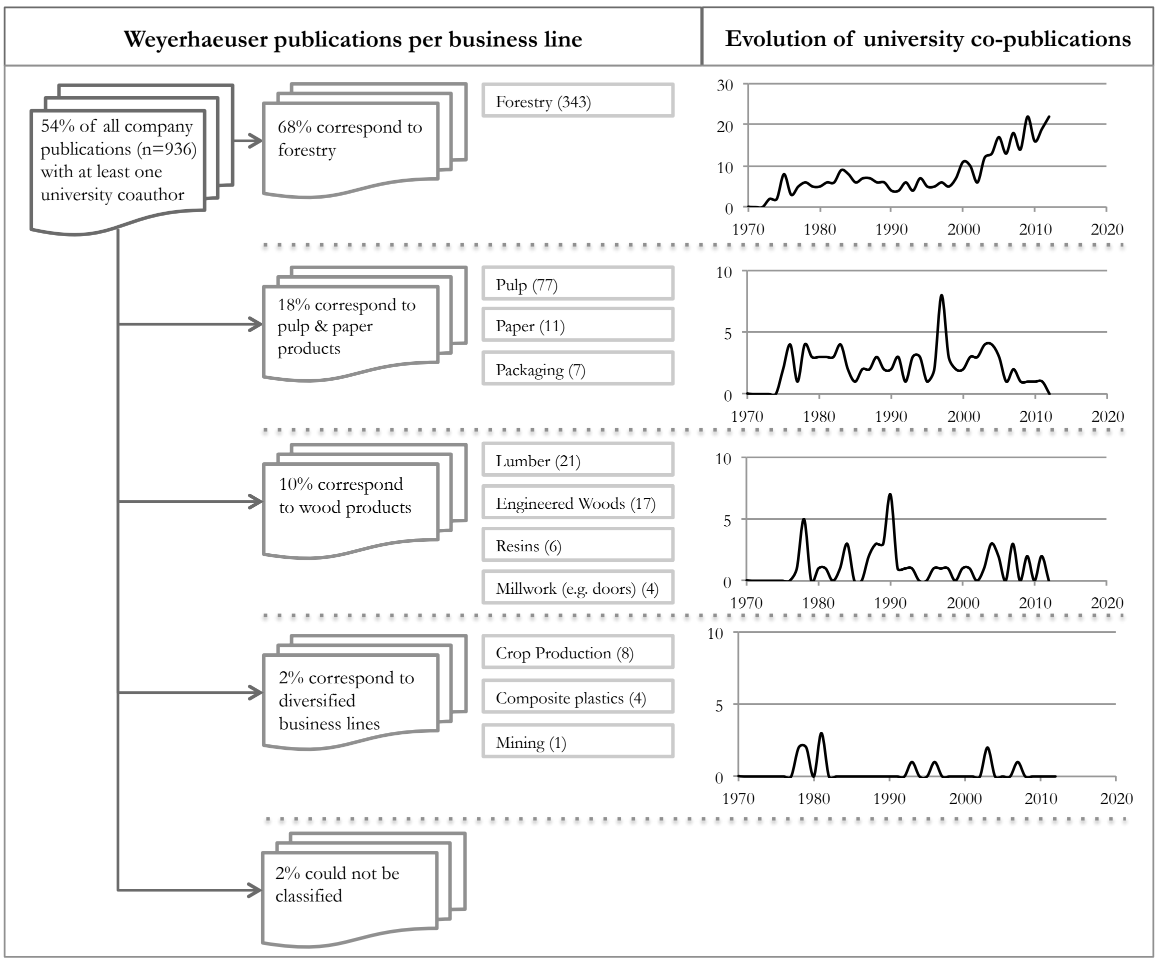


FIGURE 72: COEVOLUTION OF UNIVERSITY CO-PUBLICATIONS AND WEYERHAEUSER'S BUSINESS LINES

Between 1974 and 1978, Weyerhaeuser increased its level of R&D investment. During the 1980s, however, the company started losing terrain in the international forest products market, also in the US market after the entrance of low cost manufacturers of paper, particleboard, and other forest products [279]. This, coupled with the hosing crisis at the beginning of the 80s, made the company revise its R&D intensity, which has declined since then (see Figure 70 at the beginning of the case).

The incorporation of the spotted owl to the list of endangered species in 1994 pushed Weyerhaeuser to revise its forest management practices. Industry practices such as clear-cutting were criticized and the use of herbicides, fungicides, and fertilizers was subject to heavy public scrutiny. Weyerhaeuser established a series of university collaborations focused on environmental issues. In 1994, Weyerhaeuser along with several other companies of the American Paper and Forest Association launched the Sustainable Forestry Initiative, a NGO devoted to the certify the forest practices of timberland owners. As in Figure 72, there has been a steady increase in the number of co-publications in the area of forestry since the 1990s.

As shown in Figure 72, shows the decline in Weyerhaeuser's university co-publications in the area of pulp and paper technologies since 2004. This is consistent with two strategic trends described in section 2 of this case. First, Weyerhaeuser divested its fine papers division to Domtar in 2006. Second, Weyerhaeuser faced a decline in the demand for corrugated boxes, as US manufacturing had been gradually moving overseas and shifted its research focus to specialty packages. In 2006, Weyerhaeuser focused the research and development resources to expand and improve the range of applications for cellulose fiber, including chemically modified fibers and to find new product opportunities for liquid packaging and newsprint [280].

In recent years, university coauthors have become more frequent in company publications. Figure 73 indicates that since 2000, between 80-90% of all company publications have been written in collaboration with a university author.

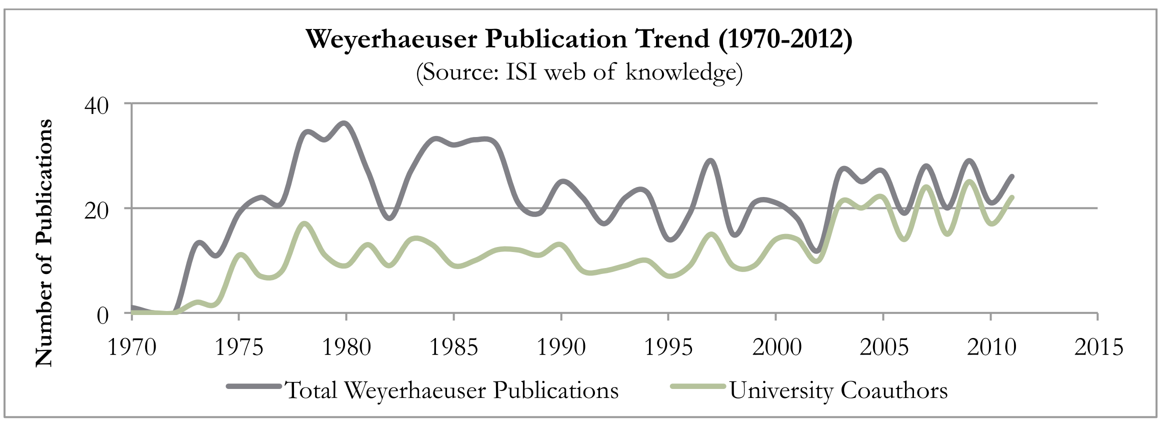


FIGURE 73: WEYERHAEUSER'S PUBLICATION TREND

After the 2007 sub-prime housing market crisis, Weyerhaeuser reduced its R&D expenditures from 69 million in 2006 to 30 million in 2011 [258]. The company opened its technology base for licensing and has established several collaborations with universities to explore new products. Weyerhaeuser invented and patented a process to manufacture lyocell, a nonwoven fabric for textiles in collaboration with the Fraunhofer Institute of Germany, and they established collaboration with Mitsubishi for producing energy from bio-pellets.

3.1. RESEARCH PRIORITIES ALONG WEYERHAEUSER'S VALUE CHAIN

We have analyzed Weyerhaeuser's university relationships from a value chain perspective, distinguishing between six value chains according to the different industries in which this company has been active.

FORESTRY COLLABORATIONS

Most of the Weyerhaeuser's university relationships have been in the area of forestry research, historically a core competency of the company. We organized Weyerhaeuser forestry co-publications according to different positions of the value chain as in Figure 74. Most of the articles (132) are on assessing the environmental impact of the company's forestry operations. Areas of study are the impact of Weyerhaeuser's forestry practices on wildlife (e.g. game, birds, bats, and fish among others), and the effects of forestry and logging on watersheds, rivers and soil (e.g. nutrients and erosion). Many articles have been written in collaboration with the US Forest Service (23 articles) and with universities located near Weyerhaeuser's forestlands, including U. Washington (16 articles), North Carolina State University (13 articles), Mississippi State (11 articles), and Oregon State (10 articles). Since 2000, the number of publications in the area of environmental impact has risen steadily.

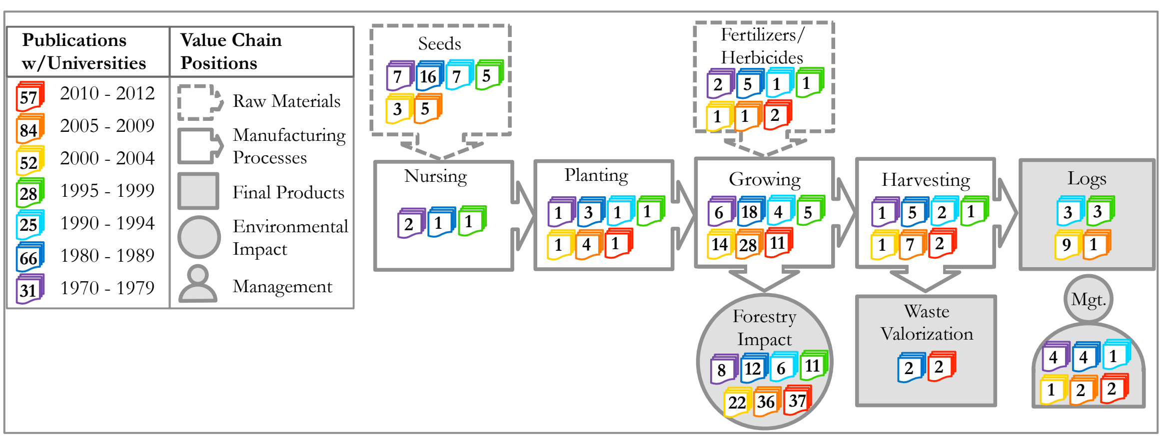


FIGURE 74: EVOLUTION OF WEYERHAEUSER'S UNIVERSITY CO-PUBLICATIONS IN FORESTRY

Growing is the second area in the forestry value with most articles (86 articles) is growing. Since the 1940s Weyerhaeuser has conducted research on growing timber as a crop and since the late 1960s the company has experimented with a High Yield Forestry program, which has doubled the annual growth rates of the company's timberlands [272]. Several articles with universities have been written on different areas of growing forestlands, including plant disease, tree physiology, thinning techniques, forest biometrics, and forest growth models.

Weyerhaeuser has also experimented with the use of remote sensing techniques for monitoring the growth of the forestlands: the use of LiDAR technology for biomass estimation, the use of Geographic Information Systems (GIS) for mapping and classifying forestlands, and the use of acoustic tools for measuring the stiffness of standing trees. Most of the articles on growing have been in collaboration with the US and the Canadian Forest service (33 articles between both), or with universities close to the company's timberlands, including North Carolina State University (12), University of Oregon (9), University of Georgia (9), and University of Washington (7).

The area of forest genetics has also attracted Weyerhaeuser's research attention. The company has been active in the use of genetic tools and breeding programs to produce seeds and cloned trees, coauthoring 43 articles mainly with the US Forest Service (10), with Oregon State (5), with North Carolina State (4) and with U.C. Davis (4). A related research area is the use of Quantitative Trait Loci (QTL) techniques for characterizing the genetic characteristics of the trees in order to select the best candidates for cloning and seeding programs. Most of the articles on QTL have been written with the US Forest Service (8) and with the U.C. Davis (7).

PULP AND PAPER COLLABORATIONS

Two strategic decisions are relevant in understanding Weyerhaeuser's pulp and paper co-publications. First, since the 1970s, Weyerhaeuser has moved towards high-volume commodity-grade papers, which explains why few articles have been written on improving the paper characteristics (e.g. coating, calendaring, furnishings) and why most of the collaborations have been in the area of pulp production. Second, since 2005, there has been a steady decline in the number of articles written in the pulp and paper value chain, consistent with the divesture of the fine paper's division to Domtar in 2006.

Most of Weyerhaeuser's university co-publications in the pulp and paper value chain were written before 1992. The segments of the value chain that have received most attention are pulping (e.g. cooking and refining of pulps), chemical recovery, and waste management (see Figure 75). Weyerhaeuser's most common university partners have been the Institute of Paper Science and Technology at Georgia Tech (13), University of Washington (11), and University of British Columbia (11).

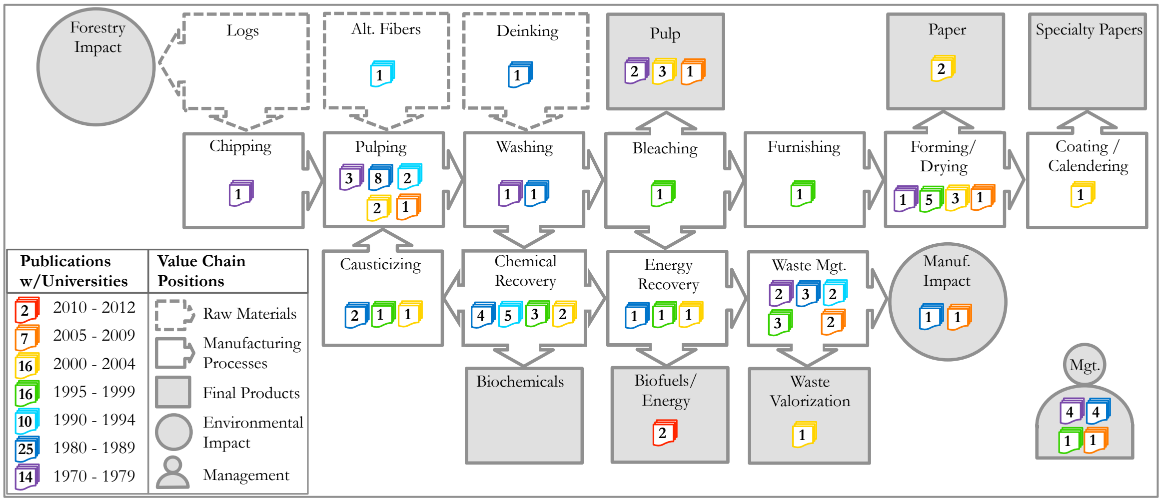


FIGURE 75: EVOLUTION OF WEYERHAEUSER'S UNIVERSITY CO-PUBLICATIONS IN PULP AND PAPER

Packaging Collaborations

Only three papers have been coauthored with a university partner in the area of packaging. Two of these articles refer to the use of paraffin wax to reinforce the structural characteristics of boxes and one article aimed at characterizing the shear properties of corrugated linerboard. In the area of packaging, researchers from the US forest products laboratory have been the most common coauthors.

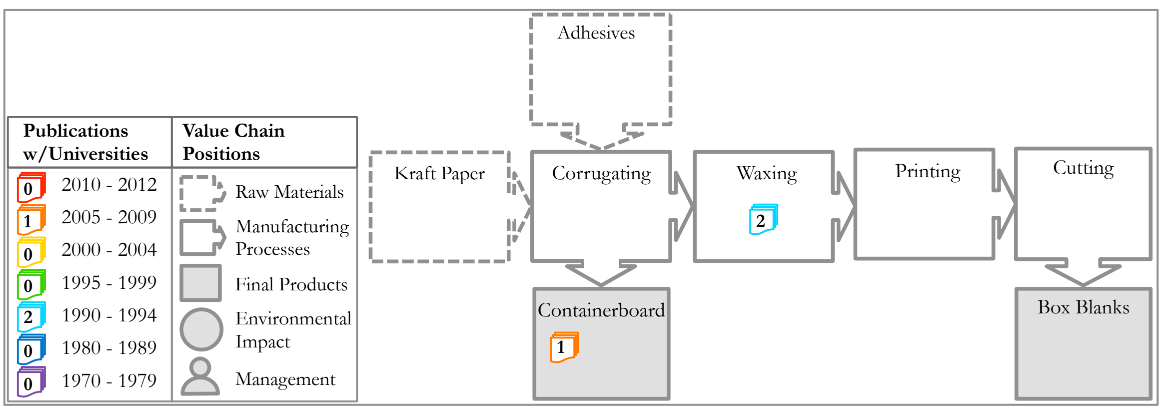


FIGURE 76: EVOLUTION OF WEYERHAEUSER'S UNIVERSITY CO-PUBLICATIONS IN PACKAGES

Lumber products collaborations

Figure 77 shows that most of the collaborations in lumber products have been in the areas of kilning, grading, management, and final product characterization (lumber and engineered structures). In the area of kilning, Weyerhaeuser has conducted studies of the airflow in wood kilns, and on how to control microbial colonizers on freshly sawn timber. In the area of grading, Weyerhaeuser has utilized different techniques for non-destructive characterization of wood properties, including acoustics and infrared spectroscopy. In management, Weyerhaeuser has conducted market studies to evaluate the competitive position of their products. Finally, in the area of product characterization, Weyerhaeuser has analyzed the strength properties and structural behavior of lumber products including jointed lumber, composite lumber (e.g. Glulam) and structural components (e.g. joists, roof trusses). The most frequent partners in these articles have been the US Forest Service (4), Virginia Tech (4), Texas A&M (3), University of Georgia (3), UC Berkeley (3), and Washington State (3).

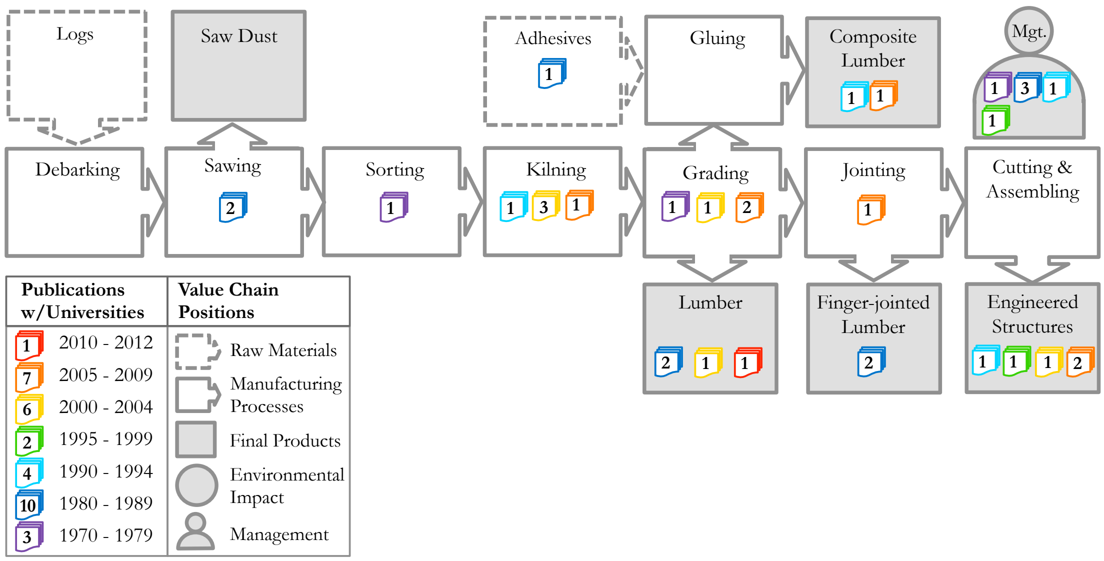


FIGURE 77: EVOLUTION OF WEYERHAEUSER'S UNIVERSITY CO-PUBLICATIONS IN LUMBER PRODUCTS

In the area of fiberboards and structural panels, most of Weyerhaeuser university co-publications have been in the area of resins, bonding, and the environmental impact of the use of adhesives (see Figure 78). The majority of these articles were written more than 20 years ago mostly in collaboration with Mississippi State University (6 articles).

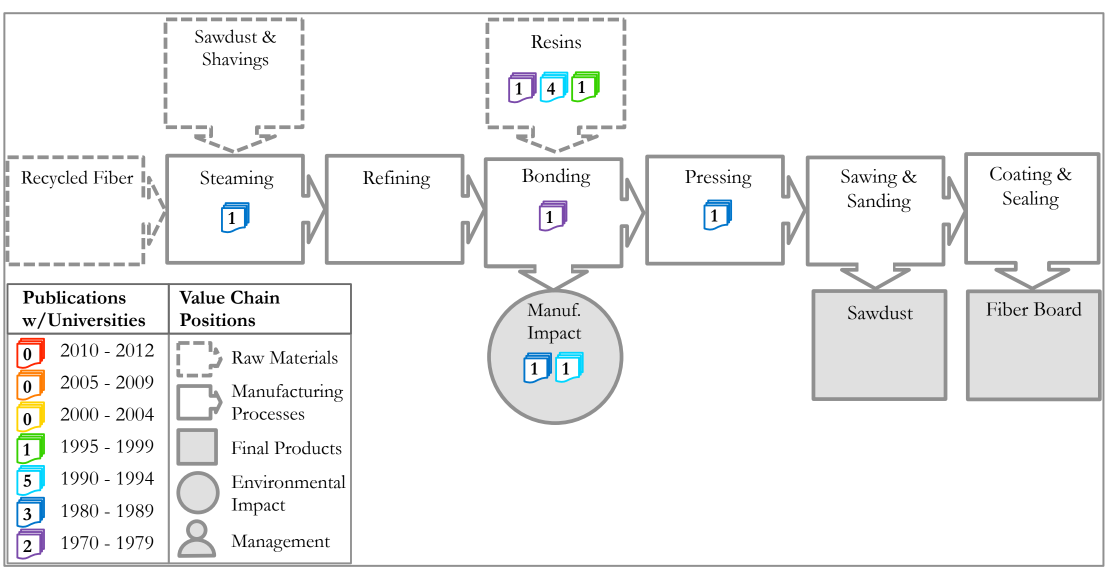


FIGURE 78: EVOLUTION OF WEYERHAEUSER'S UNIVERSITY CO-PUBLICATIONS IN FIBERBOARDS

In the area of veneers and plywood, three papers have been coauthored with Oregon State University (see Figure 79). Two papers aim at characterizing the strength properties and aging behavior of plywood, and one paper characterizes the strength properties of laminated veneer lumber (LVL) using optical and ultrasonic techniques.

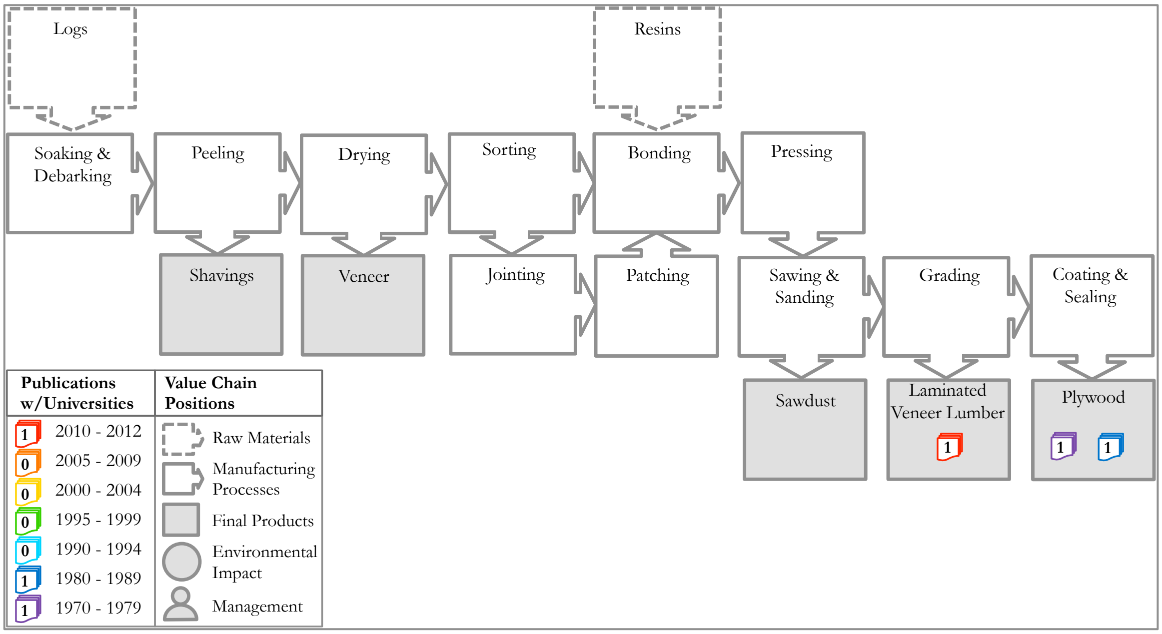


FIGURE 79: EVOLUTION OF WEYERHAEUSER'S UNIVERSITY CO-PUBLICATIONS IN PLYWOOD

Diversified Products collaborations

During the late 1970s and early 1980s, Weyerhaeuser diversified into non-forest areas including Salmon ranching and crop production. We found 8 articles on food production (e.g. production of maize seeds, fruits, vegetables) written mainly with U.C. Davis, between 1978 and 1981.

More recently, Weyerhaeuser has been experimenting with wood plastic composites with Washington State University, and also on the development of switchgrass for the biofuel industry. The company has established cooperation with universities, including participation in the Consortium for Jet biofuel with the University of Washington in 2008, and with Washington State University through a donation to the creation of the Institute of Sustainable Design in 2008.

3.2. Geography of university partners

We analyzed the geographic distribution of Weyerhaeuser's university partners based on the company's publication records. Historically, Weyerhaeuser's university network has been concentrated in the US and Canada as shown in Figure 80.

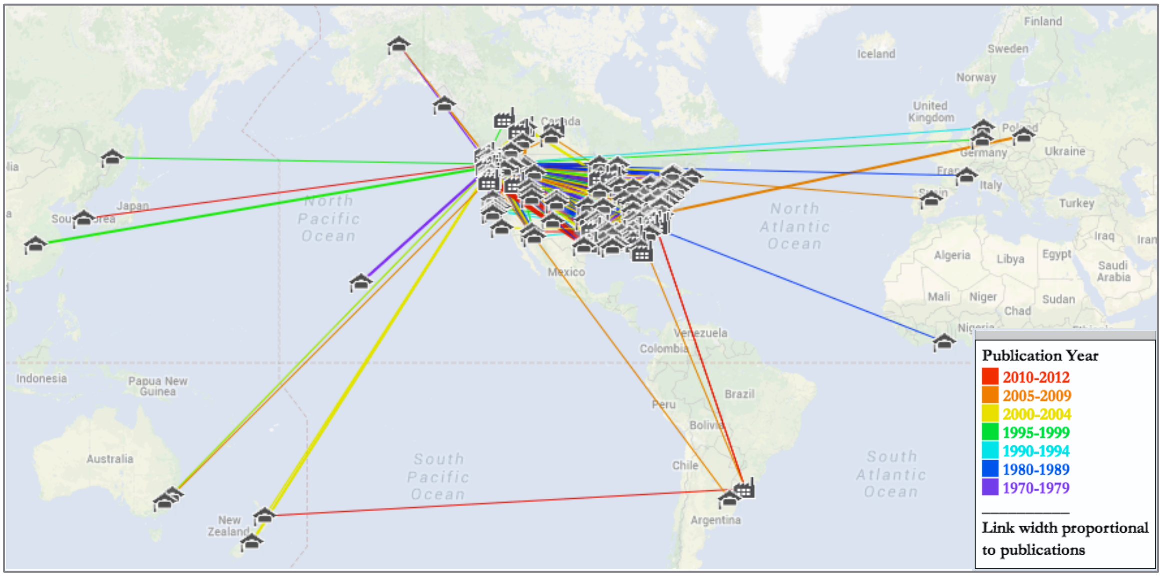


FIGURE 80: WEYERHAEUSER'S GLOBAL UNIVERSITY NETWORK

Weyerhaeuser's collaborations outside North America have historically been limited because the company, during the 1970s and 1980s, had the policy of not practicing High Yield Forestry on government owned lands [281]. Thus, while Weyerhaeuser had harvesting rights on timberlands in Borneo, Philippines, and Indonesia, we did not observe publications with research institutions in these countries. Weyerhaeuser did, however, establish a tropical forest research center in Indonesia in 1975. We found publications from this tropical forest research center, but there was no evidence that they were written in collaboration with local university partners.

During the late 1990s, Weyerhaeuser acquired timberlands in New Zealand and Uruguay resulting in co-publications with New Zealand institutions such as the University of Canterbury, the Crown Research Institute on Forestry (SCION), and the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO). Weyerhaeuser's New Zealand operations were divested in 2007. More recently, Weyerhaeuser's Uruguayan operations have established collaborations with North Carolina State University, University of Georgia, and with Universidad de la Republica of Uruguay. Weyerhaeuser is collaborating with these institutions on afforestation studies, and on research applicable to Weyerhaeuser's eucalyptus timberlands in Uruguay. As explained by a senior company manager "Timberlands has a more international research base because in forestry you want to have local expertise virtually on the ground, trained on the ground, trained and conversing with local regulators, laws, that is very important.[270]"

North American University Network

Figure 81 shows that Weyerhaeuser has written articles with a wide variety of public research institutions in North America. This diversified network of partners is explained both by the territorial diversity of Weyerhaeuser's manufacturing operations and also by the territorial diversity of the US Forest Service, which has historically been Weyerhaeuser's main publication partner. Weyerhaeuser has coauthored approximately 113 articles with researchers belonging to 42 different locations of the US Forest Service.

