Technological Change for Environmental Improvement: The Case of the Mexican Automobile Sector

by

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ABSTRACT

The main objective of this research was to articulate the processes and factors of technological change that promote environmental improvement while contributing to development goals in the Mexican automobile sector. The motivation stemmed from the need for air pollution mitigation in the Mexico City Metropolitan Area (MCMA). The research analyzed three cases of environmental technology introduction in passenger vehicles, and synthesized the case findings into a conceptual model. The case studies were complemented with quantitative analyses of parameters of national technological capability acquisition, and scenario analysis of emission mitigation potential.

The research showed that environmental technological change in the Mexican auto sector is increasingly influenced by external factors, specifically global sector development and conditions in countries with major auto producers and export markets. Environmental technological change could be articulated within the framework of conventional technological change, with some differences, such as: the need to account for environmental policy as a distinct factor, different motivations of private sector actors in acquiring technological capabilities and deploying technology, and interactions and conflicts between environmental policy and other factors, which can create barriers.

The research found that environmental policy is a necessary but not sufficient factor to induce environmental technological change in Mexico. Environmental policy did and does influence environmental technological change by specifying the time and pacing of technology introduction. The scenario analysis showed the projected effectiveness of technology options.

Recommendations for the Mexican policymakers include: (1) the role and limitations of environmental policy in the process of environmental technological change should be recognized; (2) policymakers should strive to minimize institutional fragmentation, which undermines policy implementation; (3) vehicle technology options should be considered further, due to their effectiveness, and political and institutional feasibility; (4) the environmental authorities are likely to encounter opposition to Mexico-specific

technology requirements, particularly if they are more stringent than in the US or Europe; and (5) the authorities' ability to benefit from the export platform to introduce advanced technologies in Mexico will be diminished if export markets shift towards markets with less stringent emission standards than the US and Europe.

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Chapter 1.
Introduction and Context

Section 1.1: Research Motivation

Technological change is a key agent of economic growth.[1] It improves industrial production, enabling economies to generate the wealth required to increase social welfare and development. Technological change is especially pertinent for industrial sectors that are technologically intensive, such as the automobile sector. The automobile sector is considered as an example of a vehicle of development, due to its extensive and dynamic linkage with sectors that produce intermediate inputs, its large workforce, and the final product that symbolizes progress to many (Womack, 1990). The automobile sector in some developing countries, including Mexico, has played an important role in the process of industrial development.

From the sustainability perspective, however, the role of technological change and industrialization is ambiguous. On the positive side, technology has played a crucial role in reducing or controlling environmental damage, such as air pollution. Technology has also allowed us to produce more with less energy and resources, or to substitute one resource for another. On the negative side, industrialization has been associated with increasing demands for natural resources, which often translate to higher rates of toxic and greenhouse emissions and natural resource degradation and/or depletion. In addition, the income growth associated with development tends to result in higher levels of consumption of goods and services, with commensurate environmental impacts.[2]

The automobile sector and cars embody several specific concerns for sustainability, particularly for developing countries. Growing numbers of private vehicles, many of which are equipped with inadequate or antiquated emission control technologies, rising travel distances, and frequency have made the transportation sector responsible for a disproportionate amount of emissions and energy use. Congestion, inadequate and

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1 See Solow, 1962, Hill, 1979, and others as described further in this chapter.

2 Various analyses have shown an inverse-U-shared relationship between environmental degradation and income. This pattern has been called the environmental Kuznets curve, as the relationship is similar to the time-series income inequality described by Kuznets (Kuznets, 1955). Various explanations for this relationship have emerged in the literature. Some have argued that the natural progression of economic development, from agriculture to industry and ultimately to service economy, is reflected in the Kuznets curve (Arrow, Bolin et al., 1995). This progression may accompany the exportation of highly polluting industrial activities to developing countries (Suri and Chapman, 1996). Others have argued that pollution abatement requires advanced institutions and collective decision making, which may only emerge in developed countries (Jones and Manuelli, 1995). Another explanation is based on the technological link between consumption and abatement (Andreoni and Levinson, 1998). Understanding why this relationship is observed is important, as corresponding interventions have significant policy implications.

polluting public transportation, and limited access also affect mobility in large metropolitan areas, such as the Mexico City Metropolitan Area (MCMA). Together, these factors curtail socioeconomic development and pose equity concerns (WBCSD-MIT-CRA, 2001, Marks, 2001).