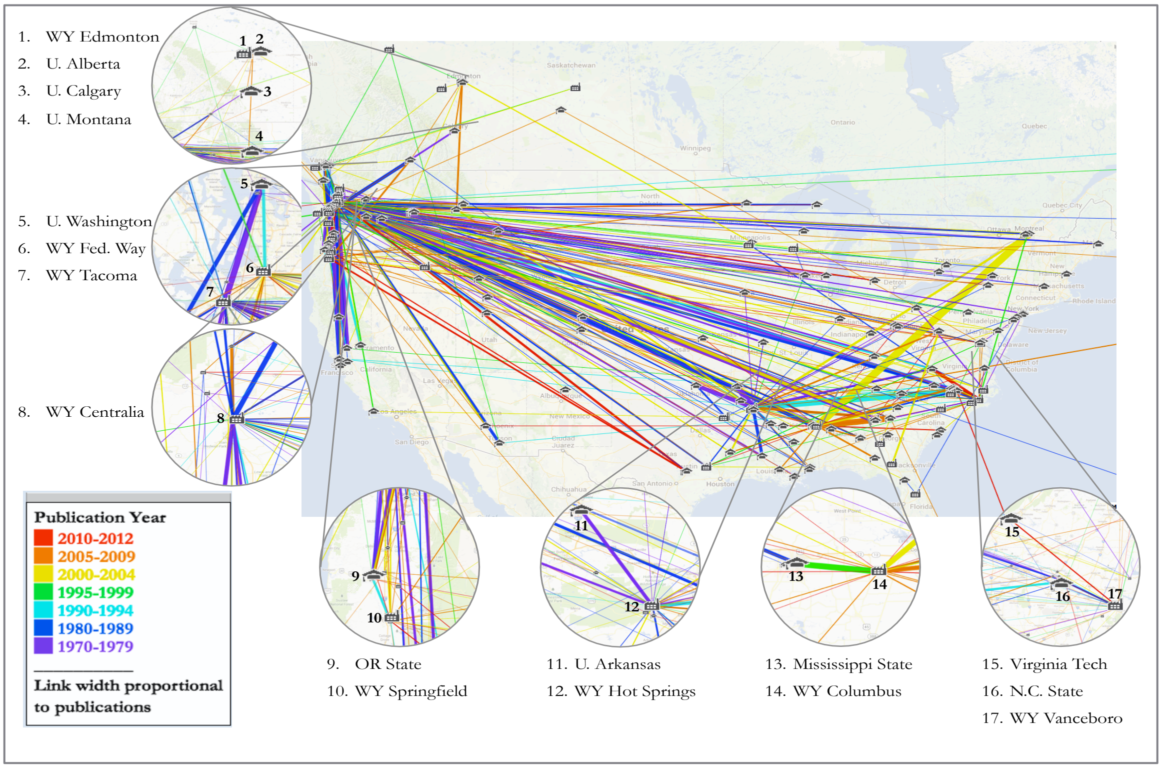


FIGURE 81: WEYERHAEUSER'S NORTH AMERICAN UNIVERSITY NETWORK

There are different hubs within Weyerhaeuser's network. As in Figure 81, the company's headquarters and the Weyerhaeuser Technology Center (WTC) are located at Federal Way, WA (the P.O. Box is in Tacoma, WA). Researchers from the WTC have written approximately 40% of all company publications with universities. The University of Washington (number 5 in Figure 81) has been the most common university coauthor, participating in approximately 11% of Weyerhaeuser's publications with universities. Weyerhaeuser has also held close collaborations with the university of Washington State on wood technologies (see the vignette on the emergence of these collaborations in page 200).

Weyerhaeuser's George R. Staebler Forest Resources Research Center is located in Centralia, WA (number 8 in Figure 81). This research center also acts as a hub connecting different Universities on forestry and environmental research. Since 1974, Weyerhaeuser has also a Southern Forestry Research Center in Hot Springs, AR (number 8 in Figure 81) which acts as a hub connecting different research institutions in the southeastern United States.

Weyerhaeuser's Canadian facilities tend to have connections with Canadian institutions. For example, Weyerhaeuser's facilities near Edmonton (number 1 in Figure 81) are connected to the University of Alberta, the University of Calgary, the University of British Columbia, the University of Victoria, and with the University of Montana in the US.

Finally, Weyerhaeuser's pulp mills located in Vanceboro, NC (number 17 in Figure 81) also acts as a hub connecting research institutions in the Southeast, in particular with Virginia Tech and North Carolina State University.

Figure 82 presents an historical evolution of Weyerhaeuser's university network. During the 1970s and 1980s (Letters A and B in the Figure), Weyerhaeuser constructed a wide network of university partners, which coincides with the period of diversification of the firm. During the 1990s (Letters C and D), few new university connections were formed, consistent with the focalization period described in Section 2. In the early 2000s, the company increased creation of new university connections, which coincides with the period of growth through large acquisitions of forest products firms (Letter E). Since 2007 the company has been narrowing its forest business base, with a reduction in the formation of new university connections (Letter G).

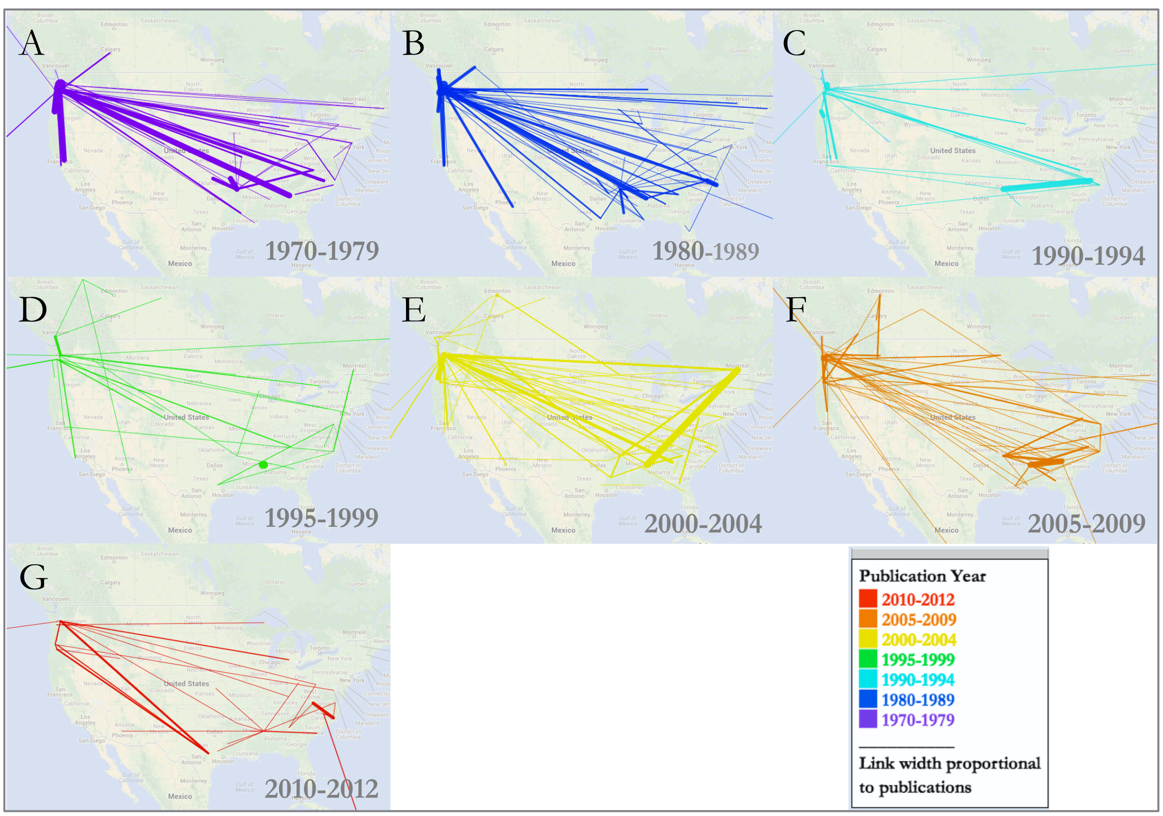


FIGURE 82: EVOLUTION OF WEYERHAEUSER'S UNIVERSITY NETWORK

3.3. Technology transfer through people flows

To analyze the academic and professional trajectories of Weyerhaeuser's most prolific authors and inventors we used the company's publications and patenting records to develop a list of 120 people involved in R&D activities. Each of the names in this list have either patented at least 6 inventions or published at least 4 papers under Weyerhaeuser's name.

Analysis of the professional trajectories shows that most of Weyerhaeuser's R&D personnel have been recruited from academic or research institutions, in particular, the University of Washington, North Carolina State University, UC Davis, Georgia Tech, University of British Columbia, and Oregon State University. Approximately 60% of these recruits were recent graduates. The remaining 40% held staff or faculty appointments at these and other universities.

Figure 83 shows that, Weyerhaeuser's R&D personnel peaked at the beginning of the 2000s after which there has was a decline in the number of people working in R&D declined, consistent with the narrowing of the firm's business base since 2006 and with the reduction in Weyerhaeuser's R&D from approximately US$ 70 Millions in 2006, to US$ 30 millions in 2012. As explained by a Senior Scientist: "We went through some significant reduction when we spun out and sold the paper and packaging businesses. We no longer needed people to serve those industries, and a lot of them left with the companies that acquired these businesses [282]."

After leaving Weyerhaeuser, 19% of the company's researchers in our sample joined other firms, 18% retired, and 19% went back to research institutions, in particular, to the US Forest Service, the University of Washington, and Virginia Tech.

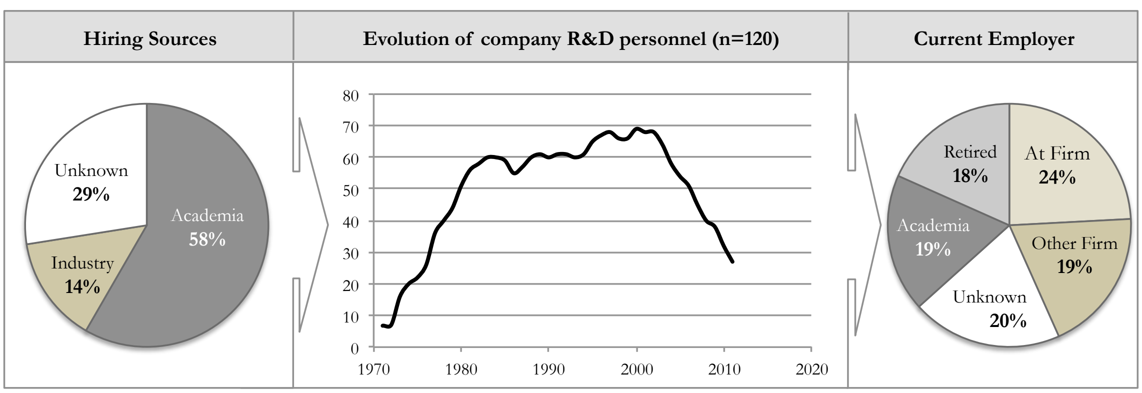


FIGURE 83: EVOLUTION OF WEYERHAEUSER'S R&D PERSONNEL

Analysis of the academic training of Weyerhaeuser's researchers shows an overlap between the academic institutions attended by these people and the company's publication partners (Figure 84). The University of Washington has been the most important academic partner, participating in approximately 11% of Weyerhaeuser's publications with universities and helping in the training of several of the company's personnel. At least 8% of Weyerhaeuser researchers in the sample have been recruited from the U. of Washington, and several others have pursued graduate studies at this university while working a Weyerhaeuser. Two former researchers from Weyerhaeuser became professors at the University of Washington after leaving the company.

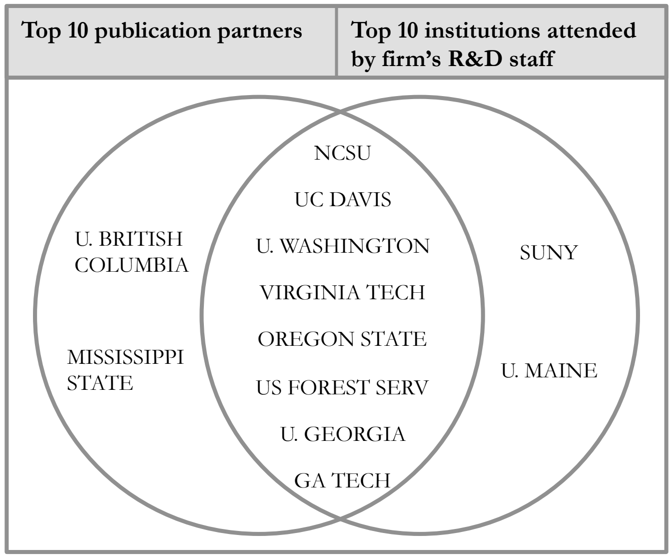


FIGURE 84: OVERLAP BETWEEN WEYERHAEUSER'S HIRING AND PUBLISHING PARTNERS

Closer examination of the universities listed in Figure 84 reveals that Weyerhaeuser's relationships with these institutions go far beyond the joint publication of a papers or the recruiting of students. Weyerhaeuser endowed a chair in the Faculty of Applied Sciences at the University of British Columbia in 1996, provided grants to the Mississippi State University Institute of Furniture Manufacturing and Management in 2004, endowed two scholarships at the NCSU pulp and paper foundation in 1980 and 1991, became member of the Empire State Paper Research Associates of SUNY College of Environmental Science and Forestry in 2007, is currently a member of the Institute of Paper Science and Technology at Georgia Tech, has donated funds to the College of Forestry at the Oregon State University in 2009, and has been a long standing member of the University of Washington Pulp and Paper Foundation. All these forms of industry-university interaction help explain the observed overlap between hiring and publishing partners.

4. Case Study Discussion

Weyerhaeuser has endured several strategic changes and participated in a diverse mix of industries over time. This provides an opportunity to analyze how Weyerhaeuser's changes in corporate strategy have affected its relationship with universities and research institutes. Table 15 presents a summary of these findings. The table shows the different strategic periods of the firm, and how Weyerhaeuser's research priorities, people flows, and institutional networks were modified as a consequence of the changes in the firm's strategy.

TABLE 15: SUMMARY OF HOW WEYERHAEUSER UNIVERSITY RELATIONSHISP COEVOLVED

University Links / Firm Strategies	Research Priorities	People Flows	Institutional Networks
Period 1: **Integration** (1900-1928)	**Forest By-Products** • Additional uses for wood	**Hired first full-time forester** • Surveyed lands and planned production	**First University Collaboration** • Burgess Lab, U. Wisconsin
Period 2: **Diversification** (1929-1955)	**Forestry Research** • Grow timber as a crop **Cellulose Research** • Pulping, bleaching, specialty chemicals • Odor control studies	**First Forestry R&D Dept.** • 55 staff: foresters, soil researchers, entomologists **First cellulose R&D Lab.** • 10 staff; mainly chemists	**Weyerhaeuser Foundation** • Offered fellowships at Yale, UWA, OSU, U. Wisconsin U. Chicago, NCSU
Period 3: **Integration** (1956-1965)	**Forestry Research** • Long range basic R&D **Cellulose Research** • Diversification of pulp and paper grades **Construction materials** • Adhesives, melamine, resins, thermoplastics	**Internal R&D Growth** • 170 full time researchers • Increased recruiting of advance degree graduates • Employees attend special programs at universities	**Extended Recruiting Network** • Extended scholarships to 16 colleges and universities. • Provision of grants to nontax supported colleges and universities
Period 4: **Diversification** (1966-1987)	**High Yield Forestry** • Genetic improvement, fertilizers **Environmental Research** • Eliminate Kraft mill odor	**Consolidation of R&D Ctr.** • Weyerhaeuser Technology Center (500 in staff) • Researchers in more than 20 knowledge areas **Southern Forestry R&D** • Extended recruiting to southern states	**University Network Expansion** • First collaboration (1967) with UWA on Kraft mill odor control • Several collaborations with growing network of partners • Increased network of universities in southern states
Period 5: **Focalization** (1988-1998)	**Environmental Research** • Forestry certification • Mill effluent treatment	**Reduction in R&D** • Reduction in staff and areas of expertise	**University Network Contraction** • Few new partnerships established
Period 6: **Integration** (1999-2005)	**Advance Packaging** • Pilot projects in RFID **Wood Products** • Engineered woods	**New Wood products Lab** • Boise, ID after acquisition of TJ International	**Large Strategic Partnerships** • E.g. IPST, STFI, YKI **International Forestry Partners** • E.g. Scion (NZ); U la Republica (Uruguay)
Period 7: **Focalization** (2006-Onwards)	**Wood Products** • Wood composites **Cellulose Fibers** • Textiles and plastics form cellulose	**Reduction in R&D staff** • After divestures **New hiring sources** • Gain technological competencies in new areas	**Reduction of large partnerships** • Fewer consortia-based collaborations **Grass root collaborations** • One-off R&D projects with different institutions

During the first period, Weyerhaeuser began building a strong research base in forestry. Forestry schools were just being created at US universities and Weyerhaeuser began recruiting forestry graduates for managing the company's timberlands. The only formal university collaboration we found in this period was with Prof. Burgess of the University of Wisconsin who was asked to find additional uses for wood. Several new products came out of this collaboration, in particular in the area of insulation and construction materials.

The second period was characterized by the diversification of Weyerhaeuser into pulp, paper, packaging, and engineered woods. Weyerhaeuser created a cellulose research lab and staffed it with 10 scientists who conducted research on pulping technologies and chemical byproducts of wood (e.g. lignin). In the forestry side, Weyerhaeuser increased the number of people working in R&D and also increased the diversity of research areas (e.g. soil science, entomology, etc.). At the university level, the company created the Weyerhaeuser Foundation and began scholarships at six universities as a means to promote and recruit graduates with interest in forest products.

The third period was marked by large acquisitions in packaging and fine papers. Weyerhaeuser continued growing its internal R&D capabilities adding new areas of research such as adhesives, polymers and construction materials. Weyerhaeuser extended the range of the fellowship program to 16 universities and concentrated in hiring students with advance degrees. At the end of the 1950s, Weyerhaeuser had the largest non-government research laboratory in the forest industry [261].

During the fourth period Weyerhaeuser began diversifying into non-forest products areas including financial services, real estate, and the food industry and the company began formal research collaborations with an increasing number of universities and research institutions. Weyerhaeuser built a large network of university partners, concentrated predominantly in the US, close to the company's timberlands and production sites.

The fifth period was characterized by the narrowing of Weyerhaeuser's business base. The company exited several industries such as personal care products (e.g. diapers) and concentrated on timberlands and forest products. The firm's R&D expenditures were reduced by a third, and, as shown in Figure 82 of Section 3.2, few new university partnerships were formed during this period.

During the sixth period, Weyerhaeuser grew through large acquisitions in construction products. The company also moved up the value chain in packaging, experimenting with RFID technologies. The company also engaged in several large consortia based collaborations with different institutions in the US and abroad.

The seventh period is characterized by the economic difficulties that led the company to reduce its size by 75%. Weyerhaeuser exited several industries, including packaging and fine papers. The company contracted geographically, selling its timberlands in New Zealand and several mills in Canada. These strategic changes have several repercussions for the firm's university relationships, as explained in the following sections.

THE DECOUPLING OF CONSORTIA-BASED RESEARCH MODELS

After 2006, the housing market crisis that lead to the collapse of the construction materials industry caught Weyerhaeuser in a bad position. The company lost 80% of their demand and had to reduce its R&D expenditures by 60%. With fewer resources available, external collaborations were reduced.

Weyerhaeuser began divesting different business lines to make cash and several researchers left the company with these divestures. As explained by a Senior Scientist, "we still have university relationships, but not at the same scale than before. The company has gone out of businesses, sold businesses. So the size of the company has changed and you would expect with that some of our interactions with the universities have also changed. For example, when we were in the paper business we had significant interactions with universities that were active in research related to paper like printing and things like that. We are no longer in the paper business, so we now we don't have interactions with them" [282].

A final trend affecting Weyerhaeuser's university relationships has been a structural shift in the locus of innovation for the firm. Weyerhaeuser is moving away from large consortia-based collaborations and placing more attention on smaller research projects with a more diversified set of university partners. As explained by a senior technology manager "the driver for restructuring Weyerhaeuser university relationships had less to do with the divesture of businesses, which were important, but most to do with a change in the locus of innovation. Before 2005, we placed strategic investments in large organizations such as the IPST. We invested hundred of thousands of dollars per contract. Now (after 2005), we do much more one-off personal relationships. For example, we support a company researcher working with a particular professor from a specific department. We are building those types of grass roots relationships, and we are reaching a much broader set of universities and professors and disciplines. Weyerhaeuser is still member of the IPST and we value this collaboration, but in terms of the total amount of dollars and total people-time the company has lessened the interactions with these large institutions and focused on pursuing the one-off collaborations"[270].

The change in the locus of innovation for Weyerhaeuser has to do with the types of products and technologies the firm is seeking to develop. In cellulosic fibers, for example, the company is moving away from commodity grade products and moving up the value chain towards textiles and value-added chemicals. It has thus formed new partnerships to gain technological capabilities in these areas, as described below.

REBUILDING RESEARCH CAPABILITIES AFTER DECOUPLING: THE CASE OF TEXTILES AND LIGNIN

During the 1940s, Weyerhaeuser developed an internal capability in textiles such as rayon and other types of cellulose fabrics, and also conducted experiments for obtaining value added chemicals such as lignin from their pulping operations [271]. Weyerhaeuser began producing Rayon in 1947 and the company continued commercializing this product throughout the 1950s. During the 1960s, the rayon industry suffered a slump. New synthetic fibers of petrochemical origin including nylon, polyester, and acrylics began disrupting the cellulosic fibers industry. Several rayon producers such as DuPont exited or phased out their rayon production [283]. Weyerhaeuser, for example, stopped advertising rayon in the company's annual reports in 1965.

During the late 1960s, the rayon industry tried to reinvent itself by creating hybrid rayon-polyester or rayon-acrylic fibers, which had better performance than regular rayon [283]. During the 1970s, the rayon industry faced environmental pressures concerning their manufacturing processes and waste disposal methods and they reduced R&D investments during the 1970s. The industry faced an over supply problem which dropped production by almost 50% during this decade [283]. This oversupply coupled with the emergence of new producers of synthetic fibers in Asia and Eastern European countries forced several US producers to close their operations.

As the synthetic fibers industry began moving away from the US, the amount of research conducted at local universities on cellulosic fibers reduced. As explained by a senior research scientist "there has been a major change in the textile industry in the US as you might know. Most of the textile goods that are used in the US come from offshore. So the amount of research that is done in textiles in the US is a lot less than it used to be in the sixties and seventies" [282]. Figure 85 illustrates the point. Since the mid 1970s, there has been a decline in the number of publications on rayon coming out of US institutions. A growing number of publications, however, can be observed from Asian countries as the textile industry has migrated to these nations.

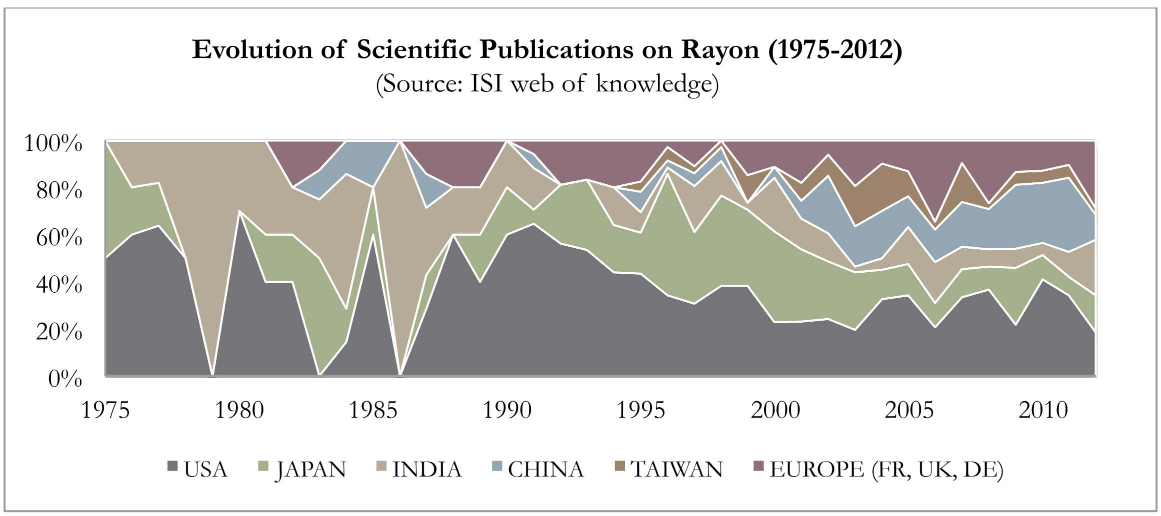


FIGURE 85: EVOLUTION OF SCIENTIFIC PUBLICATIONS ON RAYON

During the 1980s and 1990s, the demand for rayon in the US began to grow, fueled by several trends. Rayon found niche applications in children clothing, sports gear, working garments, and home furnishings such as curtains. The supply of cotton, one of rayon's rival fibers, also became limited due to increased competition of land for food production. Companies began marketing rayon as an environmentally friendly and biodegradable product and thus were able to differentiate their product from oil-based synthetic fibers [283].

During the 2000s, the cellulosic fibers industry continued to expand, and Weyerhaeuser began offering three different types of dissolving grade pulps for textiles: Peach 426, Pearl 428, and Meltblown Lyocell, which is a non-woven textile fabric. To produce these cellulosic fibers, Weyerhaeuser has relied on their internal knowledge and also began exploring collaboration opportunities with universities in Europe. As explained by a senior scientist: "there is some internally generated knowledge, and then we look at what at what some of the universities in Europe are doing. I don't think there is a lot of activities in the US universities in the area of textiles" [282].

As illustrated in this textile case, as the industry moves overseas, the locus of innovation shifts to the countries where the industry relocates. In cellulosic fibers, most of the research is now being conducted in Asian or European universities. This imposes challenges for firms seeking to build new technological competencies. If the locus of innovation is overseas, firms need extra resources or need to form international alliances to regain their technological competencies; Weyerhaeuser has recently signed a joint venture with the Lenzig Group to build a nonwoven textile facility in Austria.

The same trend of technological decoupling was observed in lignin production. Weyerhaeuser produced lignin during the 1940s and 1950s, but stopped after petrochemicals became widely available. Weyerhaeuser thus focalized on other products, changed its research interests and modified its university relationships accordingly. Recently, however, the company is reinvesting in lignin production and had to rely on international partners to update its knowledge base. Weyerhaeuser is currently working on a consortium called Lignoworks, led by several Canadian universities with expertise in lignin production. The goal of the consortium is to created lignin-based technologies for replacing fossil fuels and chemicals.

CHANGES IN STRATEGY MODIFY RECRUITING ROUTINES

The Weyerhaeuser case also illustrates how changes in the firm's strategy affect the firm's hiring routines, which historically have been an important conduit for establishing new university relationships. During the 1950s Weyerhaeuser began offering scholarships at leading universities as a means to stimulate the formation of new graduates in forestry and pulp and paper chemistry. This scholarship program was an important recruiting mechanism for Weyerhaeuser. Universities, in turn, also benefited from these funds and created pulp and paper foundations and research programs in areas relevant for the forest products industry.

Changes in the firm's strategy, however, affected the firm's recruiting routines. During periods of focalization, for example, Weyerhaeuser reduced hiring and reduced the funding given to universities for these purposes. As explained by a senior technology manager, after the economic downturn of 2007 "we have squeezed and done a lot less hiring, in some areas no hiring, and we have lessened and squeezed those university relationships that had funding" [270].

After the period of focalization, firms begin establishing university relationships and "place[ing] strategic investments with universities for the purpose of hiring" [270]. However, if the company decides to grow into new areas and/or diversify their knowledge base, they change their recruiting routines and allocate funds to different universities. In cellulose fibers Weyerhaeuser is moving towards value added products such as lignin, textiles, and composite plastics and the company has changed its hiring routines. As explained by a senior technology manager: "we have gone to totally new places that we haven't hired from before and we are also hiring in different ways. For example, we are going to global conferences, for example American Chemical Society (ACS). We go to all the sessions and listen to student presentations and we find graduates from different disciplines to hire them. This is a very different from the approach we took in the past. For example, we used to call Professor X at University Y and ask: 'who do you have?' We still do that, and that's a great way to find great students, but we are also doing the 'wow, that is an area I hadn't heard about and that's a great student. Lets pursue that college or individual.' Thus our search is a lot broader because we are hiring people with biomedical background. Why do we do that? Well, because they just bring a different skill set, different perspective" [270].

New hires are instrumental in solidifying these new university relationships. As explained by this senior manager: "If you found a really great student and you were very impressed by them and you wanted to have any longer term relationship with their department, then fine (we would pursue that strategic partnership) [270]". Weyerhaeuser has established new university collaborations that started after the recruitment of a university graduate.

TECHNOLOGY LIFECYCLES AND CHANGES IN R&D

Finally, the Weyerhaeuser case also illustrates how the technology's lifecycle affects the firm's research priorities and the locus of innovation for the firm. During the 1960s, Weyerhaeuser became active in adhesive and polymer research through the acquisition of Martin Marietta's R&D group. As the technology matured, however, the company reduced the amount of research conducted in this area. As explained by a senior research scientist "we had a lot of activity in adhesives and at that time adhesives were a developing technology. When it matured, however, the level of emphasis came down" [282]. As shown in the analysis of the firm's university relationship along the value chain (section 3.1), we observed that most of the company's publications in the areas of resins and adhesives were old.

The same technological lifecycle trend is observed in pulp mill environmental technologies. During the 1970s, 1980s, and early 1990s, Weyerhaeuser invested heavily on research aimed at reducing the effluent emissions of their pulp mills to reduce chlorine dioxins created as a byproduct of the pulp bleaching process. The invention of Elemental Chlorine Free (ECF) and Totally Chlorine Free (TCF) bleaching processes during the early 1990s, which became the dominant technologies for bleaching pulp, changed the Weyerhaeuser's research priorities in this area. As explained by a senior scientist "we were very active in that process so that we can meet the environmental standards. And now that we have met these standards, there is less emphasis on that area"[282].