A major challenge for sustainable industrial development is the technological capability acquisition in sectors with significant economic and social impacts, *and* whose products or processes have substantial environmental impacts. In this context, the fundamental question that motivates my research is stated as follows:

> *What are the processes and factors of technological change that promote environmental improvement while contributing to development goals in the Mexican automobile sector?*

This research is concerned with two fundamental issues for sustainable industrial development: technological capability of the Mexican automobile sector, and the potential for environmental technologies mandated by environmental policy to address air pollution. Because these two fundamental issues are influenced by policy, the research aims to understand the conditions under which policy can facilitate technological change for environmental improvement. The research is based on cross-applications of theories and frameworks of general technological change to analyze environmental technological change, as described in further detail in this chapter and beyond.

Section 1.2: Theoretical Basis of Research

This research draws upon different bodies of literature, including technological change for general and environmental reasons, and sustainable development. They are described further in this section and elaborated further in Chapter 6.

1.2.1 Technological Change

The adoption of industrial modes of production is the primary means by which economies generate the wealth required to increase social welfare and development. This transformation of production is fundamentally a process of technological change, which has been recognized as the key agent of growth by many scholars.[3] Technological change is concerned with change in the way in which inputs are transformed into outputs, including changes in output quality (Fransman, 1984).

Technology refers to the process of physical transformation of inputs to outputs, and knowledge and skills that structure the activities involved with such transformations (Kim, 1997). Theoretical development in the past 20 years has resulted in the broadening

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3 Solow estimated that technical change accounted for approximately 90% of the increase in output per capita in the US economy over the period 1909 to 1949. Other scholars, such as Jorgenson, Griliches, and Denison, also found that technological change contributed to growth, but more modestly than Solow (Solow, 1962, Hill, 1979).

of the traditional conception of technology to recognize the "software" elements, including technical and managerial capacity, and related organizational and institutional arrangements. Such software elements are considered critical for successful technology transfer. Technology transfer refers to the diffusion of technology, including the transfer of scientific knowledge into technology, and adaptation of an existing technology to a new use (Brooks, 1966, OECD, 1981). For developing countries, technology transfer has been a key mechanism for technological change.

Technological capability and its acquisition can be conceptualized as one key component of the process of technological change (Norberg-Bohm, 1996). Describing technological change as a process implies that it is a sequence of interconnected events, with activities and motivations discerned at different points in time to facilitate the understanding of the process (Girifalco, 1991).

Achieving technological change requires technological capability, which refers to the capacity to adopt, adapt, or create new technologies. Dahlman et al. (Dahlman, Ross-Larsen et al., 1987) articulated three types of technological capability as production capability, investment capability, and innovation capability. These steps are similar to the three elements of technological capability acquisition advocated by Amsden (Amsden, 1989), which include production capability, project execution capability, and innovation capability. The literature on technological capability has grown since the late 1970s, due to an increasing acknowledgment that traditional theories of technological change were inadequate in explaining industrial development in developing countries. There has also been a growing recognition that technological capability acquisition is sector and context specific, and requires in-depth analysis. Various scholars have since carried out inductive studies at the firm and sector level in various developing countries.[4] A large number of variables that influence technological change have been identified from such studies, which were analyzed in this research.

Technological change, as defined earlier, includes change in a product or a production process. As such, technological change can be thought to encompass all, or part, of invention, innovation, and diffusion, articulated by Schumpeter (Schumpeter, 1935).[5]

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4 Some key contributions include an analysis of metal working industries in Latin America (Katz, 1984), an analysis of effects of trade, science and technology policy on technological capacity in India (Lall, 1984), and the firm level analysis of an integrated steel mill in Brazil (Dahlman, Ross-Larsen et al., 1987).

5 Schumpeter defined these concepts as follows:

- <u>Invention:</u> creation of a new device, idea, or product, process, or system. The term implies an expectation of its theoretical functionality, but not at the stage of commercialization or prototyping
- <u>Innovation:</u> entails commercial or practical application of the new device (first application of an invention)
- <u>Diffusion:</u> process whereby a new technology or technique is adopted over the course of time (Schumpeter, 1935)

Schumpeter's articulation, where technological change plays a dominant role in economic development, has had a significant impact on analyzing technological development in developing countries (Fransman, 1984).

Within the developing country context, technological change has tended to be based on diffusion, enabled through technology transfer as explained earlier. Also, incremental innovation, which refers to technology adaptations or assimilations to suit local conditions under which technologies must operate (Nelson and Winter, 1982) has played a role for developing countries.

Developments in the theoretical literature have highlighted a set of critical market failures typical of the developing country context to be considered in policy formulation, including:

- Lack of information and technological capability
- Non-competitiveness of technology markets in developing countries
- Path-dependency

Lall conceptualized technological capability acquisition as an interaction of incentive structures with technological effort, human resources, and institutional factors, facilitated by government policy to overcome market failures and to protect activities with genuine dynamic potential. While the notion of government intervention in the case of market failure is a well-established one, especially within the context of environmental protection, the scope of such intervention and policy instruments appropriate to address these market failures within the context of industrial development is more controversial, especially for developing countries (Lall, 1996, Lall, 1992).[6][7] In addition to the role of policy, the role of institutions has been well articulated in the literature.[8] Within the developed country context, the evolution of institutions within and outside the political realm has been attributed as a significant contributor to economic growth (Rosenberg and Birdzell, 1986). Rosenberg and Birdzell further argued that institutional limitations have hampered the developing countries to achieve economic development.

1.2.2 Sustainable Development

Concurrent to the evolution of the technological development theory, the need for a fundamental change in production processes and products for a move towards sustainable development has become more widely accepted.[9] The principle that environmental performance of an economy is a function of the nature, scope, and scale of technologies

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6 For example, Ashford and Heaton articulated the rationale for government intervention in environmental and safety issues as a way to internalize social costs associated with market activities (Ashford and Heaton, 1976).

7 Some critics argue that the market failure model constitutes an insufficiently broad framework for policy interventions for industrial development. Others, such as Von Hayek and Ostry question the ability of the government to make sound decisions. The market failures identified above, however, enjoy wider agreement as a basis of intervention within the technological development literature (Weiss, 1997).

8 There exists a large body of literature on the role of institutions in economic development. See Powell and DiMaggio, 1991 for in-depth analysis of this literature.

9 See Pezzoli, 1997 for a multidisciplinary review of the literature on sustainable development.

in economic activities is well understood.[10] The importance of technological change for sustainable development was articulated in the definition of sustainable development in the World Commission on Environment and Development (WCED) as follows:

> *Sustainability is a set of activities that "meets the needs of the present without compromising the ability of future generations to meet their own needs. The concept of sustainable development does not imply limits – not absolute limits but limitations imposed by the present state of technology and social organization on environmental resources and by the ability of the biosphere to absorb the effects of human activities. But technology and social organization can both be managed and improved to make way for a new era of economic growth (WCED (World Commission on Environment and Development), 1987)."*

The Commission further observed that procedures and policies that influence the international exchange of technologies must stimulate innovation and ensure ready and widespread access to environmentally sound technologies. In this respect, the importance of environmentally sound technologies has been recognized as an essential strategy to achieve sustainable production and consumption in the international community, and endorsed in seminal documents such as Agenda 21 (United Nations, 1992).