The locus of innovation also changes after a dominant technology is developed. Researchers at the University of Toronto initially developed the Elemental Chlorine Free bleaching process. Equipment manufacturers, however, were in charge of diffusing this technology across the industry. As explained by a company manager, if Weyerhaeuser patents a new pulping process, it would be very difficult to obtain the returns of the investment in a 20-year period by applying that technology to 4 or 5 mills "maybe there are 400 pulp mills that could use that technology world wide but you are going to use it in 4, so again, it is equipment manufactures they have more incentives to really gain a return on those types of gigantic R&D investments. That doesn't mean that small tweaks or things that impact how you work with purchased equipment can be done, but the giant industry-changing technologies are really best left to the equipment suppliers" [270]. Since it is difficult for an individual firm to appropriate the returns of R&D investments in pulping technologies because of a problem of scale, the task of developing and diffusing these technologies is left to equipment manufacturers.

REGIONAL COEVOLUTION AND RESEARCH SPECIALIZATION: THE CASE OF THE WOOD MATERIALS AND ENGINEERING LABORATORY AT WASHINGTON STATE

Weyerhaeuser has built strong relationships with universities close to the company's manufacturing sites. This is not a coincidence, but the result of the coevolution of the universities research agendas in response to the needs of the industry. The case of the Wood Materials and Engineering Laboratory (WMEL) of the College of Engineering and Architecture at Washington State University is useful to illustrate the point.

During the 1940s, the state legislature of Washington established the Washington State Institute of Technology. Initially, the Institute had a College of Engineering, a Division of Industrial Research, and a Division of Industrial Services with the explicit goal of assisting the technical and economic development of the state of Washington.

During the late 1940s a Wood Technology Section was formed with the goal of creating a pulp and paper research program to assist the regional industry. In 1950, however, the director of the laboratory realized that developing a pulp and paper research laboratory would be expensive and hard to fund, given that the University of Washington at Seattle had already developed a strong research capability in this area. He thus concentrated on wood technologies: particleboard, fiberboard, oriented strand board (OSB) and medium density fiberboard technologies, which became the initial core research areas of the Wood Materials and Engineering Laboratory (WMEL).

Initially, about half of the funding for research came from the state of Washington and the other half from external grants and contract research projects [284]. Since its origins the WMEL has held close relationships with industry. With Weyerhaeuser the WMEL has contributed with different technologies including the creation of engineered structures such as I-beams, the development of new composite wood building products such as OSB and fiberboards, and the development of the Stored Heat system for gluing, which is used by Weyerhaeuser for the rapid curing of glue joints. Weyerhaeuser has actively supported this laboratory; in 1985, Weyerhaeuser contributed with funds for enlarging the laboratory and in 1994, Weyerhaeuser endowed a Professorship to this laboratory and offered graduate scholarships [284].

APPENDIX VII: STORAENSO

1. INTRODUCTION

StoraEnso is a large manufacturer of forest products including pulp, paper, packaging, and building materials (e.g. joinery, engineered woods, housing systems). The company is organized around four business areas: Biomaterials, Printing and Reading, Renewable Packaging, Building and Living. In 2012, StoraEnso achieved €10,815 Million in sales and employed 28,000 people worldwide. The company is headquartered in Helsinki, Finland, and in Stockholm, Sweden, and has production plants in 35 countries [285].

Figure 86 presents an overview of StoraEnsos's sales and R&D expenditures versus time. The company has historically spent between 0.6% and 0.8% of sales in R&D, which is in the high-end of the companies in our sample. The growth in sales occurred in 1998 was the result of the merger of Enso a large Finnish firm with Stora, a large forest product company from Sweden. The result was a new company named StoraEnso.

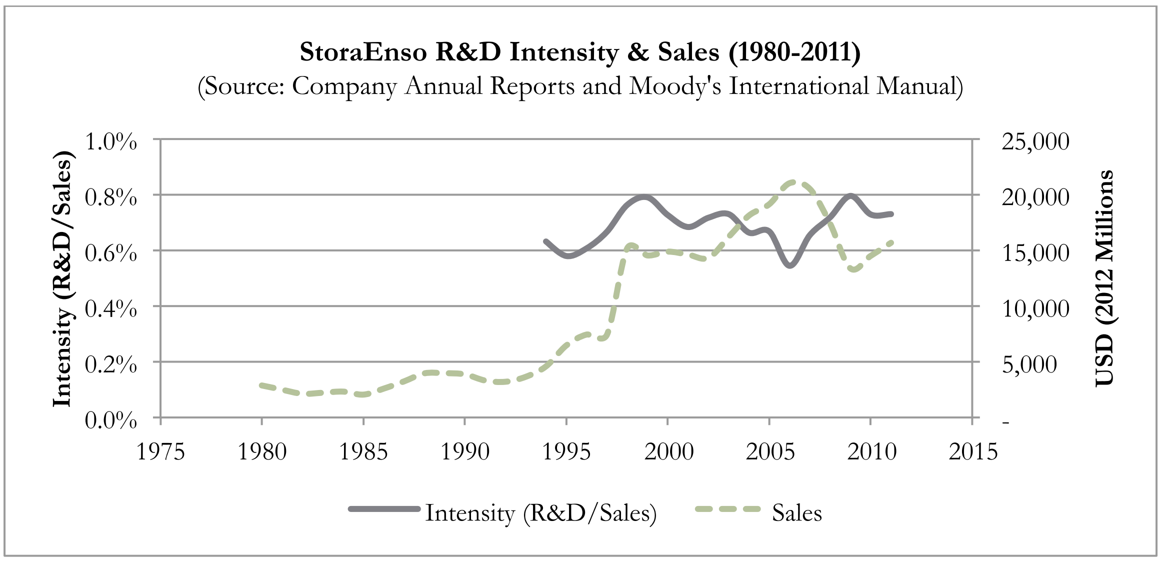


FIGURE 86: EVOLUTION OF STORAENSO R&D INTENSITY

This case study presents a longitudinal review of changes in (i) the company's businesses, (ii) research strategy and (iii) connections to universities and public research institutes during each strategic period of the firm.

Section 2 characterizes the different strategic periods of StoraEnso. Section 3 describes the origins and evolution of the firm's university relationships as judged by changes in the research priorities of the firm, changes in the firm's university network, and people flows between partnering institutions. Section 4 summarizes the main findings and lessons.

2. Historical Changes in Company Strategy

Data on StoraEnsos's strategy was obtained by analyzing the company's annual reports and secondary sources of information, including journals, press articles, and company historical retrospectives. We also conducted one on-site interview with a senior manager of the firm. Based on the data, we defined 8 different strategic as in the left hand side of Figure 87, which tended to coincide with changes in the CEO of the firm. The right hand side of the figure shows the strategic trajectory followed by StoraEnso.

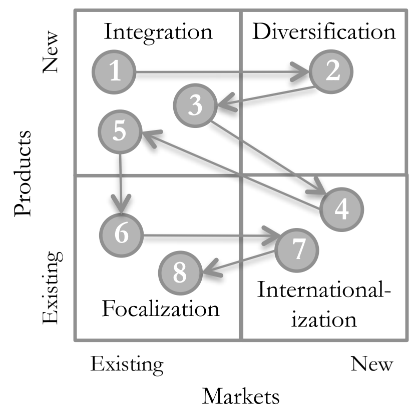
Strategic Periods	**Strategic Trajectory**
Period 1 (1872-1917): Integration into pulp and paper	
Period 2 (1918-1944): Diversification into unrelated industries	
Period 3: (1945-1961): Integration into engineered woods and packaging	
Period 4 (1962-1972): Internationalization into Europe	
Period 5 (1973-1982): Integration into engineered woods	
Period 6 (1983-1988): Focalization and divesture of unrelated business lines	
Period 7 (1989-2006): Internationalization into North and South America	
Period 8 (2007-Onwards): Focalization and regional concentration	

FIGURE 87: STORAENSO'S STRATEGIC PERIODS

Period 1 (1872-1917): Integration into pulp and paper

In 1872, Hans Gutzeit, a Norwegian industrialist, built the first Finnish steam-powered sawing mill on the island of Kotka. This location provided good access to logs that were floated down the Paijanne lake system. Increased competition for this raw material prompted the company to vertically integrate acquiring 100,000 hectares of forestlands in Saimaa through the acquisition of Utra Wood Co [286].

In 1896, the company was incorporated as Aktiebolaget W. Gutzeit & Co, and began producing sulfate pulp from waste wood at the Kotka mill. In 1909, Gutzeit acquired Pankakoski, a firm in Karelia that produced groundwood pulp, and added a board mill to this facility. In 1912, Gutzeit acquired Enso, a company that produced pulpwood, paper, and had several hydropower stations in Finland. In 1913, the company acquired 70,000 hectares from the Finland Wood Co, to increase the supply of raw materials. By 1915, Gutzeit was a vertically integrated forest company with presence in the sawn timber, board, pulp, and paper markets [286].

PERIOD 2 (1918-1944): DIVERSIFICATION INTO UNRELATED INDUSTRIES

In 1917, Alexander Gullichsen, the managing director of Gutzeit died [286]. Finland became an independent country that year, and in 1918 the Finnish government acquired a majority stake in Gutzeit, naming Solve Thunstrom as managing director of the firm. During this period, the company began diversifying into packaging, chemicals, ship building industries, and furniture industries.

In 1920, Gutzeit formed a naval taskforce and began construction of a fleet to procure and transport wood through the Saimaa Lake. For these purposes, Gutzeit built a shipyard and a machine shop near Savonlinna. In 1922, the company acquired Konetehdas Oy, a mechanical engineering firm to build and repair the fleet [287].

In 1924, Thunstrom left Gutzeit and V.A. Kotilainen became managing director of the firm. Under his tenure, the company continued expanding into sulphate pulp and sawn timber. In 1927, the company was renamed Enso Gutzeit, and moved their headquarters to the town of Enso, near the Russian border. In 1931, Enso Gutzeit acquired Tornator, a manufacturer of sulphate pulp, and greaseproof paper. After this acquisition, the company became the largest paperboard manufacturer in Finland, and one of the largest landowners, with more than 500,000 hectares of forestlands in 1939[286].

In 1937, Enso Gutzeit began manufacturing bleaching chemicals, and in 1940, the company began producing packaging boxes. In 1941, Enso acquired Insulite Co, a company that produced board made from Aspen fibers, and in 1945 the company entered the furniture business through the acquisition of a company in Lahti [286].

In 1939, the Soviet Union invaded Finland. Enso Gutzeit lost several of its production sites, including its headquarters in the town of Enso and 100,000 hectares of forestlands. Several of the company's sawmills were burnt or destroyed during WWII [286].

PERIOD 3 (1945-1961): INTEGRATION INTO ENGINEERED WOODS AND PACKAGING

In 1945, William Lehtinen became CEO of Enso Gutzeit and started rebuilding the company. As War reparations, the Soviet Union demanded Finland to pay in prefabricated houses and machinery, which became a growth opportunity for Enso Gutzeit. To supply this demand in 1946, Enso acquired the Joh Parviaisen Company, a manufacturer of plywood, engineered woods, and prefabricated houses. The company also utilized the machine shops from its naval yard to produce machinery for the Soviets [286].

In 1947, Enso founded Merivienti Oy, to build a transportation fleet for exporting goods to Europe. This company, later renamed Finnlines, also began exporting goods to the US in 1948, and grew in size through the acquisition of new ships [286].

During the 1950s, Enso expanded the production of paper, pulp, and converted products by building Europe's largest paper machine in Kaukopää, a Kraft paper machine in Kotka, a newsprint machine in Summa, and a box-making plant in Lahti. The company also built a bleaching plant in Kaukopää to produce white board for consumer goods packaging, and in 1961 they built a paperboard machine for white milk containers [286].

PERIOD 4 (1962-1972): INTERNATIONALIZATION INTO EUROPE

In 1962, Pentti Halle became CEO of Enso after the retirement of Lehtinen. The company moved its headquarters to Helsinki, and began a period of internationalization in Europe and the US. In 1965, the company acquired Roermond, a Dutch paper manufacturer. In 1968, Enso Gutzeit formed joint venture to build a pulp and linerboard mill in Pineville, Louisiana. In 1970, Enso formed Eurocan, a Joint venture with other Finnish firms to produce pulp and paper in British Columbia. In 1972, the company acquired Stanley Rose, a paper products manufacturer in the UK [286]. In 1971, Enso sold its Dutch paper operations, and in 1973 it sold the linerboard plant in Louisiana [288].

During this period, the company entered the housing market through the acquisition of the Säynätsalo factory in 1971 [289]. Halle retired as CEO of Enso in 1972, and Olavi J. Mattila took his place naming Pentti Salmi as managing director of the company [286].

PERIOD 5 (1973-1982) INTEGRATION INTO ENGINEERED WOODS

The 1970s were difficult times for the pulp and paper industry worldwide due to the oil crisis, and Enso Gutzeit expanded its manufacturing base in engineered woods through the acquisition of Toisvesi Oy (sawmill) and Liimappu Oy, a manufacturer of laminated engineered woods (glulam). In 1975, the company opened a plywood mill in Heinola, and in 1977 the company revamped its pulp and paper plants in Kaukopää [289].

PERIOD 6 (1983-1988): FOCALIZATION AND DIVESTURE OF UNRELATED BUSINESS LINES

In 1983 Pentti Salmi became CEO of Enso Gutzeit and focalized in pulp and paper, which led to divesture of unrelated businesses. In 1982, Enso sold Finnish Chemicals, and several of the company's forestlands. In 1983, Enso Gutzeit divested several of its power plants, mainly to Imatran Voima Oy. In 1986, Enso exited the shipping business, and sold the machine shops in Savonlina. In the 1990s, Enso Gutzeit divested the plywood business to the Kymmene group and the housing business to Novera [289].

During this period, the company expanded its operations in paper and packaging through several acquisitions, including Ahlstrom's pulp, paper, and sawmill plants in Varkaus in 1986 [286].

PERIOD 7 (1989-2006): INTERNATIONALIZATION INTO NORTH AND SOUTH AMERICA

In 1988, Jukka Härmäla became managing director of Enso Gutzeit and expanded the geographical operations of the company. In 1989 Enso formed a joint venture with the Soviet Union to produce pulp in Uimaharju. The new company, Enocell Oy, started operations in 1992. In 1993, Enso built a plant for producing newsprint from recycled papers in Germany (Sachsen Papier) and acquired Tampella's forest products and packaging operations in Finland. In 1995, Enso acquired Veitsiluoto, another Finnish papermaker controlled by the state, and in 1997, Enso Gutzeit acquired a controlling stake in E. Holtzmann & Cie AG, a large German manufacturer of newsprint and magazine paper [289].

In 1998, Enso Gtuzeit merged with Stora, a large forest products company from Sweden. The resulting company, named StoraEnso, became Europe's largest forest company and the world's second largest production capacity after International Paper. Härmäla remained as CEO of the company and continued expanding its geographical presence. In 1998, the company acquired the Suzhou Papyrus Paper Co for targeting the Chinese market [286].

In 2000, StoraEnso announced a 5-billion euro acquisition of Consolidated Papers, a large US manufacturer of magazine and coated papers based in Wisconsin [289], but the recession of 2000 forced StoraEnso to restructure its US operations, closing several mills, and reducing its production capacity. In 2002, the company divested most of its forestlands in Europe, the US and Canada [286].

After the bad experience of acquiring Consolidated Papers, StoraEnso expanded into emergent markets. In 2003, the company acquired a sawmill in Estonia and packaging producer in Poland. In 2005, the company started producing eucalyptus pulp in Brazil through a joint venture with Aracruz Celulose SA. The company also bought forestlands in Uruguay, Brazil, and China. StoraEnso acquired Papeteries de France in 2005 and the Schneidersohne group, a German paper merchant [286].

PERIOD 8 (2007-ONWARDS): FOCALIZATION AND REGIONAL CONCENTRATION

In 2007, Jouko Karvinen became CEO of StoraEnso. The company was in a tight financial situation and his focus was on fiber-based packaging, plantation-based pulp, and selected paper grades. In 2007 StoraEnso divested its North American operations (US and Canada), and in 2008 it divested Papyrus, its paper merchant. The company also closed several European mills and reduced its manufacturing capacity in Finland to focus on emerging markets such as Russia, Brazil, Uruguay, and China [290]. In 2009, StoraEnso formed a joint venture with Arauco, a Chilean forest products firm, to acquire ENCE, a company with more than 130,000 hectares of eucalyptus plantations in Uruguay.

In 2009, StoraEnso was restructured and the company reduced the number of business areas. The publication papers, newsprint, book papers, and magazine papers divisions were merged as were the industrial packaging and consumer board divisions. The company concentrated on four business areas: packaging, publication papers, fine papers, and wood products [291]. In this last business area, StoraEnso has moved up the chain into value-added wood products. In 2008, the company opened a cross-laminated timber (CLT) mill in Austria, and in 2010 they acquired Eridomic, a manufacturer of roofing, walls, floors, and housing solutions made from CLT. In 2010, StoraEnso launched a new corporate philosophy named "rethink" to symbolize the change in practices the company needed to achieve in order to remain competitive in he forest products industry [292]. .

3. The Origins and Coevolution of StoraEnso's University Relationships

When Hans Gutzeit built the first steam-powered sawmill in Finland in 1872, there was little research conducted at local universities and all of the technology as well as the people in charge of building and operating Gutzeit's sawmill mill came from Norway [293]. Finland, at the time, was a Grand Duchy attached to Russia. Increased demand from the Russian Empire helped growing the Finnish sawmilling industry [294].

At the beginning of the 1900s, Gutzeit began to vertically integrate into forestry through the acquisition of the Utra Wood Co in 1902 [286]. After the acquisition, the company formed a forestry department and began hiring foresters to survey and manage the company's timberlands [287]. At the time, Finland had a Forestry Institute located at Evo, but no formal university faculty were in charge of conducting research on forestry. In 1902, the first faculty of agriculture was formed, and in 1909 the Finnish government moved the Forestry Institute of Evo to the University of Helsinki to enable graduate degree programs and increase the scientific content of forestry education. The first Masters student in Forestry graduated in 1911, and the first PhD dissertation in forestry was defended in 1912 [295]. During this period Enso-Gutzeit formed the first university connection by providing funds to the Finnish Forestry Society, formed in 1909 in close collaboration with the School of Forestry of the University of Helsinki [295]

World War I and the independence of Finland from Russia in 1917 triggered a transformation in the Finnish forest products industry with the result that several firms and universities began to develop in-house knowledge on forestry and forest products. In 1918 the State Forest Service of Finland was formed and Prof. A. K. Cajander from the forestry school of the University of Helsinki became its first director. That year, the Finnish government became the major shareholder of Enso-Gutzeit, which increased the exchange of people between the company and other state-owned academic institutions. Professor

Cajander, for example, was named by the government as member of Enso-Gutzeit's board of directors between 1931 until his death in 1943 [287].

During the 1920s, Enso-Gutzeit created a naval division to coordinate the company's ship fleet and transportation system. Gutzeit also created a machine shop to repair the fleet, which began producing machinery for the pulp and paper industry during the 1930s [287]. We could not find any evidence that the formation of these diversified businesses led to the formation of new university connections during the 1920s-1930s era.

UNIVERSITY RELATIONSHIPS AFTER WWII

WWII had multiple consequences for Enso-Gutzeit and for the Finnish higher education system. In 1942, the Finnish Government created a State Technical Research Center (VTT), to conduct research at the request of companies and other organizations. VTT initially had 10 research lines including building technology, wood technology, and chemical engineering, all of which conducted research relevant for Enso-Gutzeit. VTT's research facilities were located in close proximity to the Helsinki University of Technology, and several of VTT's lab directors were professors from this university [296]. Enso-Gutzeit has worked on multiple projects with researchers at VTT since then.

During the 1950s, Enso-Gutzeit formed a technical department to coordinate the activities of the engineering division (pulp and paper machinery, shipyards) and the company's research laboratory [287]. During the postwar period, the company placed increased emphasis on the production of chemical byproducts from the firm's pulping operations [287]. During the 1960s, Enso-Gutzeit forged new collaborations with the technical university of Helsinki (now Aalto University) on wood grading technologies [297] and with the Keskuslaboratorio-Centrallaboratorium (currently called KCL) on pulp and paper manufacturing. Enso-Gutzeit along with four other Finnish forest products companies owned and funded KCL.

In 1967, Enso-Gutzeit formed a joint venture with the Valmet Corporation to create a new research center in Imatra to develop new paper grades, and for improving pulp and paper machinery and production processes [287]. In 1973, an environmental research unit was added to the Imatra laboratory, which developed the Enso-biox process to treat odorous emissions in the pulping process and also helped improve the company's bleaching process [298].

During the 1970s, Enso-Gutzeti's research laboratory concentrated on the food packaging industry, particularly bleached pulps, liquid packaging and aseptic cartons. During the 1980s, the Imatra research center conducted research on food packages and printing papers. The company launched Solaris, a thin coated semi-glossed magazine paper developed by the Imatra research laboratory [298]. The number of employees of the Imatra laboratory increased to reach 160 people in 1990 [287].

University relationships after the merger with Stora

In 1998, Enso-Gutzeit merged with Stora from Sweden. This last company had a research center located at Falun, Sweden and a research center in Viersen, Germany, both of which had research connections with universities in Sweden and Germany. As a result of the merger, Stora-Enso gained an increased network of university partners in different research fields.

Figure 88 shows the different industrial sectors in which the company has been active and the number of university articles within each sector. As shown in the figure, since the 1980s the number of publications between Enso-Gutzeit and its university partners has grown, especially in the area of pulp and paper products.

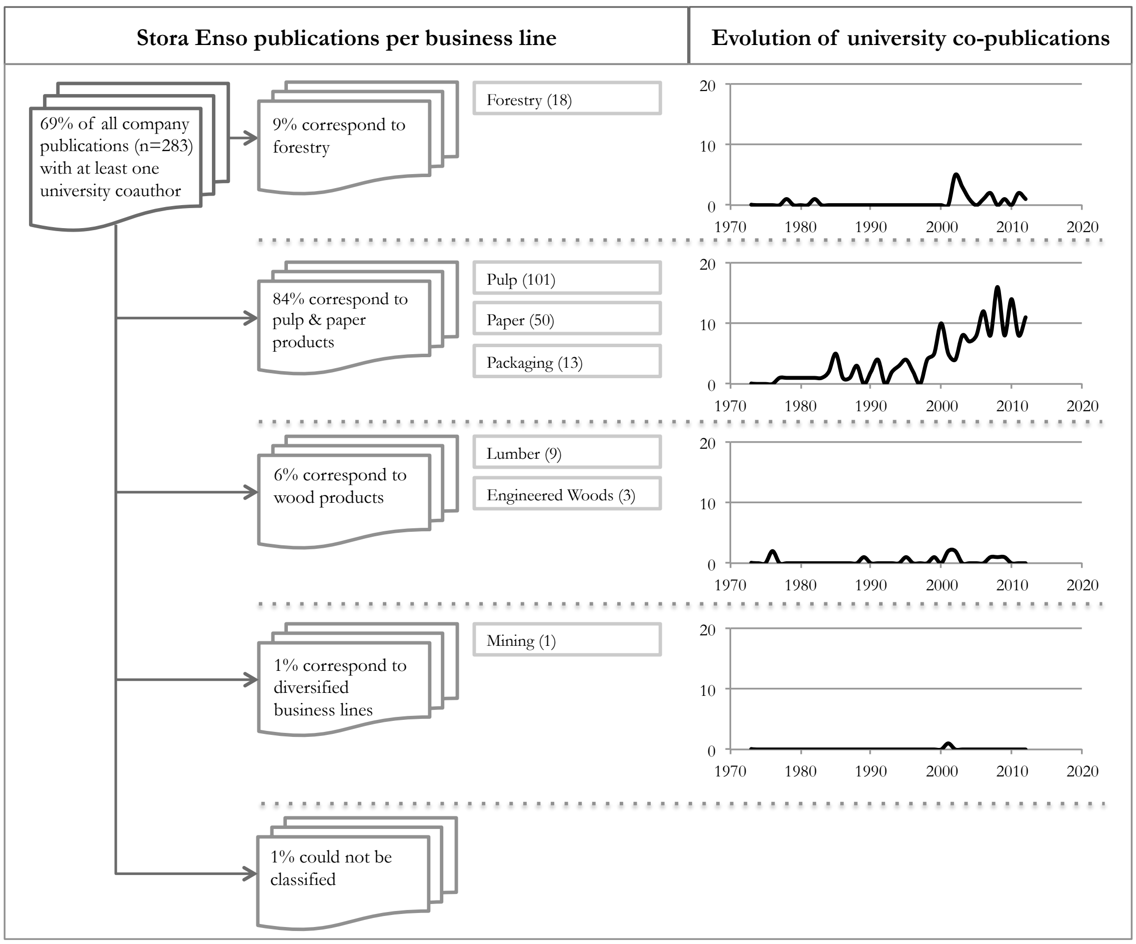


FIGURE 88: COEVOLUTION OF UNIVERSITY CO-PUBLICATIONS AND STORAENSO'S BUSINESS LINES

Figure 89 shows increase in the number of publications with universities after the merger between Stora and Enso in 1998. The figure also indicates a recent decline in publications since 2007, consistent with the focalization strategy of the firm.

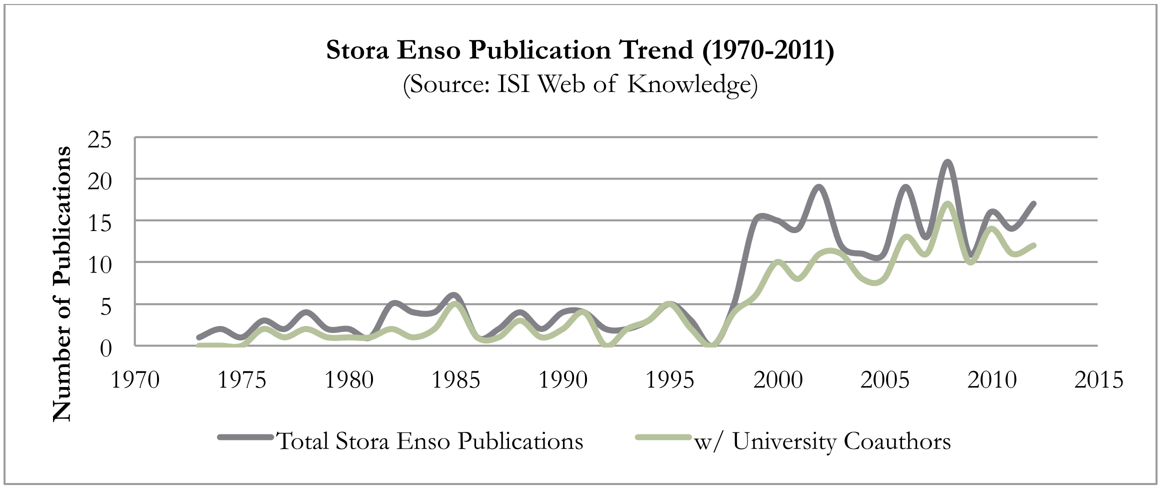


FIGURE 89: STORAENSO PUBLICATION TREND

3.1. Research priorities along StoraEnsos's value chain

We have organized StoraEnso's university relationships from a value chain perspective, distinguishing between (i) forestry, (ii) pulp and paper, (iii) packaging, (iv) timber products and (v) engineered woods value chains. Figure 90 shows the different processes involved in the forestry value chain. Most of StoraEnso's university co-publications in forestry have been in the area of forest yield management (e.g. growing, fertilizers).

The most common university partners in the area of forestry have been the University of Helsinki, the University of Turku (Finland), the Technical University of Lisbon, the University of Aveiro, and the University of Coimbra (Portugal). The relationship between Stora and the Portuguese universities dates from 1984 after Stora acquired Billerud, a Swedish company with eucalyptus plantations in Portugal. StoraEnso has established relationships with universities in China and with the Chinese forest service for improving the company's eucalyptus plantations in that country.

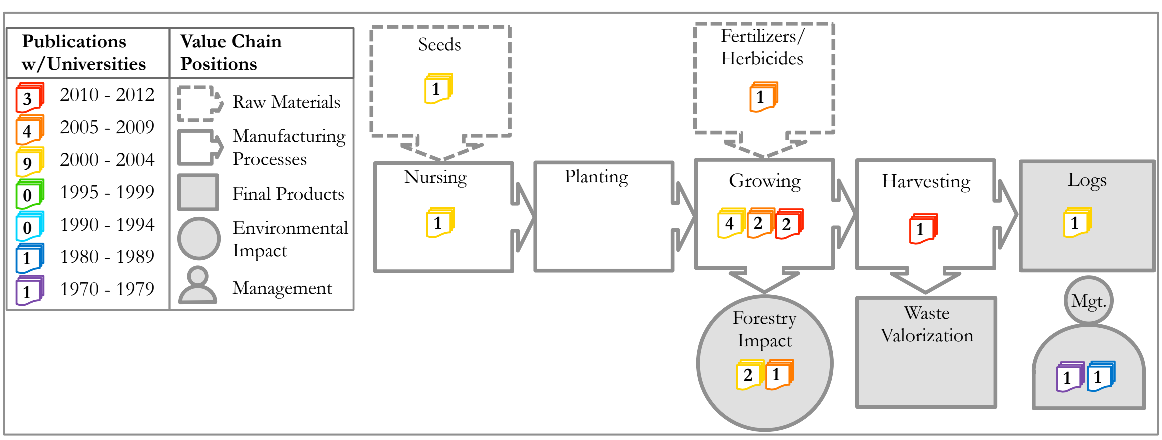


FIGURE 90: EVOLUTION OF STORAENSO'S UNIVERSITY CO-PUBLICATIONS IN FORESTRY

The pulp and paper value chain constitutes most of StoraEnso's university relationships. Figure 91 shows the different processes involved in pulp and paper production. We organized the different co-publications according to these different processes, and found that the firm's university interactions concentrated on pulping, waste management, fine papers production (e.g. furnishing, coating, calendaring), and operations management (e.g. HHRR management). An example is SoraEnso joining UPM-Kymmene and the Paper Converting Institute of the Tampere University (Prof. Antti Savolainen) to conduct research at developing new barrier-coated and barrier-laminated products such as food packages [299].