1.2.3 Technological Change for Environmental Improvement

While there exists a body of literature on general technological change in both developed and developing countries, few examples of explaining the process of environmental technological change with theories and concepts of general technological change exist, particularly in the developing country context.[11][12] To my knowledge, no systematic analysis has been conducted on environmental technological change in the automobile sector in Mexico. Previous analyses tended to focus more on manufacturing industries, with significant process impacts, rather than product impacts. One analysis of the electric

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10 Some scholars align towards technological optimism, arguing that science and technology will continue to de-couple goods and services from demands, and assuming a high degree of substitutability (or fungibility) among resources, goods, and services (Ausubel, 1996, Solow, 1993). Others have aligned towards technological pessimism, arguing that there are ecological limits beyond which technological responses are not effective, and cautioning that an over-reliance on technology may bring about unintended and undesirable consequences (Daly, 1991, Meadows, Meadows et al., 1992, Kryer and Gillette, 1985).

11 I define environmental technological change as technological change that specifically addresses environmental concerns, such as air pollution mitigation.

12 Conversely, environmental improvement has been identified as a factor of general technological change. Recent patent data analysis of the Japanese automobile sector from 1986 to 1995 found that the three major drivers of technological change are driving quality improvement, safety, and environmental improvement (Miyazaki and Kijima, 2000).

sector in Mexico has found that there exists different determinants that are important for understanding sustainable development in this particular sector that have not been identified in conventional studies on technological change (Norberg-Bohm, 1996). In addition, limitations of existing analytical frameworks, such as their general nature and limited focus on only parts of the process, have been noted for environmental technological change, as observed in general technological change. The need for sector-specific and process-based approaches has been articulated.

1.2.4 Role of Environmental Policy

The key to sustainable industrial development is finding ways to better align governmental policies and industry interests (Kauffman, 2001). The literature on the linkage between environmental regulation and industry response, however, presents a conflicting picture, resulting in an emergence of diverging theoretical frameworks. Some have written about competition in laxity, where states competing for industry are said to engage in a race towards undesirably low levels of environmental regulation (Stewart, 1977, Swire, 1996). Others have countered that firms get a competitive advantage from enhanced environmental performance, and perceive environmental regulation as an important, positive influence on their behavior (Porter and van der Linde, 1995). Alternatively, some have explained that Stiglarian incentives could be used to provide concentrated benefits to those who must bear the regulatory costs of environmental compliance, in order to overcome Olsonian collective action problems (Olson, 1965, Stigler, 1975). Others have found that the outcomes defy generalization, as the results tend to be sector specific, or depend on process versus product regulations (UNU-INTECH, 2001, Murphy and Oye, 1998).

Section 1.3: Research Significance

The specific focus of this research is the technological change for air pollution mitigation in the Mexican automobile sector. This focus on automobiles and air pollution in Mexico is pertinent and warranted due to a number of reasons. First, there is a clear need for policy and technology analysis for air pollution mitigation in the Mexico City Metropolitan Area (MCMA), particularly from transportation sources. Among the set of sustainability concerns, air pollution from automobile emissions is one of the most critical, due to its acute and chronic health effects in humans and serious impacts on economic productivity. The MCMA is a prime example of a developing country mega-city in which air pollution concerns have come to the forefront of the public policy debate.

The second reason is the well-documented effectiveness of technological options for air pollution mitigation in developed countries. For example, a significant percentage of emission reduction has been attributed to technology options in the US. Compared to other options that tend to require behavior modifications, technological options have been more effective in reducing emissions (Howitt, 1999, Howitt and Altshuler, 1992). The demonstrated effectiveness of emission mitigation technologies allows for meaningful analysis of technological change for general versus environmental reasons.

The third reason is the strategic importance of the automobile sector for overall national economy. As a developing country with a strong automobile sector, Mexico's long-term economic development relies on acquiring technological capability in this sector. The sector is characterized by dynamic technology development, which has resulted in significant production and organizational changes. The intermediate input requirements foster domestic production and technological advancements in other sectors, such as steel, plastics, and electrical machinery sectors. It generates a large number of direct and indirect jobs, many of which are in dynamic and technologically intensive environments. The sector employs about 15% of the Mexican labor force, as described in more detail in Chapter 3. The sector has generated substantial foreign exchange in Mexico, and is the second highest export sector. A large potential for spill over and learning effects exists, due to its numerous backward and forward linkages (Studer-Noguez, 1999). The sector's influence on other industries is recognized, evidenced by a large body of literature and data that can be utilized in my research.