University partners in the area of pulp and paper production have been the University of Oulu, Abo Akademi University, University of Helsinki, the Finnish Institute of Occupational Health, and Aalto University in Finland, and Karlstad University, Lund University, and the Swedish Forest Research Institute (STFI) in Sweden.

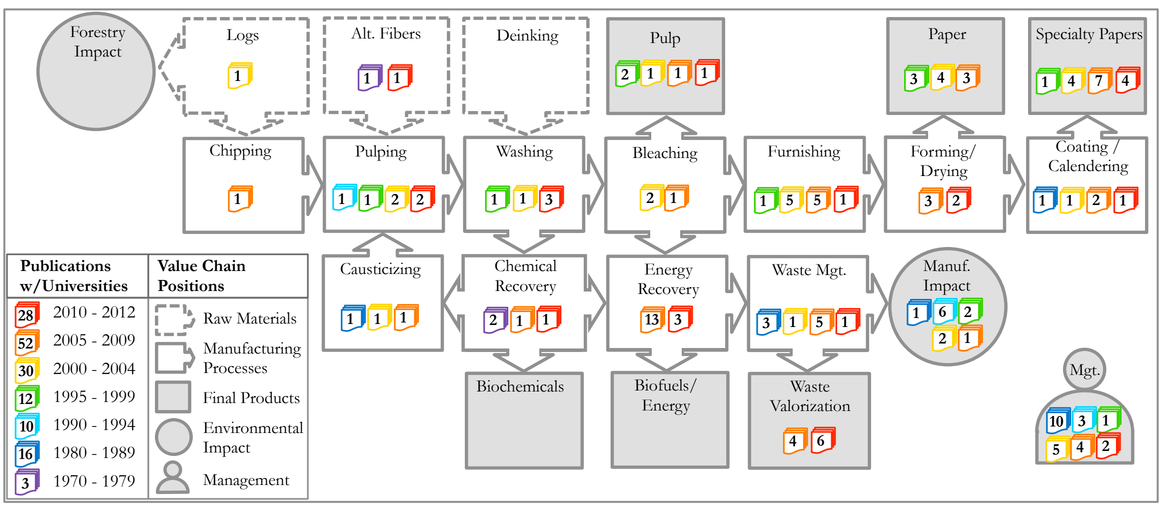


FIGURE 91: EVOLUTION OF STORAENSO'S UNIVERSITY CO-PUBLICATIONS IN PULP AND PAPER

Figure 92 shows the different processes in containerboard and packaging production. We organized the different co-publications according to these different processes, and found that most of the firm's university interactions have been on assessing the quality (e.g. strength properties) of their packages. StoraEnso's most frequent university partners in the area of packaging have been Aalto University and the University of Tampere in Finland.

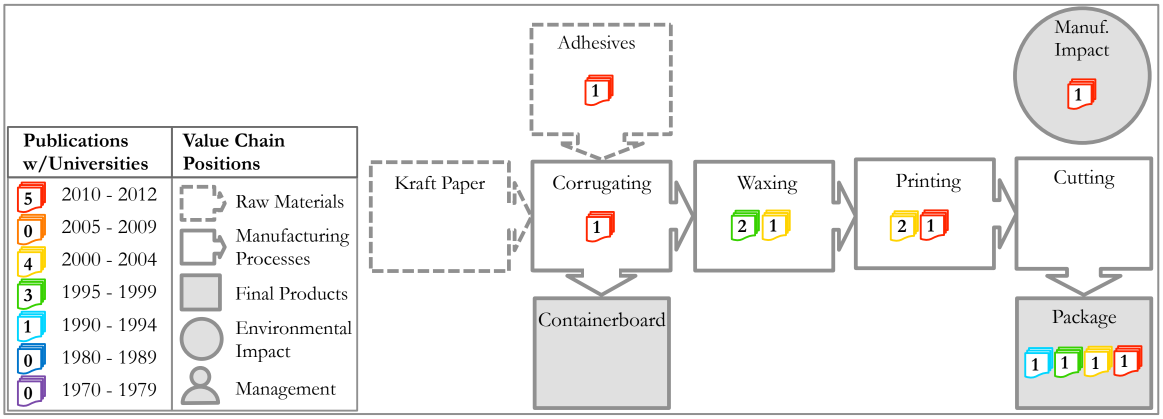


FIGURE 92: EVOLUTION OF STORAENSO'S UNIVERSITY CO-PUBLICATIONS IN PACKAGING

Figure 93 shows the different processes in the manufacture of lumber and wood structures. We found that most of the firm's university interactions have been on assessment of the environmental impact of the firm's operations and technologies aimed at improving the grading process of wood. StoraEnso's most frequent university partners in the lumber and wood structure value chain have been the Luleå University of Technology in Sweden, and the Finnish Institute of Occupational Health.

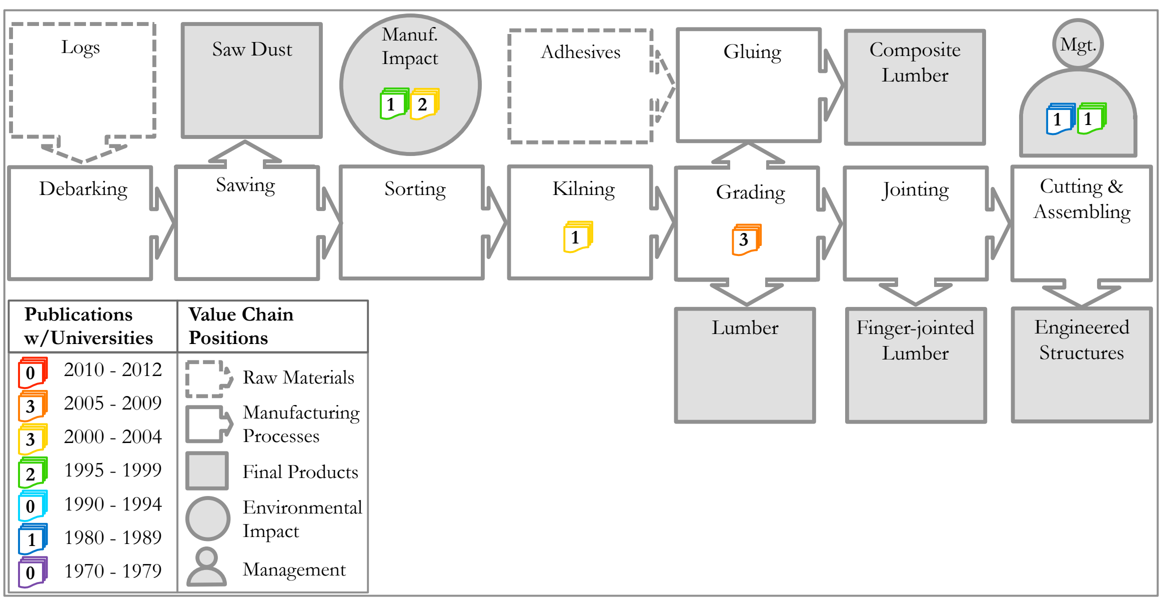


FIGURE 93: EVOLUTION OF STORAENSO'S UNIVERSITY CO-PUBLICATIONS IN TIMBER PRODUCTS

Figure 94 shows the different processes involved in the manufacture of veneer and engineered woods. We found only three publications one involving resins, one regarding the quality of veneers, and one regarding the coating and sealing process of plywood manufacture. These publications were coauthored with researchers at the University of Helsinki, and the Royal Institute of Technology (KTH) of Sweden.

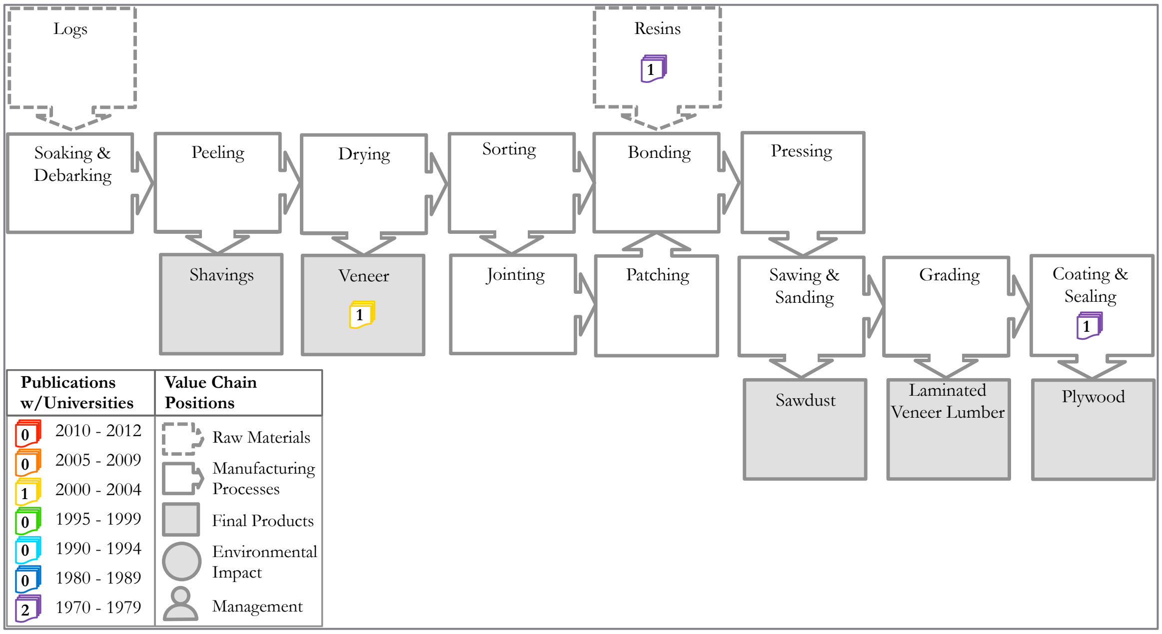


FIGURE 94: EVOLUTION OF STORAENSO'S UNIVERSITY CO-PUBLICATIONS IN ENGINEERED WOODS

3.2. Geography of university partners

Figure 95, based on StoraEnso's publication records, shows the geographic distribution of the company's local university network was originally in Finland, but after the merger with Stora, there was formation of new university connections in Sweden, where the company has different R&D labs and production sites. StoraEnso opened a new research center in Karlstad, Sweden in 1999, in close proximity to the University of Karlstad, which specializes in research related to the forest industry [300].

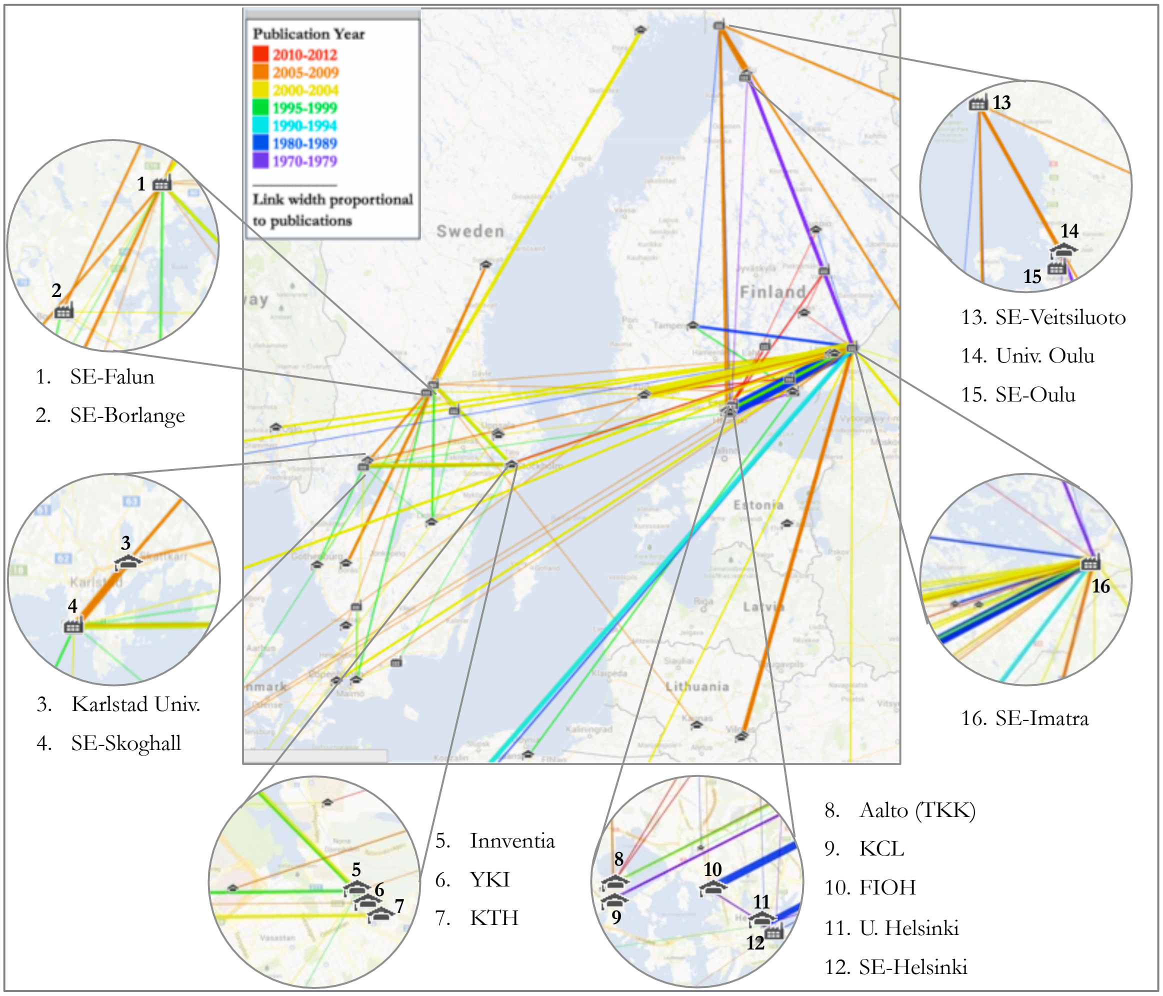


FIGURE 95: STORAENSO LOCAL UNIVERSITY NETWORK

StoraEnso's international university network is smaller and more recent than its Finnish university network. Figure 96 shows a geographical representation of StoraEnso's international university partners based on the firm's co-publication records. Most of the international university collaborations have been created to support the firm's internationalization strategy.

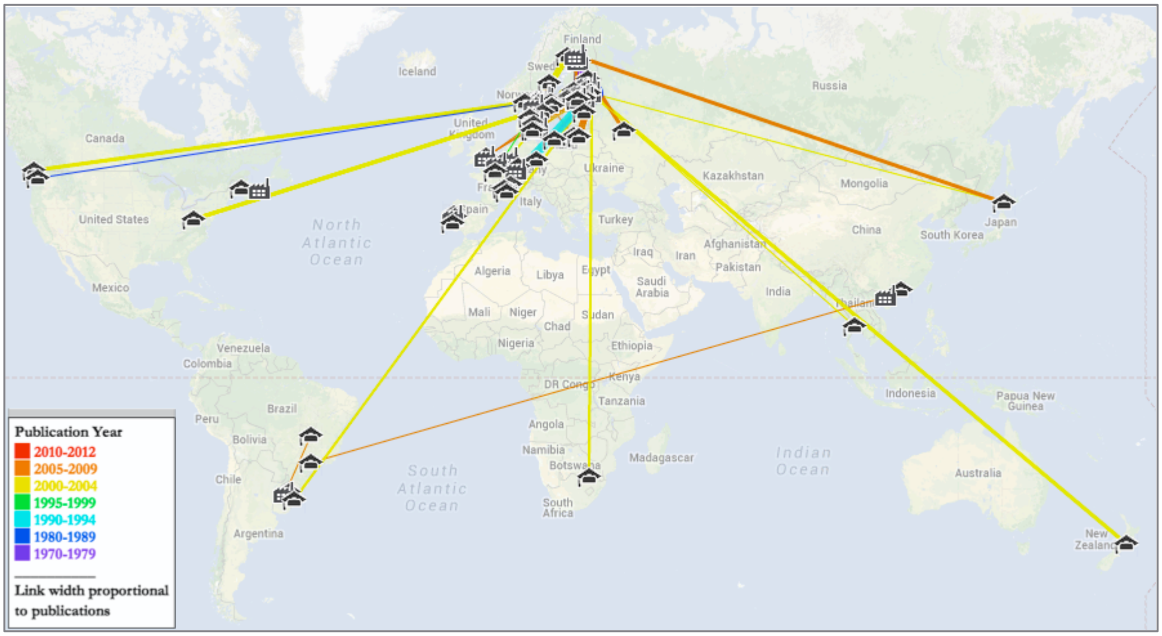


FIGURE 96: STORAENSO'S GLOBAL UNIVERSITY NETWORK

Figure 97 shows the firm's international university collaborators with respect to the company's manufacturing sites. In 2000, StoraEnso inaugurated a new research center in Mönchengladbach, Germany, which replaced the Viersen Research Centre also in Germany. The Mönchengladbach center conducts research on process analysis to improve the efficiency of the company's operations and on recycled fibers [301]. In 2002, the company signed a research cooperation agreement with the Chinese Academy of Forestry in Beijing to support the company's operations in that country [302].

FIGURE 97: INTERNATIONALIZATION OF STORAENSO'S UNIVERSITY PARTNERS

3.3. TECHNOLOGY TRANSFER THROUGH PEOPLE FLOWS

To analyze the academic and professional trajectories of StoraEnso's most prolific authors and inventors we used StoraEnso's publications and patenting records to develop a list of 78 people involved in the company's R&D activities. Each individual in the list has either patented or published at least three papers from StoraEnso's name.

Figure 98 shows the evolution of StoraEnso's research staff. As shown in the figure, most of StoraEnso's R&D personnel were recruited directly from academia. The figure also shows that StoraEnso's R&D personnel peaked in 2005. After leaving StoraEnso, 37% of these researchers joined other firms, and 10% went back to research institutions such as the Lappeenranta University of Technology, the Tampere University, and Karlstad University.

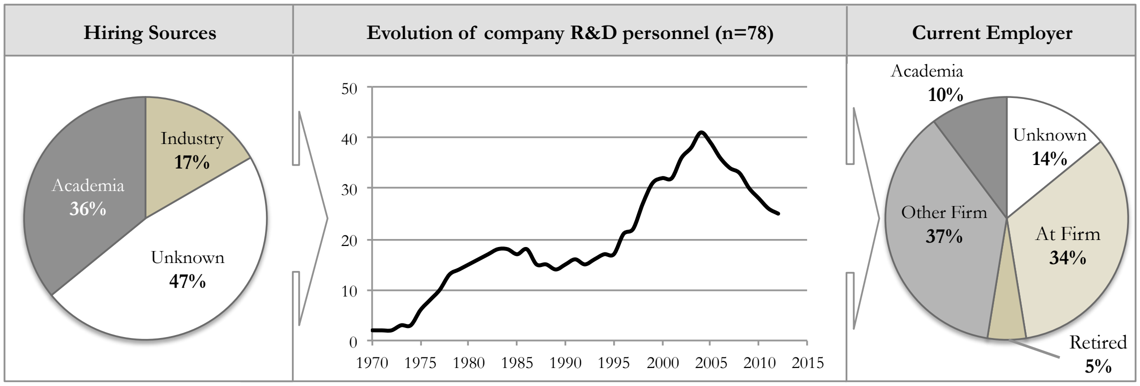


FIGURE 98: EVOLUTION OF STORAENSO'S R&D PERSONNEL

Analysis of the academic training of StoraEnso's researchers shows an overlap between the academic institutions attended by these people and the company's publication partners (See Figure 99). The most common university attended by the firm's R&D personnel is Aalto University, followed by the Lappeenranta University of Technology, the Royal Institute of Technology (KTH), and the University of Helsinki.

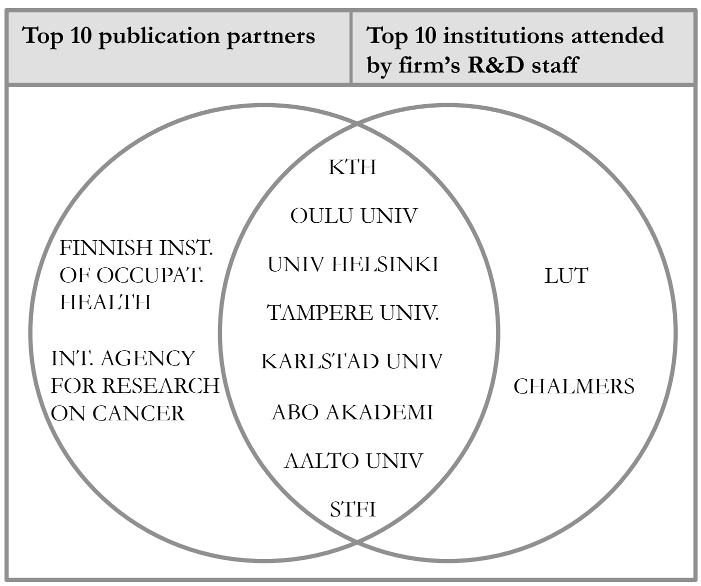


FIGURE 99: OVERLAP BETWEEN STORAENSO'S HIRING AND PUBLISHING PARTNERS

4. Case Study Discussion

StoraEnso has endured several strategic changes and participated in a diverse set of industries and regions over time. Table 18 presents a summary of the findings concerning how StoraEnso's strategy affected its relationship with universities and research institutes. The table shows the different strategic periods of the firm, and how StoraEnso's research priorities, people flows, and institutional networks were modified as a consequence of the observed changes in the firm's strategy.

TABLE 16: SUMMARY OF HOW STORAENSO'S UNIVERSITY RELATIONSHIPS COEVOLVED

University Links / Firm Strategies	Research Priorities	People Flows	Institutional Networks
Period 1: **Integration** (1872-1917)	**Forestry management** • Secure raw material and manage forestlands	**Norwegian technicians** • To build and operate sawmill in Finland **Hired first foresters** • To survey and manage forestlands	**Creation of Forestry programs** • EnsoGutzeit became one of the first sponsors of the Finnish Forestry Society, with close links to the U. of Helsinki
Period 2: **Diversification** (1918-1944)	**Machinery & Engineering** • Machinery for the ship fleet, and pulp and paper production	**Increased hiring of technical staff** • Increased flows from universities to firm facilitated by government ownership of Enso-Gutzeit	**Continuous support to forestry** • Donations to the Finnish Forestry Society, which began offering research grants and scholarships
Period 3: **Integration** (1945-1961)	**Pulp and paper production** • Machinery, chemical byproducts, new product development	**Formation of technical department** • To consolidate research on machinery and forest products	**Creation of new institutions** • 1942 creation of VTT, new links formed with this institute • 1958, creation of Oulu Univ.
Period 4: **Internationalization** (1962-1972)	**New paper grades** • Pulp bleaching • Paper coatings	**New R&D Center in Imatra** • In joint venture with Valmet Corp.	**Formal research collaborations** • With universities in Finland (U. Helsinki, TKK, KCL)
Period 5: **Integration** (1973-1982)	**Environmental research** • Effluent and odorous emission control	**Growth in R&D staff** • Expansion in the university recruitment sources	**Expansion of university links** • New projects with Oulu Univ, Tampere Univ, Turku Univ, and the Finnish Inst. Of Occupational health
Period 6: **Focalization** (1983-1988)	**Food Packaging** • Liquid packaging and aseptic cartons **Worker safety** • Occupational health	**Decline in R&D staff** • Personnel left firm to join other companies	**Occupational health collaborations** • With Finnish regional institutes of occupational health
Period 7: **Internationalization** (1989-2006)	**Fine Papers** • Paper furnishings and coatings **Eucalyptus forestry** • Yield management	**Growth in R&D staff** • Imatra R&D center peaked with 160 people **New Intl. R&D Centers** • Sweden (Falun, Karlstad) • Germany (Mönchengladbach)	**International university links** • New links in Europe after the merger with Stora • New links in Brazil, China, and Germany after acquisitions in these countries
Period 8: **Focalization** (2007-Onwards)	**Energy Recovery** • Biofuels and waste valorization	**Reduction in R&D staff** • Reduction of staff in Finland and Sweden • Closure of Falun R&D Ctr.	**Merger of Finnish Res. Ctr.** • StoraEnso sold shares in KCL, which merged with VTT

Value chain position as an strategic question

As explained by a senior company manager, the most important strategic question is where to sit within the value chain. "If you think about the value chain with consumers at the right side and providers of raw material at the left (see Figure 100), what you see is that those who sit on the raw materials and the ones in the front end [retail] operate with pretty high margins" [121].

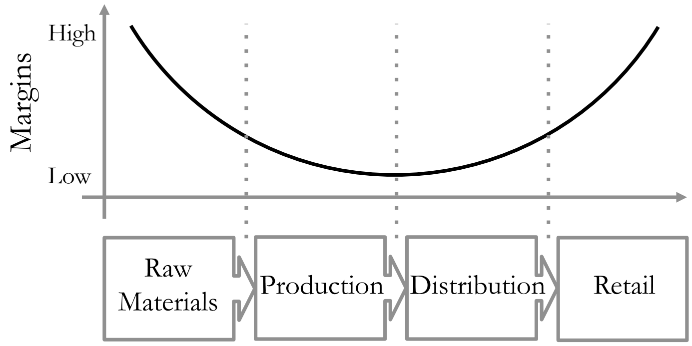


FIGURE 100: RELATIONSHIP BETWEEN VALUE CHAIN POSITION AND PROFIT MARGINS

StoraEnso has moved up and down the value chain shown in Figure 100. As described in Section 2, Enso-Gutzeit was born as a producer of sawn timber products. Around 1900, however, the company moved down the value chain to secure the provision of raw materials. The company later moved up the value chain by producing engineered woods and even prefabricated houses after WWII. During the early 1990s the company again moved down the value chain and divested the engineered woods and prefabricated house divisions. Currently, the company is moving again up the value chain, by producing engineered woods (e.g. cross-laminated timber) and even urban multi-story buildings since 2010 [292].

INDUSTRY CYCLICALITY LEADS TO DISPLACEMENTS ALONG THE VALUE CHAIN

The observed displacements along the value chain are explained by the cyclicality of the forest products industry. In the words of a company manager: "If you don't have a good grip on the raw materials, or on the final customers, then you are stuck. This is why, in terms of the value chain, you have to choose whether to move up or down. If you move up the chain, you leave the raw materials behind, and then you are exposed because raw material suppliers control approximately 70% of your production costs. If you [move down the value chain], you don't have access to the consumer, and then you are incapable of impacting the way they buy or what [products] they want to buy. Then you are also at the mercy of the retailers. So what you see is a cycle where we go in and out of these different [value chain] positions" [121].

The cyclicality of the forest products industry often translates into a periodic "reinvention of the wheel" for StoraEnso. As explained by the company manager: "This is always the big strategic question: where should you sit in the value chain. When you see that your main profit is diminishing quite earlier in the value chain, then you effectively look at opportunities to move up the value chain, and to try to extract more value [of the raw materials]. If [this strategy] works, great, and if it doesn't, then you close it down and you go back to the old way, and this is why you see these cycles. When you enter the housing business, for example, you follow directly the construction cycles. As soon as the economy goes down, however, your profitability drops, and you are stuck with fixed assets that then get divested. That is exactly what happened in the 1980s, and it will happen again, and it will keep happening like that. It is frustrating because you build up competencies and knowledge and then when bad times come it is all swept out and then you have to start from scratch again after 10-15 years" [121].

EFFECTS OF CYCLICALITY ON UNIVERSITY SYSTEMS

Cyclicality of the forest products industry affects the local universities and their research agendas. As explained by a senior manager "if you take for example VTT, which is the state research institute, you can see the same cycles. In the peak time they had maybe 20-30 people working on forest and wood products. Now maybe it is just a handful, so it also fluctuates. But then the question is do they ever come back? What we see in organizations like VTT and when I talk to the state funding organizations in Finland, is that more and more of their money goes to the [mobile] gaming industry, for example, to people inventing 'Angry Birds[8]'. Money is going somewhere else, and it doesn't seem to be coming back [to the forest industry]" [121].

When StoraEnso decided to move up the value chain into engineered woods and multi-story buildings, the company had difficulties in finding experts on these technologies within the local academic community and began relying on an international network of university partners for rebuilding their internal capabilities. As explained by the company manager: "the internal capabilities StoraEnso had in building prefabricated houses were lost after the company divested this business unit in the early 1990s. Because of the long time lag, almost 20 years, the company has found difficulties in finding experts within the local academic community" [121]. Other countries had taken the lead on the development of cross-laminated timber (CLT) structures, leading to internationalization of the firm's academic network: "There has been a lot of work on CLT development in Austria. Professors at the university of Graz, for example, are the ones driving this technology. So you have to team up with them" [121].

In recent years, StoraEnso has built an international network of university partners in the area of engineered woods and building structures. As stated by the company manager: "There are certain universities in Europe that are progressive in terms of wood-based construction and design. It is key to have good professors at those universities, and we try to team up with the best ones. Now we have a wider network of architects, structural engineering professors, and wood modification professors at different research centers. We also sponsor master's thesis, and sometimes even doctoral work. We look at these students as potential future employees " [121].

[8] Angry Birds is a popular gaming application for smartphones created by Rovio Entertainment, a Finnish computer game developer.

APPENDIX VIII: SCA

1. INTRODUCTION

Svenska Cellulosa Aktiebolaget (SCA) is a vertically integrated forest products company specializing in personal care, tissue, publication papers, pulp, and solid wood products. The company is the world's third largest manufacturer of tissue and Europe's largest private forest owner with more than 2.6 million hectares. In 2011, SCA achieved a sales volume of €11.7 billion and employed 37,000 people worldwide. The company is headquartered in Stockholm, Sweden and has facilities in 20 countries [303].

Figure 101 presents an overview of SCA's sales and R&D expenditures versus time. The company has historically spent between 0.5% and 1.4% of sales in R&D. SCA is currently the company that invests most in R&D, both in absolute terms and as a fraction of sales, when compared with the other firms in our dataset. The growth in sales occurred in 1995 was the result of the acquisition of PWA, a large German forest product company.

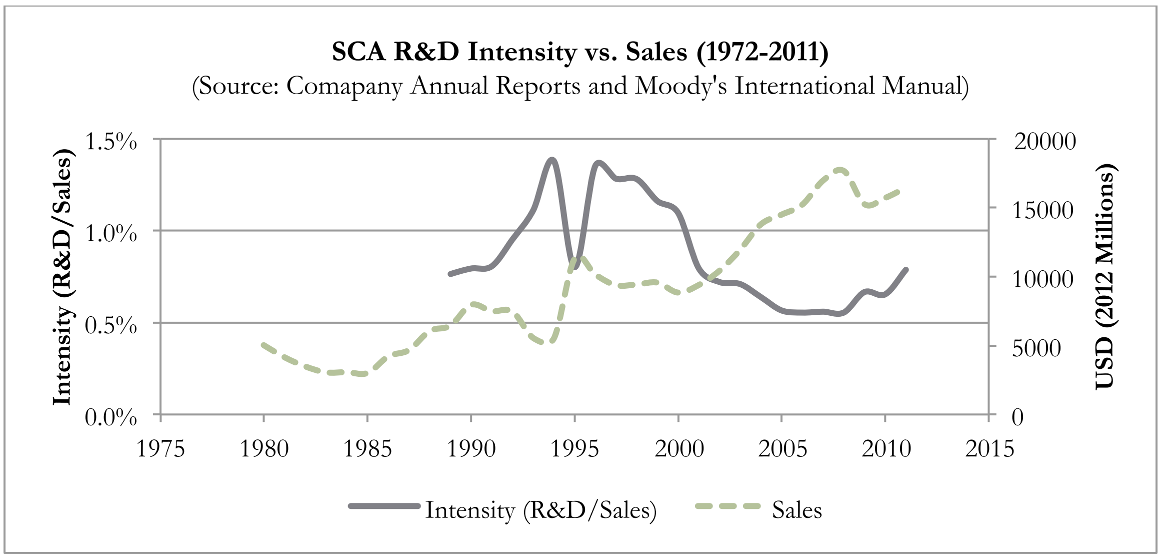


FIGURE 101: EVOLUTION OF SCA R&D INTENSITY

This case study presents a longitudinal review of the changes in (i) the company's businesses, (ii) research strategy and (iii) connections to universities and public research institutes during each strategic period of the firm.

In Section 2 characterizes the different strategic periods of SCA. In Section 3 describes the origins and evolution of the firm's university relationships as judged by changes in the research priorities of the firm, changes in the firm's university network, and people flows between partnering institutions. Finally, Section 4 summarizes the main findings and lessons.

2. Historical Changes in SCA's Strategy

Data on SCA's strategy was obtained by analyzing the company's annual reports and secondary sources of information, including journals, press articles, and company historical retrospectives. We also conducted one telephone interview with a senior manager of the firm. Based on this data, we defined 8 different strategic periods as in the left hand side of Figure 102, which tended to coincide with changes in the CEO of the firm. The right hand side of the figure depicts the strategic trajectory followed by SCA.

Strategic Periods

Period 1 (1929-1949): Focalization in pulp

Period 2 (1950-1959): Integration into paper and packaging

Period 3: (1960-1971): Internationalization into Europe

Period 4 (1972-1988): Diversification into consumer products and industrial machinery

Period 5 (1989-1994): Focalization

Period 6 (1995-2001): Internationalization into Europe, Asia, and the US.

Period 7 (2002-2006): Integration into premium packages

Period 8 (2007-Onwards): Focalization in consumer products

Strategic trajectory

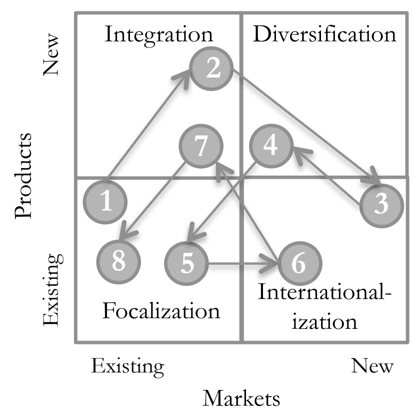


FIGURE 102: SCA STRATEGIC PERIODS

Period 1 (1929-1949): Focalization in Pulp

In 1929, Ivar Kreuger, a Swedish safety match industrialist, formed SCA as an umbrella company for marketing and selling the production of ten different pulp companies from Northern Sweden. The combined production of these mills accounted for 1/3 of Sweden's pulp exports [286]. In 1932, Kreuger committed suicide after the economic collapse of his industries following the great depression, and SCA was taken over by the Swedish Handelsbanken bank who sold a controlling stake of the company to Axel Wenner-Gren, the founder of Electrolux. Wenner-Gren streamlined the pulping operations and built in 1936 a new cellulose plant in Ostrand [304]. During WWII, SCA's pulp production was reduced and the company focused on the production of charcoal, wood tar, turpentine, and cellulose acetate for the war. The US, however, threatened to freeze SCA's US assets due to allegations linking Wenner-Gren's with the Nazi Regime [286]. Thus, in 1941, Handelsbanken acquired 66% of Wenner-Gren's SCA shares and took control of the firm. The company divested its hydroelectric plants and tugboat fleet in 1943 to concentrate on pulp. [286]. In 1947, Handelsbanken acquired Wenner-Gren's remaining shares and SCA became a fully owned subsidiary.

PERIOD 2 (1950-1959): INTEGRATION INTO PAPER AND PACKAGING

During the postwar period there was increased demand for forest products and in 1950 Handelsbanken listed SCA on Stockholm's Stock Exchange. That year, Axel Enstrom became president of SCA and consolidated the different SCA subsidiaries into one single integrated forest products company [286].

With increased revenues, SCA began looking for new growth opportunities. In 1955, the company decided to vertically integrate into newsprint production and in 1956 built a newsprint mill in Ortviken with a total capacity of 160,000 tons [304]. SCA increased the mechanization of the forestry operations through the use of chainsaws and mechanical debarkers. In 1959, SCA entered the packaging business and built a corrugated board plant in Munksund [305]. By the end of this period, SCA had become an integrated producer of sawn timber, pulp, newsprint, Kraft paper and packages.

PERIOD 3 (1960-1971): INTERNATIONALIZATION INTO EUROPE

In 1960, Eije Mossberg became CEO defined a long-term strategic plan that limited SCA's manufacturing operations in Sweden, in anticipation of shortage in wood supply [306]. During the first half of the 1960, the company closed 18 plants in Sweden to concentrate on more efficient mills. In 1961, SCA built a containerboard machine in Munksund, Sweden, with a capacity of 110,000 tons [304].

In 1963, an oversupply in the Swedish containerboard market pressured SCA to expand into Europe acquiring in 1963 Colon Emballage of Denmark, in 1964 Papeteries Léon Clergeau of France and in 1966 Värnamo Wellpappfabrik of Sweden. After these acquisitions SCA consolidated all packaging operations in Sweden, Germany, Denmark and France through the creation of a subsidiary named SCA Emballage AB [305]. SCA also expanded into Canada in 1965 and built a pulping mill in Prince Rupert, British Columbia. In 1970, however, SCA sold the Canadian subsidiary [305].

During this period, SCA also improved its manufacturing operations. Timber rafting was abandoned in favor of roads and trucks. In 1967, the company acquired three new vessels and invested in a new transportation system to reduce transportation costs to Europe [305]. Despite all these changes, during the 1960s SCA faced low operational margins, which limited the company's expansion capacity [304].

PERIOD 4 (1972-1988): DIVERSIFICATION INTO CONSUMER PRODUCTS AND MACHINERY

In 1972, Bo Rydin became president and started diversifying the company into fiber-based consumer products. This decision, however, was not immediate. In 1963, SCA scientists developed a new product for female sanitary protection [306]. As the sales of sanitary napkins grew, SCA was faced with the strategic decision to continue investing in hygiene products or to concentrate back on conventional forest products (i.e. pulp, newsprint). In

1973, SCA opted for the second alternative arguing: *"If we were to continue our operations within this sector [hygiene products], we would be faced with extremely high costs for product research and marketing development; these resources could, I feel, be put to better use within the forest industry."* (Bo Rydin 1973, cited in [306]). In 1973 SCA sold the hygiene products division to Mölnlycke, a Swedish manufacturer of personal care products. SCA, however, retained a stake in Mölnlycke and continued selling pulp to this company. In 1975, Mölnlycke faced financial problems and SCA acquired the company, thus reentering the personal care business [305].

The Oil crises of the 1970's increased SCA's production and transportation costs. In 1975, the Swedish economy entered in recession and in 1977 the Swedish Krona was devaluated. During the late 1970s, the Swedish forest products industry continued to deteriorate and a referendum banning nuclear power threatened to increase the industry's production costs [307]. In 1978, a Boston Consulting Group report concluded that the emergence of new pulp-producing countries coupled with an increased capacity of North American producers would drive the Swedish industry out of business [306]. Given this context, SCA decided to reduce production of pulp and low-grade papers and to diversify into industrial machinery through the acquisition of Defibrator (1979) and Rauma Repola's industrial machinery division (1988) [305].

SCA also expanded in three business areas: packaging, personal care products, and graphic papers. In 1985, SCA acquired a controlling stake in Obbola Linerboard and in 1988 made several acquisitions including Italcarta, Italy's largest corrugated board manufacturer; Laakirchen, an Austrian producer of magazine and tissue paper; and Peaudouce, a French manufacturer of disposable diapers. These acquisitions allowed SCA to become Europe's largest producer of packaging boards and tissue paper and the largest supplier of hygiene products in Western Europe [286].

PERIOD 5 (1989-1994): FOCALIZATION

In 1989, Sverker Martin-Löf became CEO. To strengthen the company's position in packaging, SCA acquired in 1990 Reedpack, a UK manufacturer of corrugated boxes, newsprint and recycled papers. SCA also acquired several small companies in Europe, which allowed increasing packaging sales by 42% [304] and reduce dependence on virgin fibers through the use of recycled papers. In 1990, SCA acquired a controlling stake in MoDo, Sweden's third largest forest products company.

The beginning of the 1990s, however, was marked by a recession in the Swedish forest products industry. SCA reduced pulp, linerboard and newsprint production and shifted attention towards lightweight coated papers. As consequence of the recession, 10% of SCA's employees were laid off and several inefficient mills were closed. The company also divested non-core assets including Sunds Defibrator (machinery), Mölnlycke Mobility (wheelchairs and homecare products), Reedpack's plastics operations in the UK, Laarkirchen tissue operations in Austria, Båkab Energi in Sweden, and SCA's shares in MoDo in 1994 [305].

By the end of this period, SCA started two international joint ventures. In 1992, SCA formed an alliance with two South African companies, Minorco and Mondi, to build a newsprint plant in the UK that utilized recycled papers as feedstock [286]. SCA also formed a joint venture with Scott Paper from the US to create a healthcare unit devoted to incontinence and wound care products. In 1994, SCA took full ownership this healthcare venture.

PERIOD 6 (1995-2001): INTERNATIONALIZATION INTO EUROPE, THE US AND ASIA

In 1995 the economic recession was over and SCA obtained record profits (See Figure 101 in Section 1). SCA thus began a series of acquisitions and joint ventures aimed at expanding its presence in Europe, North America and Asia.

In Europe, SCA acquired in 1997 75% of PWA, a German manufacturer of tissue, packaging and graphic papers. This purchase allowed SCA to become Europe's largest manufacturer of personal hygiene products [286]. SCA also made acquisitions in the UK, Italy, Denmark, Portugal, Spain, Russia, and France, to strengthen the position in the European packaging and tissue markets.

In North America, SCA acquired Johnson & Johnson's incontinence products division to gain access the US retail sector. SCA bought a tissue plant form Georgia-Pacific and the Tuscararora Packaging Co. of New Brighton, Pennsylvania. After these acquisitions, SCA became the third largest player in the North American tissue market [304].

In 1996, SCA formed an alliance with Weyerhaeuser to build a packaging plant in Asia, and formed a joint venture with Uni-Charm to produce personal care products in Japan. In 1997, SCA formed a joint venture with the Rank Group to produce packages in India and with Advancetek Enterprise of Taiwan to produce personal care products [308]. In 1998, SCA spent SEK 1 billion in high growth markets including the acquisitions of Productos Familia, a Colombian manufacturer of personal care products, Holland Pacific Paper of the Philippines, Svetogorsk Tissue in Russia, Obalex in the Czech Republic; and Central Package Group of Singapore. In parallel to this internationalization, SCA narrowed the paper products line by selling in 2000 the fine papers division to MoDo [308]. In 2001, newsprint and graphic papers accounted for only 15% of SCA's sales.

PERIOD 7 (2002-2006) INTEGRATION INO PREMIUM PACKAGES

In 2002, Martin-Löf stepped down as CEO being succeeded by Jan Åström who led SCA's expansion into premium packages. In 2003, SCA acquired DeKalb, and Illinois-based firm that manufactured plastic blister packages. SCA also began producing premium packaging through the acquisition of V+D Stabernack (Germany), Bertako (Spain), and Cartonvest (Italy) [308]. In 2004, the company acquired Carter Holt Harvey's New Zealand tissue operations and increased its shares in Singapore's Cenpack, a major player in the Chinese packaging industry [286].

PERIOD 8 (2007-ONWARDS): FOCALIZATION INTO CONSUMER PRODUCTS

In 2007, Jan Johansson became CEO. SCA faced increased competition and price wars in the packaging business due to an overcapacity in the European market. Johansson moved away from packaging and to focus on personal care products. Between 2007 and 2012, SCA sold its entire packaging division. The North American packaging operations ware divested in 2007, the UK packaging operations in 2008, the Asian packaging operations in 2010, the Greek and Russian packaging units in 2011, and sold the remaining packaging assets in Europe to DS Smith for €1.7 billion in 2012 [308].

In parallel, SCA expanded into personal care products in emerging markets through several acquisitions. In 2007, SCA formed a joint venture with Godrej, an Indian manufacturer of personal care products to produce diapers and feminine products in India, Nepal and Bhutan. That same year, SCA acquired Procter & Gamble's European tissue operations and a minority stake in Chinese tissue manufacturer Vinda. In 2009, SCA acquired Algodonera Aconcagua, an Argentinean feminine products manufacturer and in 2010 Copamex a diaper manufacturer with presence in Mexico and Central America. In 2011, SCA acquired different personal care companies in Turkey, Brazil, Chile, and New Zealand. In 2012 the company completed the acquisition of Georgia-Pacific's European tissue operations, becoming the world's third largest tissue manufacturer [308].

3. THE ORIGINS AND COEVOLUTION OF SCA'S UNIVERSITY RELATIONSHIPS

SCA's department of planning, development and research was formed in 1943 to stimulate the development of new and improve the quality of existing products. Because of WWII this department opened in 1946 with a staff of 80 people [309]. The formation of SCA's R&D department coincided with the birth of several Swedish institutions aimed at stimulating industrial research. Of particular relevance for the forest products industry was the creation of the Swedish Forest Research Institute (Svenska Träforskningsinstitutet or STFI) in 1942. The STFI was established and managed by the Swedish forest industry in collaboration with the Swedish State. Both partners contributed equal parts to the creation of this institute, which was housed at the Swedish Royal Institute of Technology (KTH) [306].

During the 1950s, SCA's R&D department grew in size to 90 people, 12 of whom had advanced academic degrees (MSc, PhD) [310]. Most of SCA's R&D personnel were trained at KTH and STFI. As summarized by Lars Sundblad, CEO of Iggesund[9], "STFI also has the function of serving as a recruitment base for the pulp and paper industry. Many Swedish pulp and paper engineers started [their] careers with two, three or four years at the STFI. This is a very efficient way of technology transfer" (Sundbald, L. G., 1985, quoted in [306]).

[9] Iggessund became part of MoDo in 1988 and SCA controlled this company between 1990 and 1994.

SCA's R&D director, Dr. Hilding Tydén was a graduate of KTH and several department heads such as Karl-Erik Ohlsson and Sven Rydholm[10] were trained KTH and STFI before joining the firm.

During the 1950s, several new public research institutes were formed including the Graphical Research Laboratory (Grafiska Forskningslaboratoriet or GFL), the Paper Central Laboratory (Pappersbrukens Centrallaboratorium or PCL), the Wood Pulp Central Laboratory (Trämasseindustriens Centrallaboratorium or TCL), the Newsprint Research Laboratory (Tidningspappersbrukens Forskningslaboratorium or TFL), the Wood Technology Central Laboratory (Trätekniska Centrallaboratoriet or TTCL), and the Wallboard Industry Central Laboratory (Wallboardindustriens Centrallaboratorium or WCL). During the 1960s, the Swedish forest products industry pressed to consolidate these research laboratories in order to better compete for public research funds. In 1968, these different research laboratories were merged with STFI, which became a central research partner for SCA and the Swedish forest products industry [311].

SCA's university Collaborations in healthcare

During the 1970s, SCA began diversifying into fiber-based consumer products as an effort to level out the cyclicality of the pulp and paper business and in 1975 acquired Mölnlycke, a Swedish manufacturer of hygienic products, textiles, boats, and sewing threads [306].

Mölnlycke had been selling gauze to the Sahlgrenska Hospital in Gothenburg since the 1940s and thus frequently collaborated with university hospitals to improve its products. During the 1980s, we observed several publications with university hospitals in the area of healthcare, in particular with the Huddinge University Hospital (currently the Karolinksa University Hospital) on microbiological studies of wound dressings, the Sahlgrenska University Hospital of the University of Gothenburg on patient draping, the Helsinki University Central Hospital on surgical gowns, the University of Mainz Medical Center on wound dressing permeability, the University Hospital of Uppsala on wound contamination and with the Danish Statens Serum Institute on sterilization technologies. SCA's Health Care Division was responsible for several company innovations including the creation of new surgical scrubs, powder-free surgical gloves, and new wound dressing technologies.

SCA proposed to close the STFI

During the second half of the 1980s, the Swedish economy entered in recession and the future of the STFI was at stake [312]. SCA's CEO Sverker Martin-Löf proposed to close this research institute. In 1987, he argued that basic R&D should be financed by the government, and that the Swedish forest industry should focus on applied R&D projects in collaboration

[10] Rydholm moved in 1952 to Billerud AB. At this company, he was responsible for establishing Celbi, a Portuguese subsidiary that manufactured eucalyptus pulps. Billerud was later acquired by Stora in 1984.

with the industry's suppliers [306]. In the words of SCA's CEO: "The future need for, and structure of specific research is very much dependent upon current industrial rationalization and restructuring. The remaining larger units must increasingly take care of their own troubleshooting and increase their process rationalization". (Martin- Löf, 1987 quoted in [306]).

Between 1987 and 1989 the STFI was restructured. Industrial resources were cut and research emphases was placed on basic research [306]. During the 1990s, STFI began an internationalization process and foreign pulp and paper companies, which often competed against Swedish firms, were allowed to fund research projects at STFI [311].

A NEW APPROACH TOWARDS UNIVERSITY COLLABORATIONS: ON-CAMPUS PRESENCE

At the beginning of the 1990s, the Swedish pulp and paper industry continued in recession. In 1994, the Ministers of Labor and Education invested SEK 30 million for developing a forest engineering research center to increase the Swedish industry's competitiveness. The Mid-Sweden College (MSU), which had recently been formed in 1993 after the merger of two institutions, obtained SEK 10 millions to build a research center on fiber science [124].

The Mid-Sweden College had a campus in close proximity to SCA's R&D center in Sundsvall, Sweden. MSU's President President Kari Marklund, thus contacted SCA's Executive Vice-President Alf de Ruvo and said: "I have 10 millions, and if you invest 10 we have 20 millions. What can we do for that money?" [124]. SCA saw this offer as an opportunity to shift away from traditional consortia research models and believed it could get a more creative and entrepreneurial atmosphere by having an on-campus presence at MSU [125]. In 1999, SCA agreed with Mid-Sweden University to establish an on-campus research center. In addition to the economic resources, SCA also transferred two senior researchers who became full-time professors at MSU.

MSU built a research program in fiber sciences that allowed obtaining full university status in 2005 [124]. In addition, we also observed an increase in the number of publications between MSU and SCA. Since 1999, SCA has coauthored 52 articles with MSU, recruited 5 researchers, and 3 SCA researchers have left the company to become faculty at MSU.

Figure 103 shows the different industrial sectors in which the company has been active and the number of university articles within each sector. As shown in the figure, since the late 1990s the number of publications between SCA and its university partners has been growing, especially with MSU in the area of pulp and paper products.

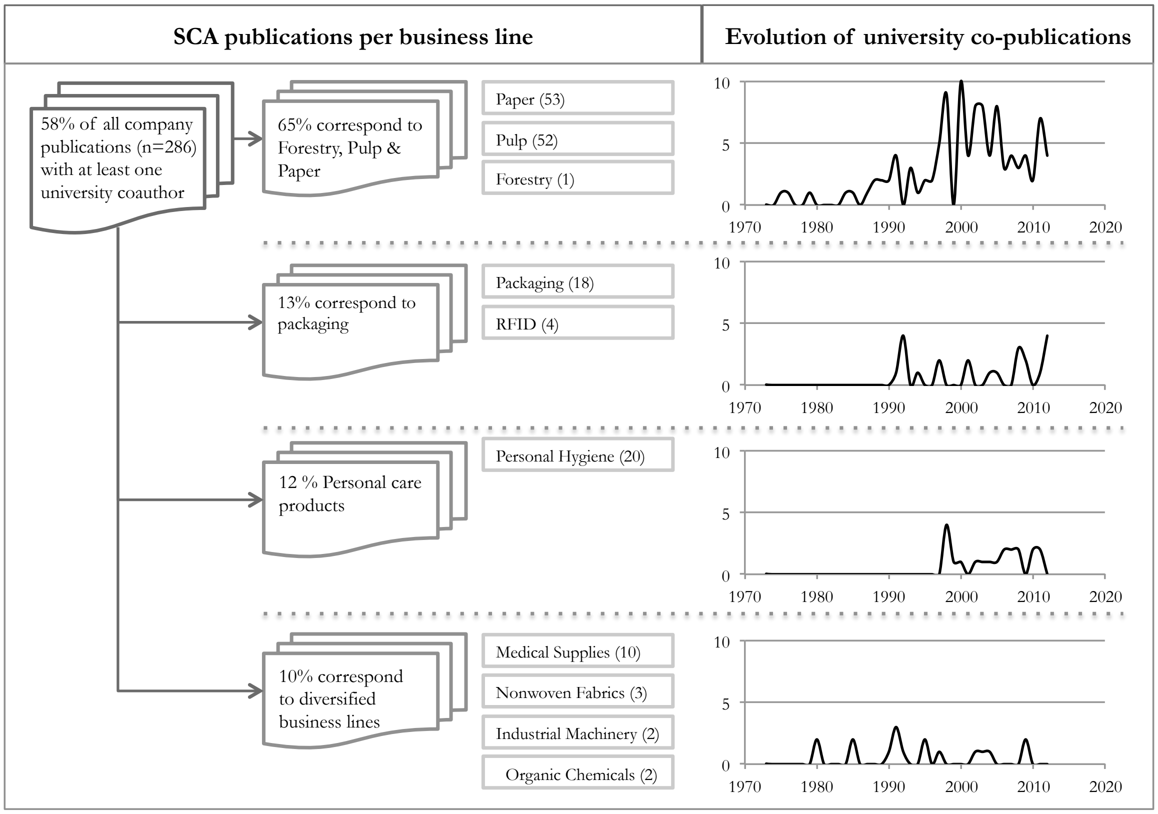


FIGURE 103: COEVOLUTION OF UNIVERSITY CO-PUBLICATIONS AND SCA'S BUSINESS LINES

Figure 104 shows that since the 1990s, publishing with academic coauthors has become more frequent for SCA. Among the company's most frequent university partners are the Mid-Sweden University, Innventia (the former STFI) and the Royal Institute of Technology (KTH).

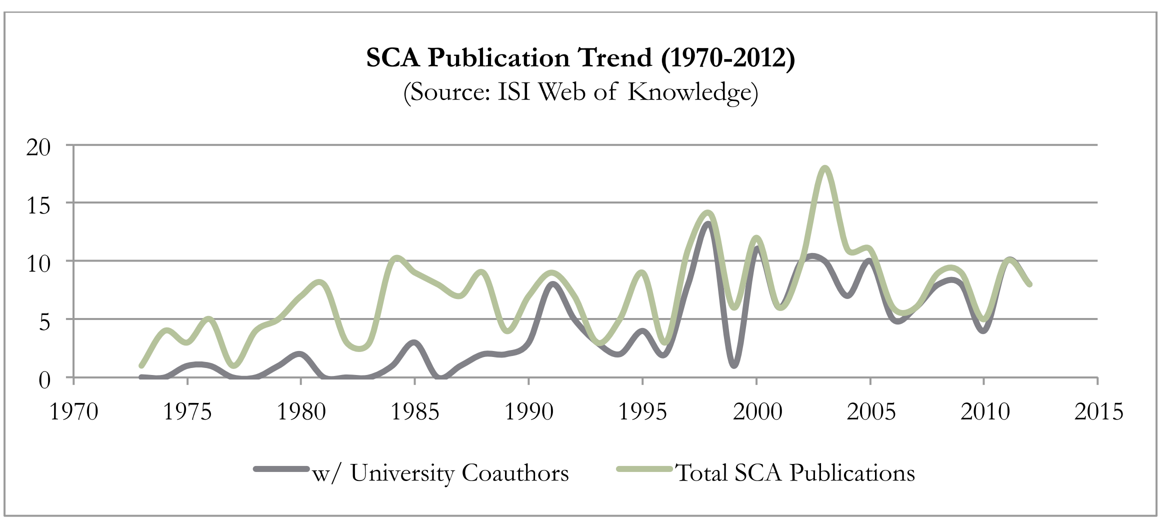


FIGURE 104: SCA PUBLICATION TREND

3.1. RESEARCH PRIORITIES ALONG SCA'S VALUE CHAIN

We have organized SCA's university relationships from a value chain perspective, distinguishing between pulp and paper, packaging, and personal care value chains. Figure 105 shows the different processes involved in pulp and paper production. SCA's university co-publications have been concentrated in the areas furnishings, coating, calendering and specialty paper properties. The majority of these publication have been written in collaboration with researchers at STFI, KTH, and more recently with researchers at Mid-Sweden University.

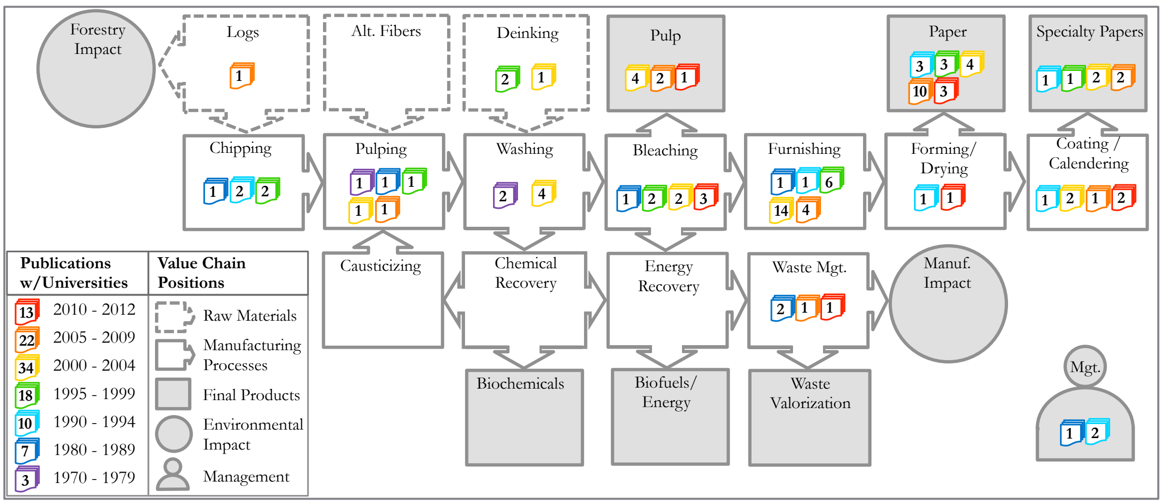


FIGURE 105: EVOLUTION OF SCA'S UNIVERSITY CO-PUBLICATIONS IN PULP AND PAPER

Figure 106, shows the different processes involved in containerboard and packaging production. As shown in the figure, most of SCA's university co-publications in this area have been on improving containerboard strength. The majority of the publications in this area have been coauthored with researchers at the Florida Atlantic University, Mid-Sweden University and Lund University. At the Florida Atlantic University, SCA collaborated with Prof. Lief A. Carlsson on improving the sandwich structures of corrugated board panels. Prof. Carlsson had previously worked at SCA while a graduate student at Chalmers University. After graduating and relocating to the United States, Prof. Carlson continued collaborating with researchers at SCA, in particular with Dr. Alf de Ruvo [313].