The fourth reason for focusing on this sector is more practical than the above reasons. There is an established and readily accessible locus of expertise on technical and policy aspects of the automobile sector at MIT. This locus of expertise has generated a considerable amount of data and analysis (see Weiss, Heywood et al., 2000, Heywood and Weiss, 2001, WBCSD-MIT-CRA, 2001). This research was conducted within the MIT Integrated Program on Urban, Regional, and Global Air pollution, also referred to as the Mexico City Project.[13] For my research, the project has provided a platform for data collection and access to primary sources of information, which are the Mexican automobile sector and various government agencies. In addition, the integrated assessment has provided a framework for my research on emission reduction potential of technologies.

Furthermore, the effects of vehicular emissions are felt at local, regional, and global levels, necessitating response that incorporates local as well as global concerns. Impacts of product use and benefits of air pollution mitigation are felt in both developed and developing countries. A large percentage of the environmental and public health impacts of automobiles are realized during product use, rather than during production (Shafer, 2000). Emission reductions have thus been driven by the environmental product standards of the country in which the product use takes place, as opposed to process and production methods of the producing countries. Mexico falls under both categories – it is a producer for developed and developing countries, as well as an importer from both developed and developing countries. To better understand the dynamics that influence technological change, the effects of production trends and various standards on production and product need to be further explored.

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[13] The Mexico City Project is a collaborative research and integrated assessment effort to assist Mexican decision makers in their efforts to improve air quality in Mexico City. It aims to gain a better understanding of physical and chemical processes of air pollution, to analyze and balance economic, social, and technological factors, and to assist in decision making in the face of uncertainty and incomplete data. Because of the close collaboration with the Mexican authorities, the project is expected to have a direct impact on improving the ability of Mexican policymakers to address air pollution issues (Mexico City Project, 2002).

Finally, the technology focus allows me to compare and contrast the role of environmental policy in developed versus developing country context. Many emission reduction technologies have initially been commercialized in developed countries, such as the United States, which have applied technology-forcing regulations to stimulate their development to comply with tightening emission standards. Developing countries, on the other hand, tend to introduce such technologies after they have been made available elsewhere, using technology-following standards (Faiz, Weaver et al., 1996). As such, the role and impacts of emission standards for technology introduction may be different between the developing and developed countries, even if the results in terms of emission reduction may be the same. Informed policy making to realize both environmental and development goals requires a better understanding of technological change for sustainability in the developing country context. These observations point to an interesting and robust case for analysis that can generate important insights into the differences and similarities in developed and developing countries.

Section 1.4: Scholarly Contribution and Relevance of Research

Two criteria have been established for research projects in the social sciences (King, Keohane et al., 1994). The first criterion of research is that a research project should make a specific contribution to an identifiable scholarly literature by increasing our collective ability to construct verified scientific explanations. The second criterion is the relevance of research to the real world. These are described in more detail in this section.

1.4.1 Contribution to Literature

My research contributes to the field of sustainable development in two ways. The primary contribution is through cross-applications of theories of general (i.e., non-environmental) technological change that promotes economic development to environmental technologies. The second contribution is developing a model to examine the effectiveness of emission mitigation technologies in automobiles for the Mexico City Metropolitan Area. The model allows me to analyze whether technological options result in emission reduction, which is the fundamental goal of introducing such technologies.

Environmental Applications of Theories on Technological Change

The primary contribution to the sustainable development literature is the cross-applications of theories or evidence from another field of literature, namely technological change and industrial development. Viewing the introduction of environmental technologies within the framework of conventional technology and technological change may generate insights for more successful environmental technological change. To date, relatively little attempt has been made to integrate mainstream development literature to problems of and challenges for environmental technology. This may be because there has been an insufficient crossover of the two disciplines to examine the role of non-environmental policy tools in the promotion of environmental technology. Two distinct disciplines and literature (development professionals versus environmental professionals) historically have not interacted. The second reason may be that while the rationale for policy intervention in environmental protection is widely accepted, focusing on the technological change inherent in environmental technology inevitably must move into the realm of industrial policy formulation, which is more controversial.

Effectiveness of Technology Options for
Air Pollution Management in Developing Countries

The second contribution to sustainable development is finding evidence of the efficacy of technology-oriented policies for air quality management within a developing country context. Air quality management options and their effectiveness in terms of cost and air quality benefits have been analyzed within the developed country context, especially within the United States. Such analyses have found that technology-oriented options tend to be more effective in terms of emission reduction, cost, and ease of implementation, compared with options that entail behavior modification, as stated earlier in this chapter (Howitt, 1999).

My analysis generates some evidence on the effectiveness of technology-oriented options for air pollution management from mobile sources in Mexico. While emission reduction options have been analyzed in Mexico before, the scope and time frame of the analyses have been limited (CAM, 2001). My analysis incorporates policy-relevant factors of environmental technological change, and is thus more comprehensive. Also, the timeframe of analysis is 25 years, which allows me to project longer-term emission reduction potential of technologies.

Finally, my research applies various theoretical frameworks on the role of environmental policy to analyze different aspects of the case study findings, and also to examine the explanatory power of these theories.

1.4.2 Relevance to Real World Issues

The second criterion of research is that a research project should pose a question that is important in the real world. My research interest, sustainable development, is an issue of critical concern in both developed and developing countries. My professional experience in the United Nations Environment Programme (UNEP) has also confirmed the urgent need to find ways to facilitate environmental technology transfer, particularly in industrializing countries. In addition, this research is part of an on-going integrated assessment project on air pollution mitigation in Mexico City, which is supported with by the Mexican government, the World Bank, National Science Foundation, and MIT. In particular, the analysis on factors of environmental technological change and analysis of future policy options (scenario analysis) have been specified in the research contract between MIT and the Mexico City Metropolitan Environmental Commission (CAM). These observations underscore the importance of the topic in the real world.

Section 1.5: Dissertation Outline

This dissertation includes eight chapters. Chapter 1 discusses motivation and significance of the issue selected for the research and provides the theoretical context. Chapter 2 presents the methodological framework of the specific research components and their rationale. Chapter 3 describes the contributing factors of air pollution as well as institutional and political frameworks of air quality management in Mexico. The economic and industrial profile of Mexico is also highlighted in Chapter 3. Chapter 4 describes the comparative analysis of technological change at the national level. Chapter 5 describes the case studies of environmental technology introduction in Mexico. Chapter 6 introduces a conceptual model that explains the three technology case studies, based on theories and concepts of general technological change. The development of an emission projection model for the Mexico City Metropolitan Area is described in Chapter 7. Chapter 8 presents the conclusion and discusses the policy and theoretical implications of the research findings.

- **Chapter 2—Research Questions and Methodology:**
  Chapter 2 introduces specific research questions and the methodological approaches used in the research. It describes the three major components of my research and rationale for the chosen methodologies.

- **Chapter 3—Environmental and Industrial Profile:**
  Chapter 3 presents historical and current states of air pollution in the MCMA, and analyzes five main contributing factors, highlighting the role of automobiles in the problem definition. Institutional and legal frameworks for air pollution mitigation are described. The chapter also summarizes the evolution of policies and strategies for air pollution mitigation from mobile sources, with an emphasis on technological responses. In addition, the economic and industrial profile of Mexico is summarized.

- **Chapter 4—Comparative Quantitative Analyses of Technological Change:**
  Chapter 4 describes the comparative analysis of parameters of technological capability acquisition from 1980 to 2000 in Mexico and its peer countries, compared to the US and Japan. The statistical and econometric analyses delineated an anomaly in the Mexican experience of technological capability acquisition. The chapter presents some numerical evidence of Mexico's reliance on exogenous sources of technological capability, as well as the decline in the relative ranking compared to other countries. The chapter also presents the econometric analysis that described the manufacturing value added performance, which includes the automobile sector, as a function of human capital and economic structure.