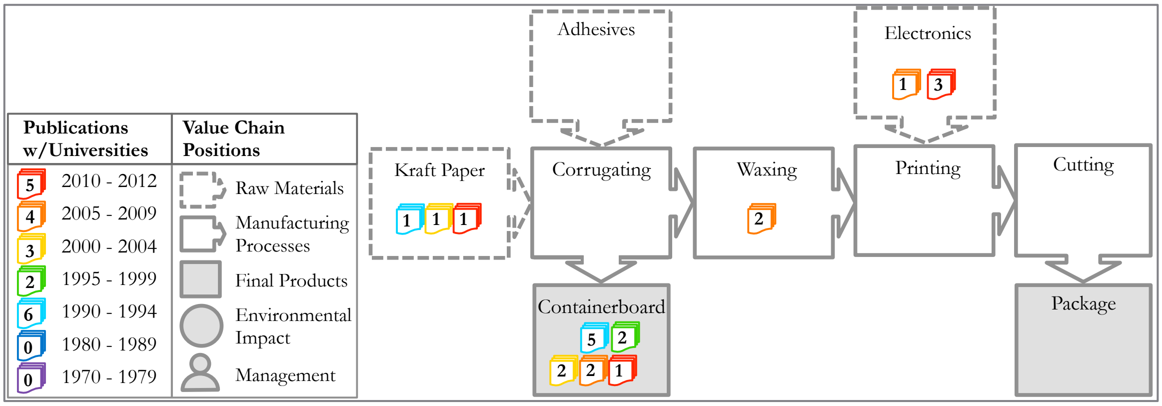


FIGURE 106: EVOLUTION OF SCA'S UNIVERSITY CO-PUBLICATIONS IN PACKAGING

Figure 107 shows the different processes involved in the manufacturing of personal care products. The figure shows that most of SCA's university co-publications in this area have been on improving the absorbent properties of fluff pulp, and on analyzing the quality of the firm's products (e.g. the impacts of SCA's products on skin). The majority of the publications in this area have been coauthored with researchers at Sahlgrenska University Hospital, Chalmers University, and the University College London (Chalmers University and the Sahlgrenska University hospital are located in close proximity to SCA's Hygiene research group in Gothenburg). Since 2001, SCA has also funded research projects at University College London, in particular with Prof. Alan Cottenden of the Continence and Skin Technology Group.

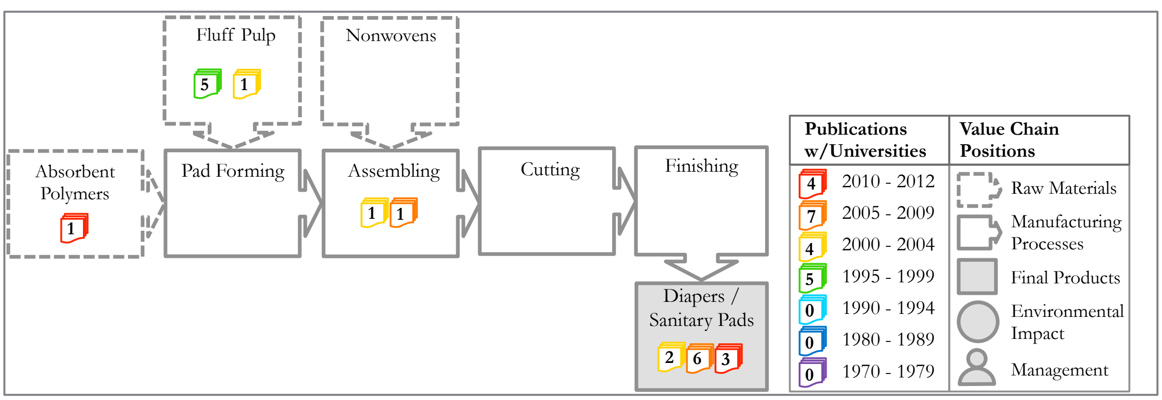


FIGURE 107: EVOLUTION OF SCA'S UNIVERSITY CO-PUBLICATIONS IN PERSONAL CARE

3.2. GEOGRAPHY OF UNIVERSITY PARTNERS

Figure 108, based on SCA's publication records, shows the geographic distribution of the company's local university network. SCA's university network has historically been in Sweden, near the company's production sites and R&D centers in Sundsvall (pulp, paper and packaging) and Gothenburg (hygiene and personal care products).

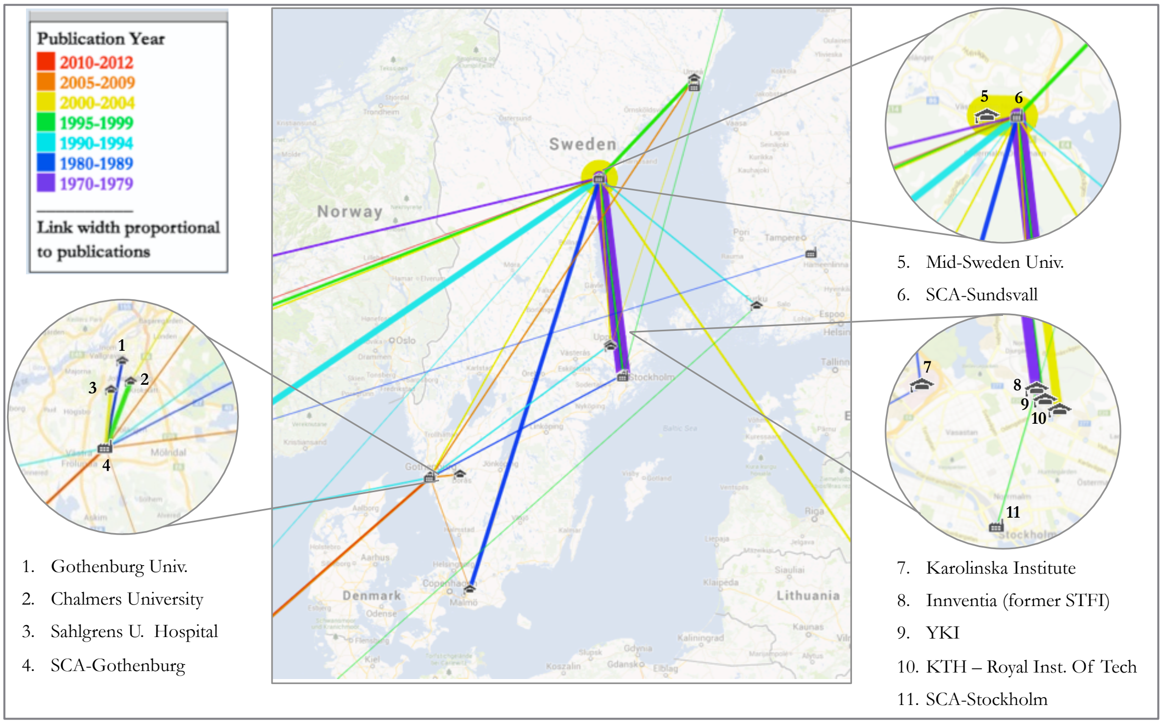


FIGURE 108: SCA'S LOCAL UNIVERSITY NETWORK

Figure 109 shows a geographical representation of SCA's international university partners based on the firm's co-publication records. Most of the international collaborations have been created in response to the firm's expansion in Europe during the second half of the 1990s. The figure also shows strong collaborations with academic institutions in North America, in particular with the Florida Atlantic University, University of Idaho, University of Maine, the Canadian Pulp and Paper Research Institute (FP Innovations), and with McMaster University of Canada. SCA has also collaborated with researchers at Monash University in Australia, in particular with Prof. Warren Batchelor of the chemical engineering department.

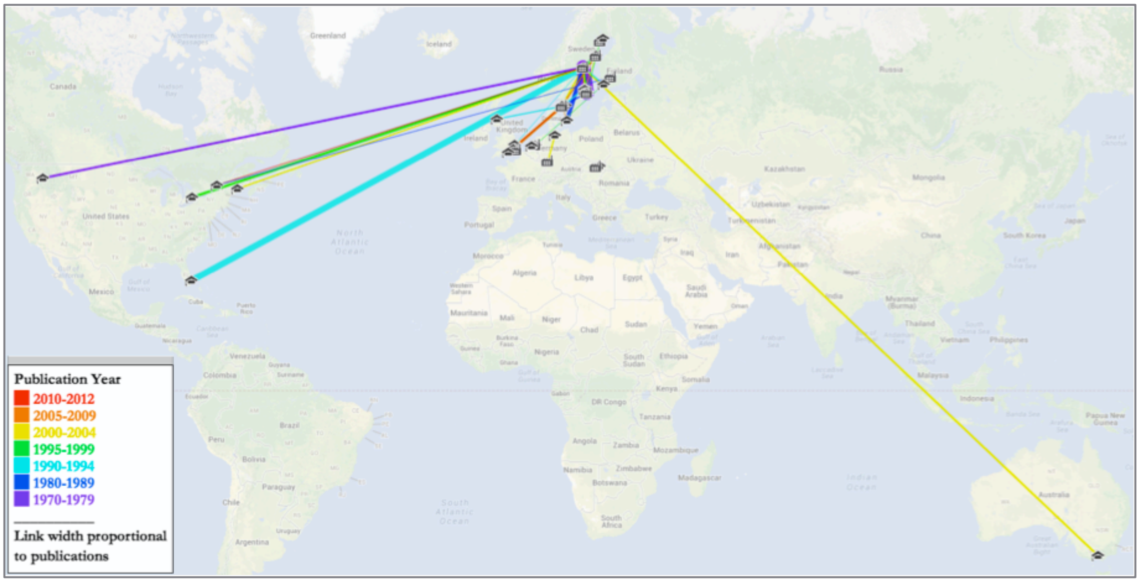


FIGURE 109: SCA'S GLOBAL UNIVERSITY NETWORK

Figure 110 shows the firm's international university collaborators with respect to the company's manufacturing sites. Researchers at SCA's Mannheim tissue mill in Germany have collaborated with researchers at the university of Hamburg and researchers at SCA's Aylesford newsprint mill in the UK (which was divested in 2012) have collaborated with researchers at the University of Cambridge. In the Netherlands, SCA established in 1996 an R&D center inside the premises of the Dutch Organization for Applied Scientific Research (TNO).

FIGURE 110: INTERNATIONALIZATION OF SCA'S UNIVERSITY PARTNERS

In 2011, SCA opened an R&D center in China devoted to research in incontinence products. As explained by SCA's manager "Once the company moved into China, then we also started looking for university partners there. For instance, we had a session with the Guangxi University, which is one of the largest universities in Shanghai. We have an innovation center in Shanghai and we collaborate with local institutions. I think that being physically close to the universities you are dealing with is a requisite. You can always contact each other by email, however, the specificity of contacts makes a whole lot of difference [314].” As emphasized by this manager, geographical proximity facilitates industry-university interactions and thus we can expect publications between SCA and Chinese universities in the future.

3.3. Technology transfer through people flows

To analyze the academic and professional trajectories of SCA’s most prolific authors and inventors we used SCA’s publications and patenting records to develop a list of 85 people involved in the company’s R&D activities. Each individual in the list has either patented or published at least three papers from SCA’s name.

Figure 111 shows the evolution of SCA’s research staff. As shown in the figure, most of SCA’s R&D personnel were recruited from academia. The figure also shows that SCA’s R&D personnel peaked in 2000, after which there was a decline after the company’s focalization strategy. After leaving the company, 33% of these researchers joined other firms, and 3% went to research institutions, including Mid Sweden University, STFI, and YKI.

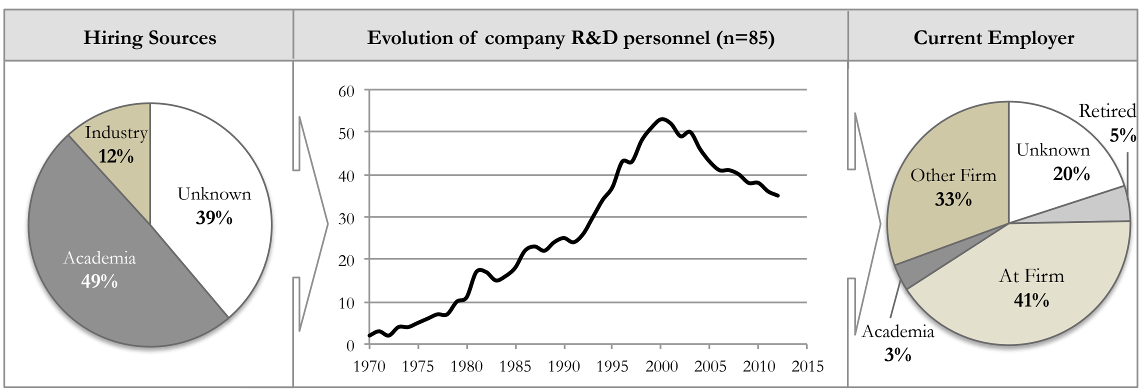


FIGURE 111: EVOLUTION OF SCA'S R&D PERSONNEL

Analysis of the academic training of SCA’s researchers shows an overlap between the academic institutions attended by these people and the company’s publication partners (See Figure 112). The most common university attended by the firm’s R&D personnel has been Chalmers University, followed by the Royal Institute of Technology (KTH), MidSweden University, the Swedish Pulp and paper research institute (former STFI, currently called Innventia), and Lund University.

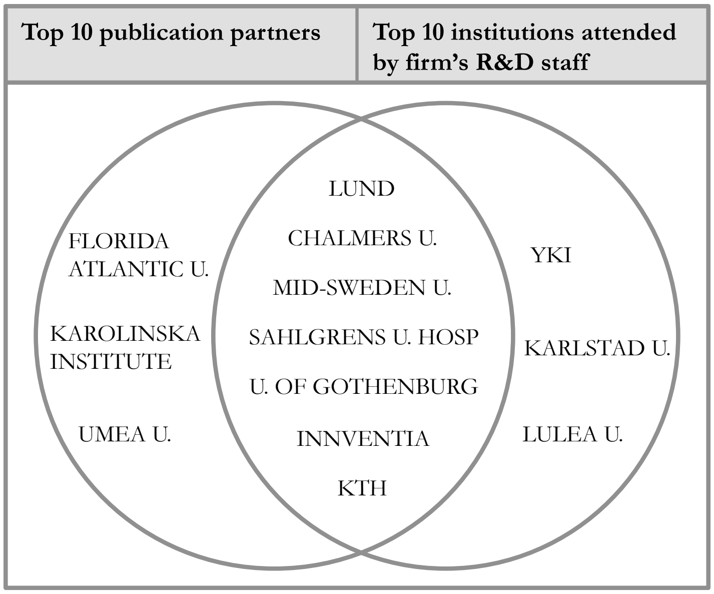


FIGURE 112: OVERLAP BETWEEN SCA'S HIRING AND PUBLISHING PARTNERS

4. Case Study Discussion

SCA has endured several strategic changes and participated in a diverse set of industries and regions over time. Table 18 presents a summary of the findings concerning how SCA's strategy affected its relationships its universities and research institutes. The table shows the different strategic periods of the firm, and how SCA's research priorities, people flows, and institutional networks were modified as a consequence of the observed changes in the firm's strategy.

TABLE 17: SUMMARY OF HOW SCA'S UNIVERSITY RELATIONSHIPS COEVOLVED

University Links Firm Strategies	Research Priorities	People Flows	Institutional Networks
Period 1: **Focalization** (1929-1949)	**Process improvement** • Improve quality and productivity of pulps	**First R&D Center** • Est. in 1943, only opened in 1946 after WWII • Research staff of 80 people	**Creation of STFI** • Funded between the Swedish government and the forest industry. Housed at KTH
Period 2: **Integration** (1950-1959)	**Paper manufacturing** • Newsprint production • Water usage and conservation	**Growth in R&D Ctr.** • R&D staff of 90 people, 12 with advance degrees • Recruited mainly from KTH and STFI	**Fragmentation of industry labs** • Creation of new industry research laboratories e.g.: TFL (newsprint), PCL (paper), GFL graphics, WCL (wallboard), etc.
Period 3: **International-ization** (1960-1971)	**Environmental research** • Effluent treatment and manufacturing environmental impact	**Local staff recruitment** • New hires from Lunds and Chalmers Universities	**Merger of industry labs** • Consolidation of STFI as a one-stop-shop for industrial research

PERIOD 4: **DIVERSIFICATION** (1972-1988)	**Hygiene and machinery** • New personal care division (Mölnlycke) • Industrial machinery for pulp and paper products (Defibrator)	**New R&D Centers** • Personal care: located in Gothenburg, close to Chalmers University • Industrial machinery: located in Stockholm	**Diversification of univ. network** • New projects with university hospitals on healthcare products (Sahlgrenska Hosp) • New projects on pulp and paper machinery (U. Idaho)
PERIOD 5: **FOCALIZATION** (1989-1994)	**Pulp and paper quality** • TMP pulping processes • Lightweight coated papers	**Divesture of Ind. Machinery R&D Lab.** • Ind. Machinery R&D staff left firm after divesture	**Proposed to close STFI** • Applied R&D projects in collaboration with suppliers • Reorganization of STFI
PERIOD 6: **INTERNATIONAL-IZATION** (1995-2001)	**Quality improvement of papers and packages** • Paper coatings and furnishings • Strength properties of containerboard	**SCA researchers to universities** • SCA researchers became faculty at Mid-Sweden University • New R&D center at TNO, Netherlands (furnishings)	**International Univ. Links** • New projects with McMaster Univ. Canada (pulp and paper) and with Florida Atlantic University, US (containerboard), and with TU Delft, Netherlands (furnishings)
PERIOD 7: **INTEGRATION** (2002-2006)	**Packaging properties** • Strength properties enhancement **Hygiene products** • Product-skin interactions	**R&D staff peaked** • New R&D Center in Kent, UK (Packaging research)	**International network growth** • New projects with universities in Germany, UK, Canada • STFI merges with Packaging Research Institute (Packforsk)
PERIOD 8: **FOCALIZATION** (2007-ONWARDS)	**Hygiene products** • Skin protection, diaper quality **Waste Management** • Effluent and emissions treatment	**R&D restructure in Sweden** • Downsizing of Sundsvall R&D Center from 85 to 40 researchers • New hygiene R&D center in Shanghai, 15 researchers.	**Restructure of STFI** • Renamed Innventia, focus on biorefinery **Reduction of Univ. partners** • In areas of packaging and graphic papers

EFFECTS OF FIRM STRATEGY ON UNIVERSITIES AND PUBLIC RESEARCH INSTITTUES

SCA's strategic changes have had rippling effects on the company's university partners. The following examples help to illustrate this point.

During the economic recession of the late 1980s, SCA divested its industrial machinery division (Sunds Defibrator) to concentrate on lightweight coated papers. This decision had consequences for STFI. SCA proposed to close this institute, which led to a major reorganization of STFI's research lines and funding structure [306].

During the early 2000's, SCA invested in premium packaging production. At the same time STFI decided strengthen packaging research line by merging with Packforsk, the Swedish institute for packaging research. According to Thomas Johannesson, the president of STFI at the time, the merger with Packforsk aimed at strengthening their knowledge base in packaging in order to meet the market demands: "We know have a broader material knowledge at our disposal and can handle various types of materials and materials combinations, for instance in packaging applications" (quoted from [315]).

SCA has been divesting its paper and packaging divisions since 2007 to focalize on personal care and hygiene products. These strategic actions have in turn affected the firm's university partners. As explained by a senior company manager "In the packaging side, we have been subsidizing some research especially in one university here in Sweden. Now that we have divested those operations, we need to compensate that loss by interacting more vividly with other institutions in hygiene [research] [314].”

In Sweden, SCA’s decision to divest the packaging business and to downsize paper production had consequences for the firm’s local university partners. SCA’s Sundsvall R&D center, which is located in close proximity to the Mid-Sweden University’s research center in fiber technologies, downsized its R&D staff from 85 to 40 researchers in 2013 [316]. While the company still considers collaborating the Mid-Sweden University, “the downsizing of our packaging efforts, [coupled with] major changes in the demand for the products like newsprint, will affect our traditional focal points in the cellulose business, which is precisely what [we] are doing at the MidSweden University [314].”

Universities as Knowledge Buffer: the TEMPO oxidizing technology

The SCA case also illustrates how universities act as knowledge buffers allowing technologies to mature after the firm has lost interest in their application. The development of the TEMPO oxidizing technology helps to illustrate this point.

Between 1992 and 1997, Arjan de Nooy, a PhD student at the Technical University of Delft found a new method for oxidizing carbohydrates [317] and researchers at TNO (the Dutch Organization for Applied Scientific Research) helped to develop this technology. SCA became interested in TEMPO as it improved the wet strength properties of cellulose fibers. In 1996, SCA formed a strategic alliance with TNO and established an R&D center at TNO’s premises in Zeist, Netherlands [318].

The collaboration between TNO and SCA led to a number of new patents and applications for the oxidizing technology, including the development of new polymers and improved wood fibers for papermaking. In total, over 20 patent families were filed [318]. In 2003, however, SCA changed strategy and closed the R&D center at Zeist. TNO continued developing the technology and in 2004 formed Glycanex, a spin-off company to commercialize TEMPO. Glycanex now produces different polysaccharide derivatives, which are currently being used by the pulp and paper industry worldwide [318]. As illustrated in this example, TNO allowed the TEMPO technology to mature, even after SCA had lost interest in its development.

APPENDIX IX: UPM

1. INTRODUCTION

UPM is an integrated manufacturer of forest products including pulp, newsprint, fine papers, adhesive labels, timber, and plywood. The company is also large producer of energy through nuclear, biomass, wind, and hydropower generation. UPM is the world's largest manufacturer of magazine papers and the second largest producer of self-adhesive labels [319]. Since 2010, the company has been expanding into value-added forest products including biofuels, biochemicals, composite materials, and biofibrils (e.g. nanocrystalline cellulose).

UPM is organized around six business areas: energy, pulp, forest and timber, paper, labels, and plywood. In 2012, UPM achieved €10,438 million in sales and employed 22,000 people worldwide. The company is headquartered in Helsinki, Finland and has production plants in 17 countries [319].

Figure 113 presents an overview of UPM's sales and R&D expenditures versus time. The company has historically spent between 0.4% and 0.6% of its sales in R&D. The observed growth in sales occurred in 1996 was the result of the merger of Kymmene and Repola, two large Finnish forest product companies that gave birth to UPM.

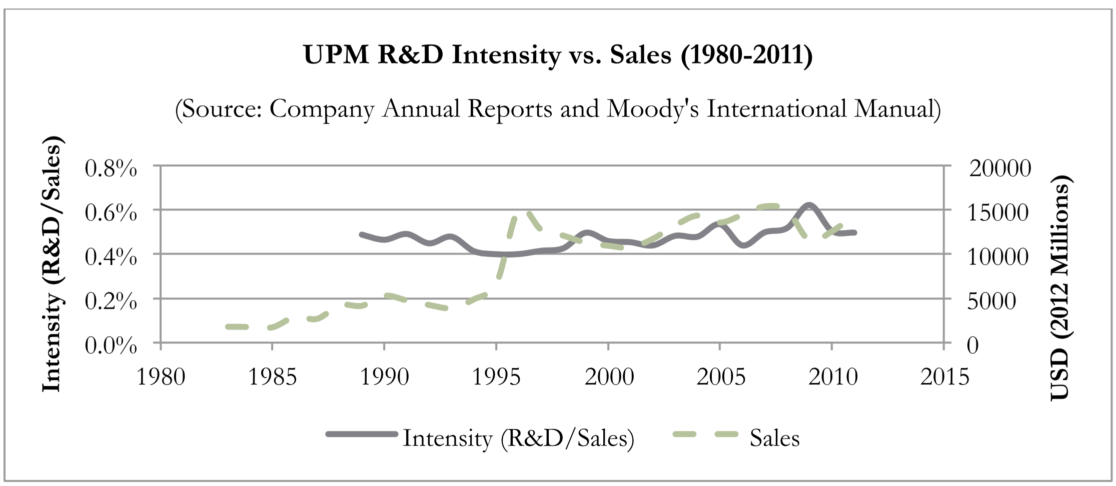


FIGURE 113: EVOLUTION OF UPM R&D INTENSITY

This case study presents a longitudinal review of changes in (i) the company's businesses, (ii) research strategy and (iii) connections to universities and public research institutes during each strategic period of the firm.

Section 2 characterizes the different strategic periods of UPM. Section 3 describes the origins and evolution of the firm's university relationships as judged by changes in the research priorities of the firm, changes in the firm's university network, and people flows between partnering institutions. Section 4 summarizes the main findings and lessons.

2. Historical Changes in UPM's Strategy

Data on UPM's strategy was obtained by analyzing the company's annual reports and secondary sources of information, including journals, press articles, and company historical retrospectives. We also conducted one on-site interview with a senior manager of the firm. From this data, we defined 9 different strategic as in the left hand side of Figure 114, which tended to coincide with changes in the CEO of the firm. The right hand side of the figure shows the trajectory followed by UPM.

Strategic Periods

Period 1 (1873-1917): Integration into pulp and paper

Period 2 (1918-1936): Internationalization

Period 3: (1937-1965): Diversification into industrial machinery and plastics

Period 4 (1966-1978): Internationalization into Europe and North America

Period 5 (1979-1986): Focalization

Period 6 (1987-1995): Integration into engineered woods

Period 7 (1996-2003): Internationalization into North America, Europe and Asia

Period 8 (2004-2010): Focalization

Period 9 (2011-Onwards): Diversification into forest byproducts

Strategic Trajectory

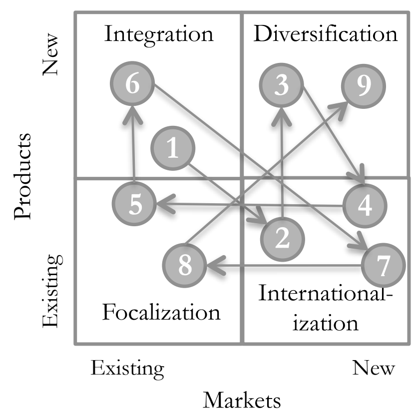


FIGURE 114: UPM'S STRATEGIC PERIODS

Period 1 (1873-1917) Integration into pulp and paper

In 1873, Wilhelm Wahren founded Kymmene Aktiebolag for producing ground wood pulp near the Kymi River in southeast Finland. This location provided strategic access to hydropower, timberlands, and was close to the Russian market. Other competitors formed similar companies along the Kymi River and began manufacturing groundwood pulp, sulfite pulp, and paper increasing competition for raw materials, which prompted Kymmene to merge with two of these competitors, Kuusankoski and Voikka, in 1904. The resulting company became the largest integrated papermaker in Scandinavia, with 76,000 hectares of forestlands [320].

In 1910, the company began exporting to the United Kingdom and in 1913, the building of the railway between Helsinki and St. Petersburg allowed Kymmene to expand into the Russian market, opening a sales office in St. Petersburg in 1916. The company also integrated into wood products through the acquisition of the Stromsdal board mill and the Halla sawmill, both producing sawn timber products. Kymmene had become the largest paper company in Europe, but the Soviet Revolution of 1917 left the company without its largest market, which prompted the company to change strategy.

PERIOD 2 (1918- 1936): INTERNATIONALIZATION

In 1918, Einar Ahlman became president of Kymmene and began looking for new customers in North America and Western Europe to compensate the loss of the Russian market. The United Kingdom had a large paper market that depended on imported pulp from Swedish and Norwegian firms. To outcompete these firms, Kymmene modernized its manufacturing base, doubling the productivity of its mills during the 1920s [321]. In 1921 Kymmene created an export marketing organization to distribute products in the UK. In 1930, Kymmene acquired the Star Paper mill Co. of Blackburn, UK, and in 1931 they acquired the Yorkshire Paper Co. of Barnsley, UK. These acquisitions were made out of fears of protectionism from British authorities who were considering increasing customs duties to protect the local paper industry [320].

During the 1930s, Kymmene continued modernizing doubling its productivity again [321]. The company also began a series of acquisitions to secure raw materials. In 1933, they acquired Högfors, a producer of boilers, radiators, and pipes. While acquisition was made because of Högfors' forestlands, it also allowed Kymmene to enter the industrial machinery industry. In 1935, Kymmene further increased its timberland holdings through the acquisition of Laskela Ab, which had 100,000 hectares of forestlands, two paper mills, and a sulfite mill in Lake Ladoga. In 1935, Kymmene became the largest landowner in Finland with 386,000 hectares [322].

PERIOD 3 (1937-1965): DIVERSIFICATION INTO MACHINERY AND PLASTICS

In 1937, Karl-Erik Eckholm became President of Kymmene. During WWII, the company's production capacity was dramatically reduced. Kymmene lost two factories (Läskelän and Leppäkosken), and one third of its forestlands came under Soviet control [320]. After the war, Finland agreed to pay the USSR war reparations in the form of wood products. Kymmene thus saw an increase in the demand for its products, but it was not until 1955 that the company was able to achieve the production level it had prior to the War [15]. During the early 1960s, the company increased its newsprint capacity with new machines at the Voikkaa mill and a new sulfate pulp mill at Kuusankoski.

During the postwar period, Kymmene also began diversifying into industrial machinery and plastics. In 1952, they acquired shares in Stromberg, an electromechanical company. They also acquired in 1954 the Heinola Radiator factory, a manufacturer of boilers and radiators. In 1955, the company established a joint venture with Kymarno to produce plastic floor products [322].

PERIOD 4 (1966-1978) INTERNATIONALIZATION INTO EUROPE AND NORTH AMERICA

In 1966, Kurt Swanljung became CEO of the company and began internationalization. In 1966, Kymmene formed a joint venture with Kaukas Ab to form Nordland Papier, a producer of fine papers in Northern Germany. In 1969, the company founded Kymmene Papier GmbH, a subsidiary that produced carbonless copy paper in Germany. In 1970, Kymmene opened Eurocan in a joint venture with Enzo-Gutzeit and Tampella to manufacture pulp and paper in British Columbia, Canada[11]. In 1976, Kymmene expanded into the US through the creation of the Leaf River Forest Products Co. to manufacture pulp in Mississippi. In 1977, the company expanded into France, through the acquisition of Papeteires Boucher, a manufacturer of coated papers.

During the 1970s, Swanljung reorganized Kymmene around seven industrial divisions: sawmills, paper, pulp, board, conversion, chemicals, and metals [320]. The company also incorporated new assets to its diversified business portfolio. In the area of plastics and chemicals, the company acquired shares in Pekema, a manufacturer of PVC and polyethylene, and began the construction of a petrochemical plant in Porvoo for the production of polyester plastics. In 1970, Kymmene formed a joint venture with Laporte (UK) and Solvay (BE) to create Finnish Peroxides and became a shareholder of Stymer, a polystyrene manufacturer. In the area of industrial machinery, in 1969 Kymmene acquired a majority shareholder status in Aerator Oy, a manufacturer of aeration equipment. In 1971, the company acquired Santasalo Oy, a manufacturer of mechanic gears and in 1977 acquired Loval, a manufacturer of heat exchangers. All these acquisitions aimed at reinforcing the company's Hogsford metal equipment division. In 1976 Kymmene entered the printing business through a joint venture with the Tilgman Company.

PERIOD 5 (1979-1986) FOCALIZATION AND DIVESTURE OF ENGINEERING DIVISION

In 1979, Fredrik Castrén became CEO of Kymmene and concentrated on a smaller number of industrial products. In 1980, Kymmene sold its brick factory at Soininlahti, and in 1981 they divested its petrochemicals division and closed the Bernsley paper mill in the UK.

In 1983, Kymmene announced it would merge with Stromberg, a large manufacturer of electromechanical equipment. Kymmene had been a minority shareholder in this company since the 1950's, but Castrén, a former CEO of Stromberg, thought there were synergies between the metal and forest products industries [15]. The merger, however, was short-lived because in 1985 Kymmene concentrated back on forest products. They divested their entire engineering division, including the Hogsfors foundry and Stromberg in 1986. The company

[11] In 1976 Kymmene became majority shareholder after acquiring Tampella's shares in Eurocan.

also contracted the range of its paper products, divesting their sticker paper division in 1984 and their shares of the Tilgman printing company in 1985.

To reinforce its forest products base, in 1981 Kymmene formed a joint venture with the Great Northern Nekoosa Corp for building a pulp mill in Mississippi. In 1984, they formed a joint venture with Metsalito, a Finnish paper manufacturer, to produce offset papers, and in 1985 Kymmene merged with Kaukas, another large Finnish forest products company.

Period 6 (1987-1995) Integration into engineered woods and specialty papers

In 1987, Casimir Ehrnrooth, the former CEO of Kaukas took over the company. During this period, the company expanded into the engineered woods and specialty papers market. In 1987, Kymmene merged with Schauman Ab, a large manufacturer of sawn timber, plywood, veneer, and particleboard. In 1990, the company acquired Enso's panel division, including two plywood mills in Heinola and Saynatsalo. In the paper division, Kymmene expanded its manufacturing base into lightweight coated papers (LWC), through the creation in 1987 of Caledonian Paper in Scotland, and through the acquisition in 1990 of French paper manufacturer Chapelle Darblay [320].

In 1991, Harri Piehl became CEO of Kymmene. He continued expanding into engineering woods, focusing exclusively on plywood. The company thus acquired Paloheimolta, a Finnish plywood manufacturer in 1991, Malvaux SA, a French plywood producer in 1992, and Pohjnmaan, a sawmilling company to secure the supply of wood for its plywood operations. In parallel, the company sold the particleboard division in 1994 [323]

Period 7 (1996-2003): Internationalization into the US, Europe and Asia

In 1996, Kymmene announced a merger with Repola, another large and diversified Finnish forest products company. The resulting firm became Europe's largest paper manufacturer and the world's second largest after International Paper [320]. Juha Niemela was named CEO and renamed the company UPM-Kymmene. UPM-Kymmene expanded internationally into North American, European and Asian markets, focusing on a narrower range of core products [324].

In the area of paper, the company moved towards high-grade and recycled papers. Between 1997 and 2002, UPM-Kymmene expanded its paper recycling capacity both in England and Finland. In 1997, the company acquired the Blandin paper Co. of Minnesota. There was interest in acquiring Champion International, but International Paper acquired this company first in 2000. UPM-Kymmene, then acquired Repap, a Canadian manufacturer of pulp and lightweight coated papers (LWC) and in 2001 Haindl, a large German manufacturer of fine papers. The company also began expanding into Asia by building a fine paper machine in China in 2002 [325].

In the area of wood products, the company concentrated on plywood and sawn timber, divesting the architectural doors business and the Nautor yacht-building subsidiary in 1997 and 1998 respectively. The company also expanded its sawmilling capacity in Finland, Canada, Russia, and Estonia through several acquisitions between 2000 and 2002.

In the area of converted papers, the company moved away from containerboards and focused on self-adhesive papers, labelstock, and RFID tags. Between 1997 and 2002 the company made several divestures including their stationery, industrial packaging, thin-films, and liquid packaging units. Internationally, UPM-Kymmene expanded its labels and self-adhesive manufacturing base through acquisitions in Malaysia, Australia, Spain, China, the US, the UK, and South Africa. By 2003, UPM-Kymmene had transformed into the world's largest producer of siliconized papers[12], and the second largest manufacturer of self-adhesive laminates [325].

Another strategic move in 1999 was to start selling electricity contracts to outside consumers. This prompted the company to increase its power generation capacity and to begin producing biofuels through new plants in Finland.

Period 8 (2004-2008) Focalization

In 2004, Jussi Pesonen became CEO and renamed the company UPM. The company was in a tight financial situation following three consecutive years of poor economic performance due to an overcapacity in the European paper market and a depressed advertising industry, the main customer for UPM's magazine papers. The company narrowed their business portfolio and streamlined its manufacturing operations and in 2004 began closing paper, pulp, and plywood mills in Europe and Canada, and shifting its manufacturing base towards China and Uruguay [326]. In 2006, UPM announced a reduction in capacity of 17% in magazine papers and 12% in fine papers in Europe, and in 2007 closed the Moramichi pulp mill in Canada.

In 2008, UPM was reorganized around three main businesses: Energy and Pulp, Paper, and Engineered Materials. In the first area, the company had been expanding its biofuels production through the construction of new power plants that utilized bark, logging waste, peat, and bio sludge as fuel sources. In the area of paper, UPM increased its paper production from eucalyptus pulp in China. The company also concentrated on labels, divesting in 2007 their industrial wrapping unit Walki Wisa and shifting its pressure-sensitive labelstocks manufacturing base to the US and China. In the area of engineered materials, UPM expanded its wood procurement base in Russia and continued focusing on plywood, but closed several unprofitable mills in Finland and Europe.

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[12] Siliconized papers are used in self-adhesive labels

PERIOD 9 (2009-ONWARDS) DIVERSIFICATION INTO FOREST BYPRODUCTS

In 2009, the company redefined itself as a bio and forest products company (Biofore strategy). UPM reorganized around six independent business units: energy, pulp, forest and timber, paper, label, and plywood [327]. In support of this strategy, UPM began diversifying into biofuels, biochemicals, biofibrils (e.g. nanocrystalline cellulose), and other forest byproducts [327]. The goal, as announced by the company's CEO, was to generate, by the end of the decade, at least 50% of UPM's sales from these new business areas [319].

In 2009, UPM expanded its biofuels business by installing new biomass boilers at their mills and completing a pilot test for producing biodiesel utilizing synthetic gas from biomass [327]. That same year, the company established a biorefinery R&D center in Lappeenranta, Finland, and in 2011 announced the creation of a biorefinery to produce second-generation biodiesel [328]. Two other energy-related strategic actions were formation of a joint venture with TuuliSaimaa Oy to develop wind power on company lands, and a decision to participate in the bidding process for building a nuclear power plant in Finland [328].

In the area of paper, UPM began a consolidation process in Europe and an expansion in South America. The company acquired in 2010 Myllykoski and Rhein Papier, two German manufacturers of coated and recycled papers with facilities in Germany, Finland, and the US. These acquisitions aimed at consolidating the European fine paper industry to avoid overcapacity. Thus, in 2011, UPM announced closure of Myllykoski's Finnish mills, a plan to remove 1.2 million tons of magazine paper capacity and a reduction in the company's newsprint manufacturing base [328]. In South America, UPM acquired in 2009 a pulp mill and a large eucalyptus plantation in Uruguay, and in 2011 it announced the expansion of its plantations through the acquisition of 25,000 hectares in that country [328].

3. THE ORIGINS AND COEVOLUTION OF UPM'S UNIVERSITY RELATIONSHIPS

During the late nineteenth century, increased demand from the Russian Empire helped grow the Finnish sawmilling, pulp and paper industries. At that time, Finland was a Grand Duchy attached to Russia, and Russian custom levies protected Finnish producers from other European competitors [294].

During the early 1900s, little internal research was conducted in Finland and most of the technologies utilized in the pulp and paper industry came from abroad [294]. Technical personnel were hired mainly from England, Germany and Austria [329]. During World War I, however, Finnish pulp and paper firms were unable to hire foreign experts, since Germany and Austria were at war with the Russian Empire.

World War I thus triggered a transformation in the Finnish pulp and paper industry with the result that several firms began to develop in-house knowledge on pulp and paper production. In particular Kymmene, UPM's parent company, opened its first R&D lab in

1913 and hired Dr. Adolf Klingstedt, to become the company's first chemist [330]. Dr. Klingsted had studied engineering at the university of Helsinki, and had obtained a PhD in 1912 from the University of Dresden, Germany, where he studied chemical pulping processes [331].

Kymmene's R&D lab was initially based at the company's Kuusankoski mill. The R&D lab conducted studies aimed at analyzing pulp production problems, in particular the use of water. Fishing was an important industry in the Kymi River and maintaining clean river waters was important for this industry and also for the company's steam boilers [329].

In 1916, the Finnish pulp and paper industry created a Pulp and Paper Research Institute (Keskuslaboratorio-Centrallaboratorium, currently called KCL) [332]. The creation of KCL was the work of Dr. Ossian Aschan, a Chemistry Professor of the University of Helsinki, who convinced the forest and chemical industries to fund this central laboratory [333]. Kymmene became one of the first shareholders of this institute, which was originally based at the University of Helsinki [330] (for the history of KCL see vignette in page 259). In 1917, the Institute of Experimental Forest Research was also formed, later renamed as the Finnish Forest Research Institute or METLA [333]. This institute was the work of Prof. A. K. Cajander from the University of Helsinki, who studied forestry in Germany and was in charge of training the first generation of Finnish foresters [333]. Both KCL and METLA have held close collaborations with researchers at UPM ever since.

The Soviet Revolution of 1917 had profound consequences for the Finnish forest products industry, as private trade was banned in Russia. After losing the Russian market, Kymmene and other firms began exporting to other Western European countries. The productivity of Finnish firms and the quality of their products, however, were not competitive against Swedish or Norwegian producers [294]. The industry thus asked KCL to change its research focus from quality assessment to fundamental research related to enhancing productivity and quality of pulp and paper products [294].

The Kuusankoski research lab initially had a research staff of only 6 people during the 1910s. In 1919, Kymmene hired a chemist, Dr. Helmer Roschier, to conduct research on pulping technologies, chemical byproducts from pulping liquors, and the use of machinery to debark trees [330]. During the 1920s, the lab grew in size and in the diversity of research lines and during the 1930s Kymmene began conducting research on water cleaning technologies to remove organic contaminants that interfered with the generation of steam power. Analytical methods to monitor water quality were developed in collaboration with Dr. N. Hagman and Prof. H. Haupt, who also helped to train the company's technical staff [329]. By 1938, the Kuusankoski lab reached 20 researchers, the facilities and equipment had been modernized [330], and the company began establishing laboratories at other factories.

UNIVERSITY RELATIONSHIPS AFTER WWII

World War II had several implications for Kymmene's university relationships. In 1942, the Finnish Government created the State Technical Research Center (VTT), which was authorized to conduct research at the request of companies and other organizations. VTT initially had 10 research labs, among which were the building technology, wood technology, and chemical engineering laboratories, all of whose research was relevant for the forest products industry. VTT's research facilities were located in close proximity to the Helsinki University of Technology, and several of VTT's lab directors were professors from this university [296]. Kymmene has worked on multiple projects with researchers at VTT.

During the postwar period, Kymmene depended on foreign providers for most of the chemicals used in the manufacture of pulp and paper including chlorine, salt, and other chemical products (e.g. Kaolin). Because the supply of these raw materials was limited, Kymmene began studies to find domestic alternatives and to develop the equipment necessary for their production. For these purposes, the company recruited Prof. Emeritus Frederick W. Klingstedt in 1948, a chemist from the Abo Akademi university [329].

In 1950, the company began research on sodium peroxide, which is used as a bleaching agent in pulp production. The synthesis of peroxide required quinone, a chemical that was banned from import. Kymmene sent its technical director Runar Örnhjelm to Germany to negotiate with BASF for producing quinone. Örnhjelm recruited Dr. G. Pleidererin to help Kymmene build a pilot plant for the production of quinone and sodium peroxide. The pilot plant results were a success and in 1959 Kymmene produced sodium peroxide at an industrial scale. In 1960, however, an explosion destroyed Kymmene's industrial plant, forcing the company to find other partners to produce this chemical. In 1970 Kymmene formed a joint venture with Laporte (UK) and Solvay (BE) creating the Finnish Peroxide Company to supply raw materials for their pulp and paper mills [329].

The development of peroxide bleaching was an important milestone as it allowed Kymmene to utilize birch trees for producing pulp. This raw material was cheaper than pine and took fewer steps to bleach. During the 1970s, Kymmene launched a new line of bleached sulfate birch pulps based on studies conducted in collaboration with researchers at Abo Akademi, in particular with Prof. E. Avellan [329].

During the 1960s, Kymmene's Kuusankoski research lab moved to a new building, with modern research facilities. The lab also gained more independence, from an organization standpoint [329]. During the late 1960s, Kymmene began internationalizing into Germany and North America and researchers at Kuusankoski were tasked to conduct studies on cooking and bleaching processes tailored for foreign tree species (e.g. hemlock, spruce).

During the 1970s, Kymmene conducted research in collaboration with KCL on paper furnishings, coatings, and additives (e.g., clays, talc, pigments) to enhance the firm's fine paper products. In addition, Kymmene began to examine how to improve the energy efficiency of their operations to lessen the effects of the oil crisis on production costs [329].

During the 1980s, in the area of lumber production, Kymmene conducted research on wood preservation technologies in collaboration with BASF, developing an anti-fungi chemical named Sinesto in 1984 [329].

INDUSTRY CONSOLIDATION EFFECTS ON UNIVERSITY RELATIONSHIPS

During the late 1980s and 1990s, Kymmene began a series of mergers and acquisitions. Some of the acquired companies also had internal R&D and thus there was an expansion of the firm's university network because the acquired firms retained their university links. Figure 115 shows the different industrial sectors in which the company has been active and the number of university articles within each sector. As shown in the figure, since the 1980s the number of publications between Kymmene and its university partners has been growing.

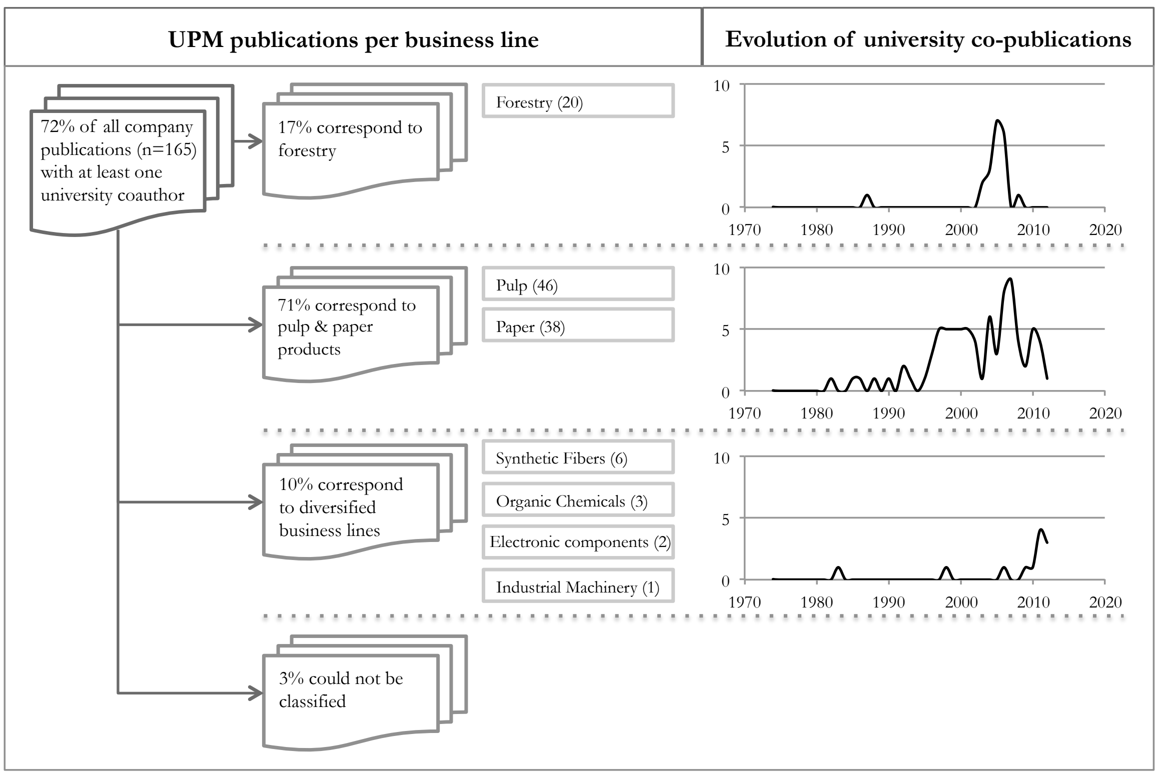

FIGURE 115: COEVOLUTION OF UNIVERSITY CO-PUBLICATIONS AND UPM'S BUSINESS LINES

Figure 115 shows that approximately 70% of UPM's university publications have been concentrated in the areas of pulp and paper technologies. After the merger with Repola in 1996 there was an increase in the number of publications in pulp and paper. More recently, the company has been diversifying into biochemical and biofuels, and we find increased publications with universities in these areas. We did not find any joint publications between UPM and universities on engineered woods.

UNIVERSITY RELATIONSHIPS DURING ECONOMIC DOWNTURNS

Since 2004, the company has been narrowing its business base, to concentrate on a smaller number of products and, as shown in Figure 116, there has been a decline in the number of publications with universities since 2006.

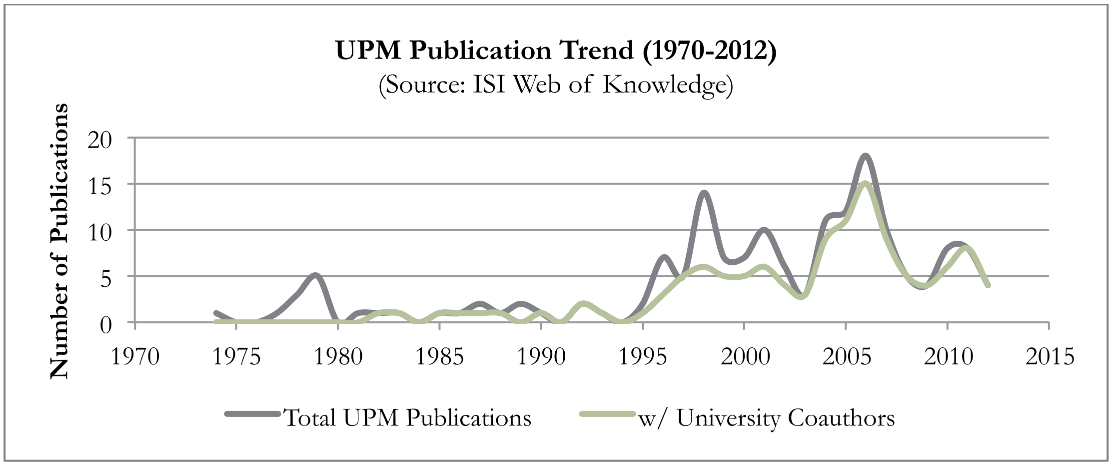

FIGURE 116: UPM PUBLICATION TREND

UPM also has reorganized its R&D in terms of its research interests and the geographical location of its laboratories. In 2005, UPM closed individual R&D labs of the mills, consolidating them through the creation of a new research center in Lappeenranta. As explained by a senior R&D manager, each of the company's paper mills had strong R&D departments during the 1980s; "it made sense since the company only had 5-6 mills, which were in different product areas." After the mergers of the 1990s, however, the company began managing more than 20 mills and thus "it made sense to have R&D activities centralized" [334]. The Lappeenranta research center has close relationships with the Lappeenranta University of Technology and conducts research on fibers, raw materials, papers, coating, printing, and other areas related to pulp and paper production.

In addition to Lappeenranta, UPM maintained two other R&D centers in Finland. The Wisa R&D center, at Lahti, conducts research on plywood and engineered wood products. The Raflatac research center in Tampere conducts research on pressure sensitive labels. UPM also has three research centers outside Finland. The Augsburg research center, which came with the acquisition of Haindl papers of Germany in 2001, conducts research on recycled fibers. The UPM Asia R&D center, in Changshu, China was created in 2007 to conduct research on local fibers and to provide technical support to company operations in the Asia-Pacific region. The company also opened a research center in Uruguay to conduct research on eucalyptus and short-fiber pulps in 2012.

CORPORATE R&D RENEWAL THROUGH UNIVERSITY TRAINING

In 2008, UPM focused its research strategy on biofuels, biochemicals, biofibrils (e.g. nanocrystalline cellulose), and other value-added forest byproducts [327]. These were new areas for the company, which updated the capabilities of UPM's R&D staff and sent 40 researchers, approximately a third of the company's research workforce, to two-year training programs at different universities including VTT and Aalto University. UPM also began building a new Center for Nanocellulosic Technologies in collaboration with VTT, and, in 2008, announced the development of a biorefinery development center for research on biofuels and biochemicals in collaboration with Lappeenranta University of Technology. As summarized by a senior R&D manager: "within UPM's existing business lines, the company already knows well what can be done in terms of research, but as the company moves into new areas of knowledge, you might not find those competencies inside the firm. In these situations, you need much more connections to [university] networks"[123].

3.1. RESEARCH PRIORITIES ALONG UPM'S VALUE CHAIN

We have organized UPM's university relationships from a value chain perspective, distinguishing between forestry and pulp and paper university partners. Figure 117 shows the different processes involved in the forestry value chain. As shown in the figure, most of UPM's university co-publications in forestry have been in the area of forest management, in particular, on decision support systems for forest planning and on stakeholder relationship management. A majority of the publications have been written in collaboration with Prof. Annika Kangas of the Faculty of Agriculture and Forestry of the University of Helsinki.

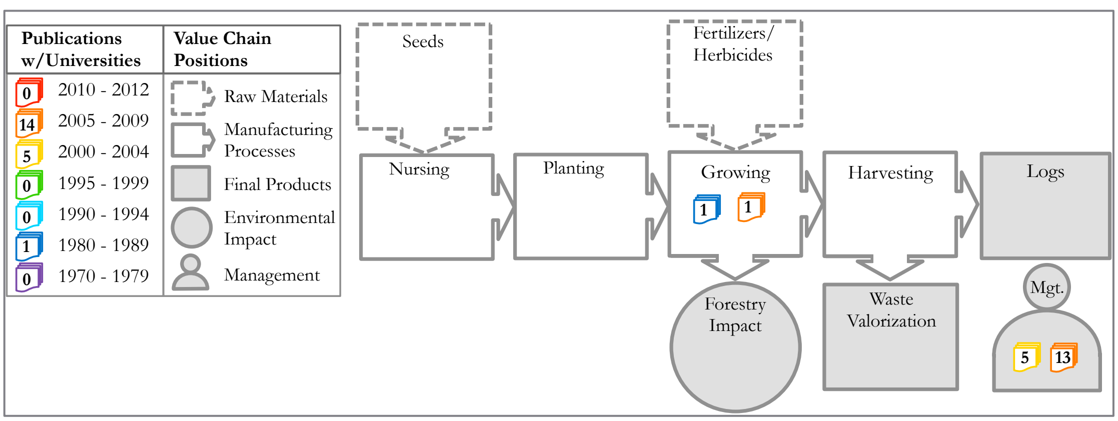

FIGURE 117: EVOLUTION OF UPM'S UNIVERSITY CO-PUBLICATIONS IN FORESTRY

Figure 118, shows the different processes involved in pulp and paper production. We organized the different co-publications according to these different segments and found that most of the firm's university interactions have been concentrated on pulping, washing, waste management, fine papers production, and operations management.

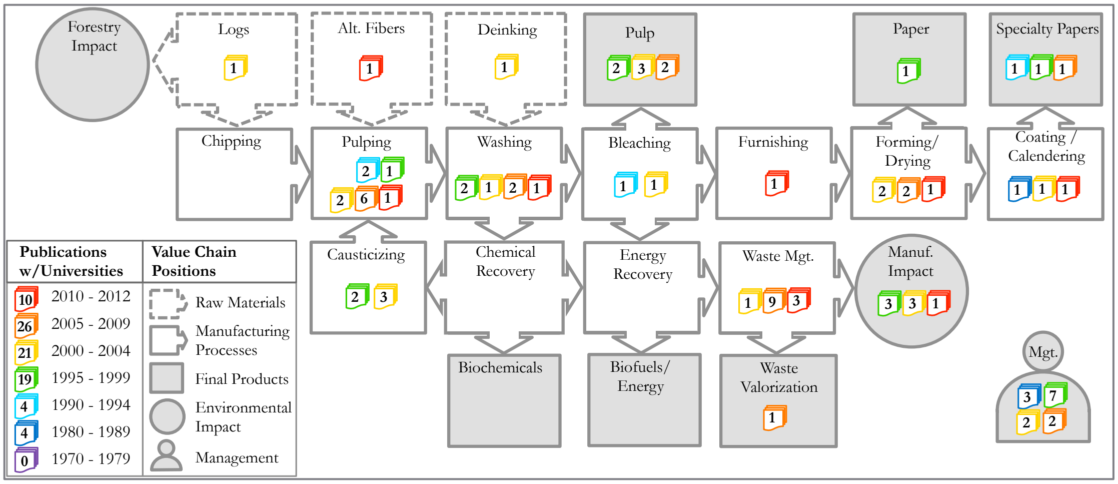

FIGURE 118: EVOLUTION OF UPM'S UNIVERSITY CO-PUBLICATIONS IN PULP AND PAPER

PULPING AND WASHING COLLABORATIONS

Most of UPM's collaborations on pulping technologies focus on improving the thermo-mechanical pulping (TMP); reducing power consumption and improving the chip screening and refining process.

Washing has also been a priority research area for UPM and several studies have been conducted on detecting and reducing the presence of microorganisms (which can cause coloring defects on papers) on paper machines. In collaboration with researchers at the University of Helsinki, the company has tested the effects of biocides and electric polarization as means to eliminate bacteria from paper machines.

FINE PAPERS MANUFACTURING COLLABORATIONS

UPM has conducted several studies to improve the quality and printability of fine papers. In collaboration with KCL, UPM has examined effects of calendaring on the gloss and roughness on printed papers. In collaboration with the University of Turku, UPM has studied the problems caused by static electricity during offset printing.

ENVIRONMENTAL MANAGEMENT COLLABORATIONS

In the area of waste management, UPM has conducted research on nanofiltration technologies in collaboration with the department of Chemistry of the Lappeenranta University of Technology. New membranes have been tested and deployed for treating effluents from the pulp and paper industry.

In terms of manufacturing operations, work has been done to analyze the effects of pulp and paper mill emissions on the environment. In collaboration with researchers at the University of Jyvaskyla, UPM has analyzed the presence of chlorinated phenolic compounds on pine tree needles and has assessed the effects of bleached pulp effluents on fish.

OPERATIONS MANAGEMENT COLLABORATIONS

UPM has collaborated with researchers at the Process Design Laboratory of Abo Akademi to improve company production processes. Research includes reducing paper trim losses and cutting time on converted paper products, and optimizing scheduling tasks through mixed integer linear programming (MILP).

3.2. GEOGRAPHY OF UNIVERSITY PARTNERS

Figure 119, based on UPM's publication records, shows the geographic distribution of the company's local university network. UPM's university network has historically been in Finland, near the company's production sites as described in Section 3.

UPM's most common university partners have been the University of Helsinki, Lappeenranta University of Technology, Aalto University, Abo Akademi, the Finnish Forest Research Institute (METLA), the University of Oulu, and VTT. As in Figure 119, these research centers are in close proximity to UPM's research centers and production sites. The Lappeenranta University of Technology, for example, is located less than 10 miles away from UPM's Lappeenranta research center. VTT, Aalto University, and KCL are all located within walking distance of each other, less than 10 miles from UPM's headquarters in Helsinki. The University of Helsinki is also within walking distance form UPM's headquarters.

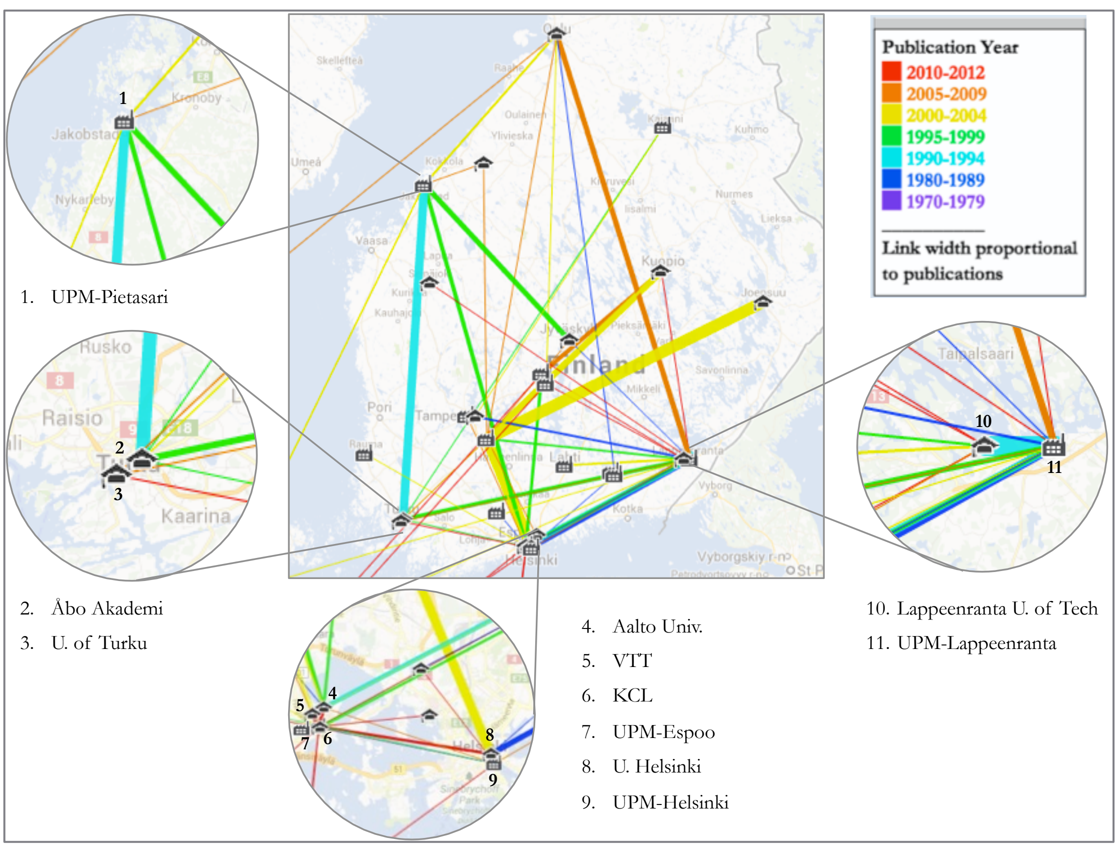

FIGURE 119: UPM'S LOCAL UNIVERSITY NETWORK

UPM's international university network is smaller and has been established more recently than its Finnish university network. Figure 120 shows a geographical representation of UPM's international university partners based on the firm's co-publication records. Most of these international university collaborations have been created to support the firm's international expansion.

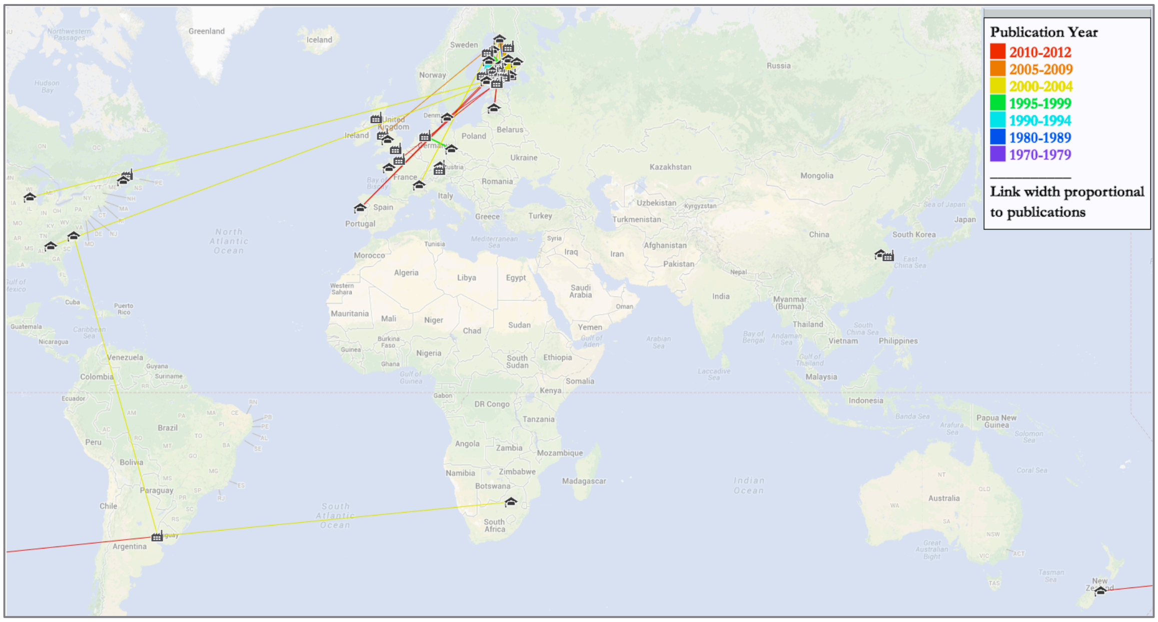

FIGURE 120: UPM'S GLOBAL UNIVERSITY NETWORK

During the late 1990s and early 2000s, UPM internationalized through different acquisitions. In 1996, UPM acquired, after merging with Rauma, a recycled pulp mill in Shotton, UK. In addition, since 1987 the firm has operated a lightweight coated paper mill in Ayshire, Scotland (Caledonian Paper). Researchers from Caldonian Paper have worked with researchers at the Chemical Engineering department of the University of Birmingham on combustion technologies applied to the mill's steam production process. Researchers from the Shotton plant have collaborated with Oulu University on recycled fibers, and researchers from UPM's Tilhill Forestry group, located at Kent, UK have worked with the Scottish Forestry Commission on fungicide control in forests. Figure 121 shows UPM's university network in the UK.

UPM expanded into Canada in the early 2000s by acquiring Repap Enterprises, a magazine paper manufacturer with a mill in Miramichi, New Brunswick. After this acquisition, there were new collaborations between UPM's Miramichi Mill and the university of New Brunswick as in Figure 121. In 2004, however, UPM began a period of focalization that led to the closure of several of the company's mills, including Miramichi in 2007. After this closure, we have not found any research collaboration between UPM and the University of New Brunswick.

UPM's presence in Germany dates from 1966, through the creation of Nordland Papier, and this presence was expanded in 2001 through the acquisition of four paper mills from Haindl Papers. Researchers from Nordland Papier have collaborated with the Technical University of Dresden and researchers from Haindl have collaborated with the University of Augsburg, which is in close proximity to the company's R&D Center in that city (Figure 121).

More recently, UPM has established a manufacturing presence in China and Uruguay (Figure 121). In 2007, UPM established a research center near Shanghai. According to the VP for Business Development: "The new R&D Center in China will enhance [UPM's] competitiveness in local product applications and in the use of locally available fiber resources. We also want to increase our cooperation with local research institutes and universities in this field" [335]. New collaborations with researchers at the NanJing Forestry University have been established on non-wood pulping feedstock (e.g. corn stovers and straw).

In 2012, UPM opened an R&D center in Uruguay. The Director for Latin American Business mentioned "The center aims to strengthen fiber research in plant species growing in the southern hemisphere"…"in addition, the aim is to increase cooperation with research institutes and universities in Uruguay" [336]. New collaborations on eucalyptus forestry have been established with researchers at the Universidad de la República in Uruguay.

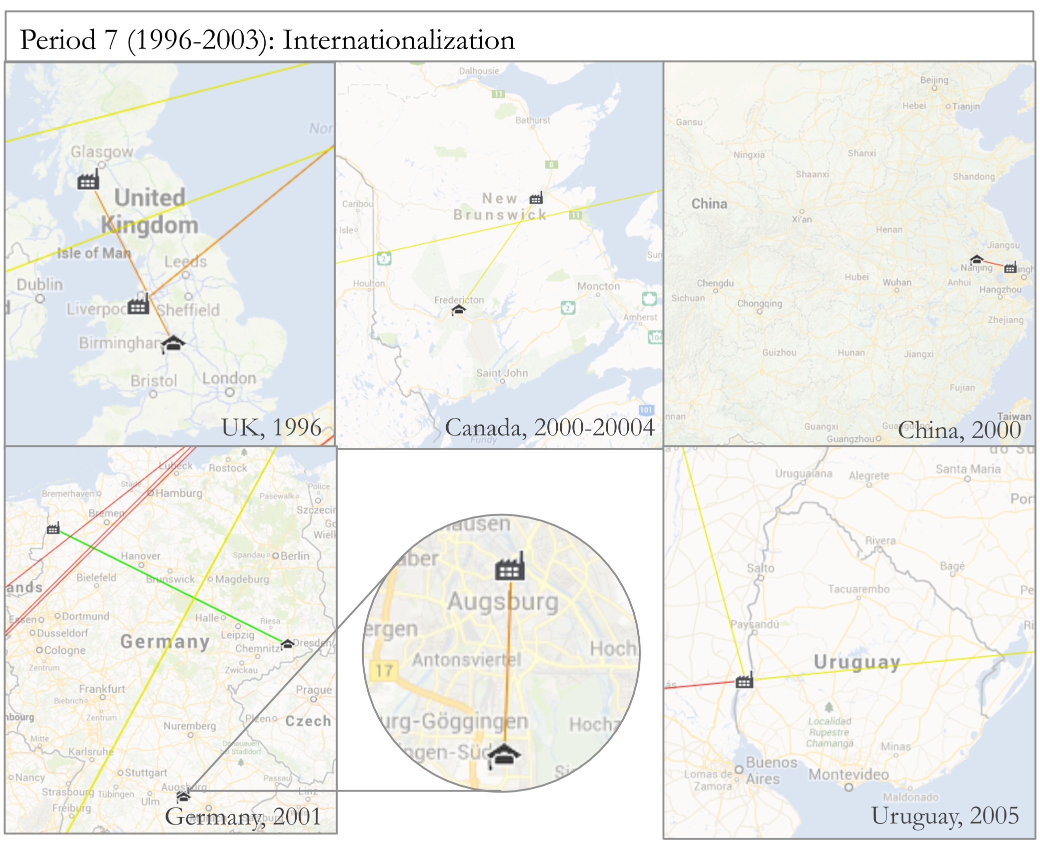

FIGURE 121: INTERNATIONALIZATION OF UPM'S UNIVERSITY PARTNERS

3.3. TECHNOLOGY TRANSFER THROUGH PEOPLE FLOWS

To analyze the academic and professional trajectories of UPM's most prolific authors and inventors we used UPM's publications and patenting records to develop a list of 68 people involved in the company's R&D activities. Each individual in the list has either patented or published at least two papers from UPM's name.

Figure 122 shows the evolution of UPM's research staff. As shown in the figure, most of UPM's R&D personnel were recruited from industry, as a result of the mergers and acquisitions of other firms. The figure also shows that UPM's R&D personnel peaked in 2005, after which the number of people working in R&D declined. After leaving UPM, 25% of these researchers joined other firms, and 6% went back to academic institutions.

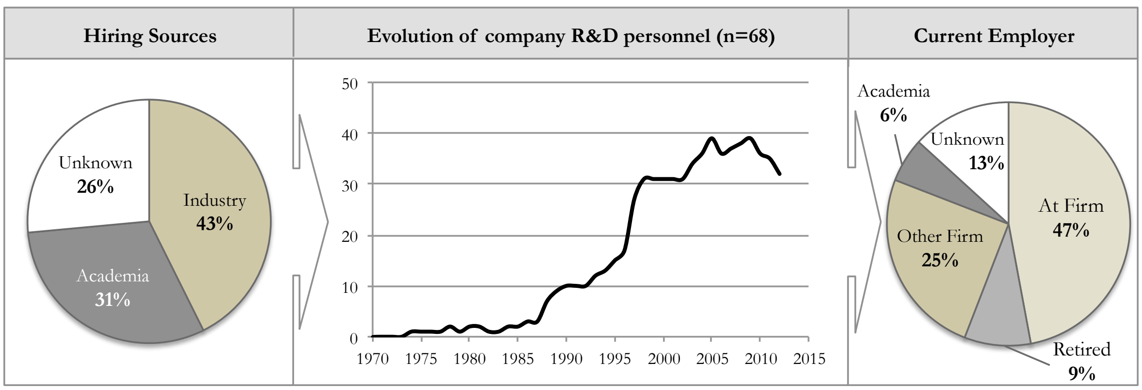

FIGURE 122: EVOLUTION OF UPM'S R&D PERSONNEL

Analysis of the academic training of UPM's researchers shows an overlap between the academic institutions attended by these people and the company's publication partners (Figure 123). The most common university attended by the firm's R&D personnel has been Abo Akademi, followed by Aalto University, Tampere University, Oulu University, the University of Helsinki, and the Lappeenranta University of Technology. This overlap is indicative that firms recruit from universities that have developed expertise in knowledge areas relevant for the firm, and that when people move across organizations they move with their networks. As explained by a senior R&D manager, "Professors in those universities are evaluating students for us. And they are saying hey, these students have good performance why don't you sponsor a Master's thesis with them and see what they can bring to your company. So they are really helping us in the recruitment of new people" [334].

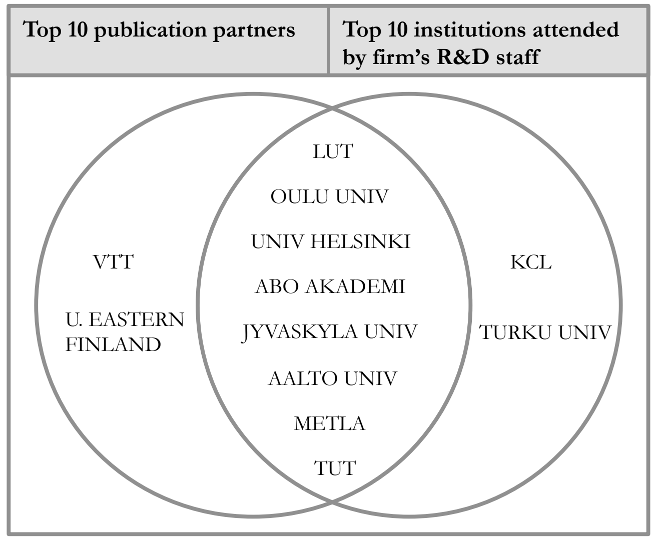

FIGURE 123: OVERLAP BETWEEN UPM'S HIRING AND PUBLISHING PARTNERS

4. Case Study Discussion

UPM has endured several strategic changes and participated in a diverse set of industries and regions over time. This provides an opportunity to analyze how changes in UPM's strategy have affected its relationship with universities and research institutes. Table 18 presents a summary of these findings. The table shows the different strategic periods of the firm, and how UPM's research priorities, people flows, and institutional networks were modified as a consequence of the changes in the firm's strategy.

TABLE 18: SUMMARY OF HOW UPM'S UNIVERSITY RELATIONSHIPS COEVOLVED

University Links / Firm Strategies	Research Priorities	People Flows	Institutional Networks
Period 1: **Integration** (1873-1917)	**Environmental mgt.** • Water usage and water cleaning technologies	**First R&D Center** • Est. in 1913 at the Kuusankoski Mill • Recruited researchers trained in Germany	**Creation of KCL and Metla** • Kymmene one of the first shareholders of KCL
Period 2: **Internationalization** (1918-1936)	**Production processes** • Improve quality and productivity of pulps • Chemical byproducts, tree debarking techs.	**Growth in R&D Ctr.** • From 6 researchers to 20 researchers in 1938 • New facilities with modernized equipment	**KCL changed research focus** • Close relationships between KCL and U. Helsinki • KCL extended reach to Abo Akademi University in Turku
Period 3: **Diversification** (1937-1965)	**Chemical raw materials** • Secure supply of raw materials and produce domestic alternatives	**New R&D centers at mills** • Creation of new R&D labs at different mills	**Creation of new institutions** • 1942 creation of VTT, new relationships with this institute • 1958, creation of Oulu Univ.
Period 4: **Internationalization** (1966-1978)	**New pulps and feedstock** • Peroxide-bleaching • Pulping of foreign tree species	**Expansion through JVs** • Collaborated with Finnish firms to expand into US, German, and Canadian markets	**Finnish Univ. network growth** • Creation of new universities in Lappeenranta (1969), and Tampere (1972)

PERIOD 5: **FOCALIZATION** (1979-1986)	**Specialty coated papers** • Furnishings, additives, printing properties • Production control	**R&D staff trained locally** • R&D staff recruited exclusively form Finnish Universities	**Mostly Finnish connections** • Few joint publications with universities
PERIOD 6: **INTEGRATION** (1987-1995)	**Printing quality of papers** • Paper coatings and furnishings	**Growth in R&D Staff** • New staff and joined through mergers	**University network expansion** • Mainly Finnish universities and research institutes
PERIOD 7: **INTERNATIONAL-IZATION** (1996-2003)	**Environmental Impact** • Forestry certifications • Effluents and emissions monitoring and control	**R&D staff peaked** • New staff and R&D centers through mergers **International R&D Staff** • New R&D center in Augsburg, Germany	**International network growth** • New projects with universities in Germany, UK, Canada
PERIOD 8: **FOCALIZATION** (2004-2008)	**Forestry Operations** • Stakeholder management **Operational efficiency** • Biomass combustion • Waste management	**R&D restructure in Finland** • Consolidation of R&D centers at Lappeenranta **New R&D Center in China** • Located at Changshu mill	**Merger of Finnish Res. Ctr.** • UPM sold shares in KCL, which merged with VTT **Joined in R&D Consortia** • Finnish Bioeconomy Cluster
PERIOD 9: **DIVERSIFICATION** (2009-ONWARDS)	**Bio-Forest products** • Biochemicals, Biofuels, Nanocrystalline cellulose, biocomposite materials **Alternative fibers** • Corn stovers and straw for papermaking	**Retraining of R&D staff** • Sent 1/3 of R&D staff to a two-year training program at local universities **New R&D Ctr. in Uruguay** • Forestry & eucalyptus pulps	**Strategic R&D Alliances** • Biorefinery pilot plant with Lappeenranta University • Biofibril research center with Aalto Univ. and VTT **International network growth** • New projects with universities in China and Uruguay

UNIVERSITIES AS A COMPETENCY RECONFIGURATION PARTNER

UPM's last strategic change led to a complete revision of the company's existing R&D practices. As explained by a senior manager, before 2009 most of the research efforts aimed at small product developments and productivity-enhancement projects related to the company's existing business lines [334]. The Biofore strategy (period 9) changed the firm's R&D focus. The company expanded into value-added forest products including biofuels, biocomposite materials, nanocrystalline cellulose, and biochemicals. "We really started thinking more on the long term and defined the strategic competencies and technological platforms needed to create these new businesses for the company. While the amount of resources we spend in R&D has remained roughly the same, the R&D portfolio is totally different. More than half of our R&D funds go to develop these new business areas" [334].

Because the Biofore strategy involves expanding into new technological areas, UPM relies on an expanded network of university partners to gain technological competencies. "Before 2008, we collaborated with the university partners we knew; however, when we started going in these new areas we needed to find other partners with the required skills" [334].

As explained by a senior R&D manager, UPM defined a "really precise process" for finding new university partners. First they conducted an Internet search looking for research groups with expertise in the areas. They analyzed where those groups were located, and narrowed the list to 5 or 10 potential partners to visit. The company then evaluated different aspects:

whether the university group had enough resources to support the collaboration, and whether they were willing to work with the firm. The company then made a selection and signed an agreement with the university group. As explained by the R&D manager "[We] start with one project, if that is successful, then we can continue to bigger programs, so it's a continuous process of deepening the cooperation with the university" [123]. Through this process, the company selected VTT and Aalto University to create a new Center for Nanocellulosic Technologies. The company has also sent 40 researchers, almost 1/3 of the company's R&D staff to update their technical knowledge at VTT and Aalto University.

UNIVERSITIES AS KNOWLEDGE BUFFERS: THE MILOX PULPING PROCESS

The UPM case also illustrates that universities act as knowledge buffers allowing corporate technologies to mature. The development of the MILOX pulping technology shows how technological knowledge can be preserved at universities even after industry loses interest in its development.

During the 1980s, there were increased environmental pressures to reduce organochlorine compounds (i.e., dioxins), a toxic byproduct of the pulp bleaching process [337]. In 1984, KCL began studying peroxy acids to replace chlorine from the bleaching process. Initial laboratory tests revealed that pulps cooked with peroxide acids could be bleached using alkaline hydrogen peroxide to a 90% brightness [338]. Based on this finding, KCL developed the MILOX (Milieu Oxidative) a three-stage process to cook and bleach sulfate pulps through the use of hydrogen peroxide and formic acid.

To develop this technology at an industrial scale, KCL worked in collaboration with TEKKES (the Finnish Innovation Agency) and with Kemira Oy, a Finnish manufacturer of hydrogen peroxide and formic acid [338]. In 1991, Kemira established a pilot plant at Oulu, and began studying how to recover formic acid from washing liquors, a necessary step for industrializing the process.

Interest in the MILOX process, however, declined after the Swedish firm Eka Nobel launched the Elemental Chlorine Free (ECF) bleaching process in 1989. This technology modified the bleaching sequence through the introduction of extended cooking and oxygen delignification pre-bleaching stages and the utilization of an oxygen and peroxide reinforced extraction stage, significantly reducing dioxin discharges. Since ECF required only minor modifications to the existing bleaching sequences, it was widely adopted [337].

Kemira and the pulp and paper company owners of KCL stopped funding the development of MILOX in the early 1990s, both in response to the emergence of ECF, and also after feasibility studies conducted by the consulting firm Jaako Poyry Oy showed that while capital costs for building a full-size plant would be similar to those required for building a conventional Kraft mill, operation costs of the MILOX process would be 20% higher [339].

In 1995, KCL transferred the rights of MILOX to Chempolis [340], a company formed by Esa Rousu, who had been the director of Kemira's Oulu plant during the pilot plant trials. During the late 1990s, Rousu continued developing the MILOX technology in collaboration with researchers at the University of Oulu. In particular with Prof. Juha Tanskanen, who was between 2001 and 2010 was part of Chempolis' R&D team and who became a partner of this company [341].

The development of the MILOX pulping technology highlights the role universities play in allowing corporate technologies to mature. UPM, who was partially owner of KCL lost interest in MILOX during the 1990s. The technology, however, was not lost and researchers at the Oulu University were able to develop this technology into a process that allowed the pulping of non-wood fibers such as straw or corn stovers. In 2008, UPM licensed this technology to produce paper from non-wood sources at UPM's China subsidiary [341]. In other words, UPM was able to regain this technological capability thanks to the work at Oulu University and Chempolis. Figure 124 summarizes the different institutions, people, and development paths followed by the MILOX technology.

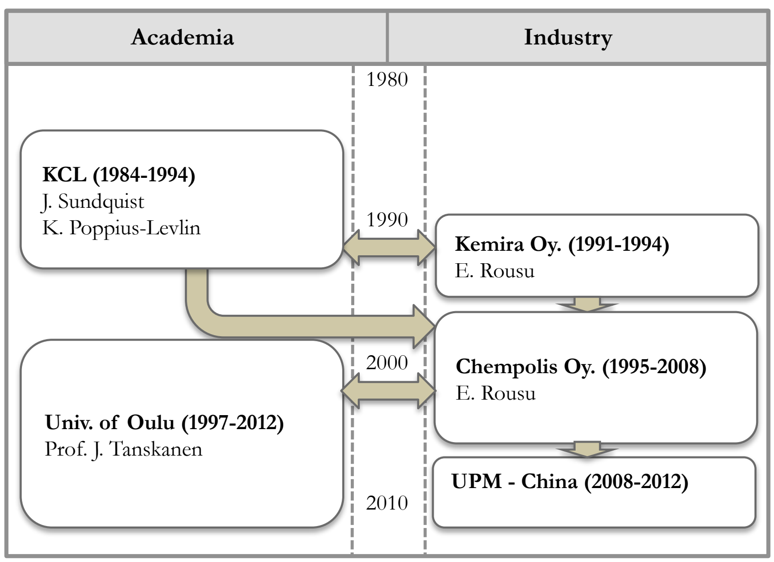

FIGURE 124: BIDIRECTIONAL KNOWLEDGE FLOWS IN THE DEVELOPMENT OF MILOX

SYSTEMIC EFFECTS OF INDUSTRIAL CONSOLIDATION

The UPM case also illustrates how changes in the firm's strategy affect the universities and research institutes research agendas. The consolidation of the Finnish pulp and paper industry during the 1990s had multiple consequences for Finnish Pulp and Paper Research Institute (KCL). Between 1985 and 2000, the number of corporate sponsors of KCL was reduced from 25 to only 4 firms [340]. Because of the drop in corporate sponsors, KCL had to narrow the diversity of business lines and concentrate only on paper products.

More recently, UPM's paper business is facing declining markets in North America and Europe. The company has closed several mills and removed production capacity in these regions to concentrate on Asia and South America where paper markets are growing. As explained by a senior manager "Our main business, paper, has been challenged a lot lately. We have many assets in Europe, but paper usage is going down. So you can say that our assets are in the wrong location because paper should be regarded today as a local business. Earlier the thinking in the company was that paper could be shipped wherever in the globe. Well, that that was the time when the business was still very profitable… but now when demand going down, we should steer our production to growing markets [334]".

The relocation of the paper industry is also affecting Finnish universities and research institutes. In 2009, KCL was merged with VTT. Approximately 160 KCL researchers were transferred to VTT, which reoriented research efforts towards biofuels, biochemical, printed intelligent products, and biocomposite materials [342]. Until January 2009, approximately 10% of UPM's research was conducted in collaboration with KCL. After the merger of KCL and VTT, UPM's collaborations with KCL have decreased [327].

UPM's local university partners are also being affected by the change in the firm's strategy. Since 2005, UPM had concentrated most of the research on paper and pulping technologies at a research center in Lappeenranta, which worked in close collaboration with researchers at the Lappeenranta University of Technology (LUT). Since 2008, UPM has focused less on pulp and paper products, with consequences for LUT. As explained by a senior manager "The competences we need at this moment are totally different. For example, with LUT we had a very strong connection on the pulp and paper [research] areas. But now that there are less and less activities happening in paper [technologies], we have reduced collaborations in that area [334]".

UPM has continued to work with LUT; however, it has reached out to other university departments. As explained by a Senior R&D manager, "Lappeenranta is very strong in separation technologies because they are working in a very tight connection with the mining industry. This is a key technology for our new projects. If we think about biochemicala, biofibrils, they need some sort of separation in their [production] process. Now we are having a much more deeper relation with that department [334]".

Because LUT had a wider set of capabilities, it could continue working with UPM. This contrasts with KCL, which had to be merged with VTT to gain the complementary competencies demanded by industry.

KCL AS A HYBRID INDUSTRY-UNIVERSITY RESEARCH ORGANIZATION

During World War I, the Finnish pulp and paper industry realized they had become dependent on foreign knowledge and technology. The War, however, limited access to foreign experts and thus in 1916 the pulp and paper industry, along with the textile and chemical industries, collaborated in the creation of a central laboratory called Keskuslaboratorio-Centrallaboratorium (currently called KCL).

The mind behind the creation of KCL was Dr. Ossian Aschan, a Chemistry Professor of the University of Helsinki, who convinced these industries to fund the lab [333]. Dr. Ossian had previously worked in Berlin between 1907-1908 for the Actien Chemical Company (Chemisch Fabrik auf Actien), and was a firm advocate for cooperation between academia and Finnish industry [333].

Since its creation, KCL has held close relationships with the Helsinki University of Technology (currently Aalto University) and with the University of Helsinki, where it was originally based [333]. In 1919, KCL moved to Turku to have a closer relationship with Åbo Akademi University. This collaboration, however, was unsuccessful and thus in 1925 KCL returned to Helsinki to be closer to industry [340]. Among the first research assistants of KCL was Dr. A. I. Virtanen, who after leaving KCL won the Nobel Prize for his work on food preservation.

In 1942, the Finnish State created VTT, a state-owned research institute. The Finnish textile and chemical industries, which were also owners of KCL, sold their participation in KCL and move all non-forest products research to VTT [340]. The Finnish pulp and paper industry thus took full ownership of KCL during the post war period.

In 1962, KCL moved to Otaniemi, to be close to Aalto University and VTT. During the 1960s, KCL had a research staff of approximately 200 people, which reached a peak of 360 people in the late 1990s [340].

KCL's technological equipment has been modernized over the years in response to industry demands. Initially, KCL was equipped with a pilot plant for the production of pulp and paper. During the late 1960s, KCL added new machines for the production of coated and calendered papers. During the 1970s, KCL added a TMP/CTMP pulping plant. These pulping technologies utilize chemicals and thermal treatments to reduce the amount of energy required in pulping, and thus constituted an important area of research during the 1970s because the industry faced increased production costs because of the oil crisis.

During the 1980s, the Institute expanded into printing technologies by adding a sheet-fed offset machine in 1985, a flexographic printing machine in 1987, and a heat offset printing press in 1988. During the 1990s, KCL increased its capacity for fine paper production by adding new coating and supercalendering machines.

KCL had also developed technologies for the production of value added chemicals form pulping waste liquors. During the 1970s, for example, KCL invented Karatex, a lignin-based adhesive used in plywood, particleboard, and fiberboard manufacturing. The advantage of Karatex, compared to urea-formaldehyde resins, is that it does not release formaldehyde into the environment and thus constitutes a safer adhesive for wood-based products (formaldehyde is known to be a human carcinogen [179]). R&D Magazine selected this innovation as one of the 100 most significant technical products of 1981 [343].The Karatex technology was acquired by the Metsä Group, a Finnish forest products firm, who began production of Karatex at its Aanekoski board mill [340]. In 1985, KCL developed the Lignobond process, which allowed separating lignin form spent pulping liquors. This technology allowed producing lignin-based coating materials for paper, enabling the production of stronger, water-resistant packages. The Metsä Group also acquired this technology in 1989.

The consolidation of the Finnish forest products industry during the 1990s had multiple consequences for KCL. In 1985, approximately 25 Finnish pulp and paper companies funded KCL. After multiple mergers and acquisitions between Finnish forest products companies, only 4 firms funded KCL in 2000 [340].

Since the 1990s, KCL has reduced in size and diversity of R&D lines. Its chemical products department, which was in charge of developing Lignobond and other chemical byproducts of pulping, was disbanded in 1990. KCL focused research on fine papers, acquiring a second coating machine in 1995, a supercalendering machine in 1999, and an ink-jet printing machine in 2008 [340]. In 2009, KCL was merged with VTT, after which it changed its research focus towards biofuels, biochemical, printed intelligent products, and biocomposite materials [342].

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