- **Chapter 5—Case Studies of Environmental Technological Change:**
  Chapter 5 presents three case studies of environmental technological change in the Mexican auto sector, namely catalytic converters, Tier 1 technologies, and on-board diagnostics. The chapter shows evidence from interviews and a survey that environmental technological change has been influenced by various policy and non-policy factors. It also describes the role of environmental policy as a determinant of timing and pace of technology introduction, and suggests that environmental policy is a necessary but not sufficient factor to induce environmental technological change.

- **Chapter 6—Conceptual Model Development:**
  The development of a conceptual model of the process and factors of

environmental technological change is presented in Chapter 6. The model is based on policy-relevant parameters, as the determinants of technological change are thought to be susceptible to policy interventions. The model is applied to analyze policy implications to facilitate environmental technological change.

- **Chapter 7 - Scenario Analysis:**
  Chapter 7 presents the scenario analysis of emission reduction potential in the private vehicle fleet in the Mexico City Metropolitan Area. The chapter describes the development of the emission projection model, which is used to estimate the emission reduction potential of various policy options and their cost implications from 2000 to 2025.

- **Chapter 8 - Conclusion:**
  Chapter 8 summarizes the findings of the research, and suggests a conceptual model that incorporates factors of technological change for environmental technologies in the Mexican auto sector. The chapter further explores implications of the research findings. The chapter concludes by presenting future research agenda.

Chapter 2.
Research Questions and Methodology

Chapter 1 introduced the foundation of this research, as well as its environmental and technological contexts. This chapter presents the research questions and methodological approach to answering the questions. Section 1 discusses the fundamental and specific questions that have motivated this research. Section 2 describes the research methodology and steps taken to answer the research questions. Section 3 presents the rationale for the methodology, as well as measures to ensure validity and reliability of the research.

Section 2.1: Research Questions

2.1.1 Fundamental Question

The fundamental question that motivates my research, as introduced in Chapter 1, is as follows:

> *What are the processes and factors of technological change that promote environmental improvement while contributing to development goals in the Mexican automobile sector?*

This research is concerned with two fundamental issues for sustainable industrial development: technological capability of the Mexican automobile sector, and the potential for environmental technologies mandated by environmental policy to address air pollution. Because these two fundamental issues are influenced by policy, the research aims to understand the conditions under which policy can facilitate technological change for environmental improvement. .

2.1.2 Specific Questions

In order to analyze the fundamental question, the following specific questions are addressed within my research:

- *How are the factors of technological change similar and different for general versus environmental technologies?*
- *How do these factor differ in the developed versus developing country contexts?*
- *What is the role of policy, especially environmental policy, in facilitating introduction of environmental technologies?*
- *What is the projected effectiveness of technological options for air pollution mitigation in the Mexico City Metropolitan Area?*

These specific questions are concerned with gaining a better understanding of technological change in general and specifically for air pollution mitigation, which may differ in developed versus developing countries. The research also addresses how technological change in general differs from technological change for environmental reasons. The last question is concerned with expected emission reduction potential of specific technologies in the Mexico City Metropolitan Area (MCMA) in the next 25 years, and how technology options compare with other, non-technology-oriented, emission reduction options.

2.1.3 Research Goal

The goal of this research is to develop a conceptual model that describes the process and factors of the introduction of environmental technologies in the Mexican automobile sector. The model development and application aims to generate policy-relevant insights by articulating factors and processes that are considered to be susceptible to policy interventions.

Another product of this research is an emission projection model that estimates impacts of various technology and non-technology policy options on criteria pollutant emissions in the Mexico City Metropolitan Area from 2000 to 2025.

Section 2.2: Research Methodology and Steps

The research was principally based on cross-applications of theories and frameworks of general technological change to analyze environmental technological change. The research included the following five specific steps:

1. Sector and country profile development
2. Comparative quantitative analyses of technological change
3. Case studies on environmental technological change
4. Conceptual model development
5. Scenario analysis of emission reduction options

First, in order to understand the specific historical and institutional contexts within which environmental technological change has taken place in Mexico, profiles of legal and institutional frameworks and the automobile sector were developed. Technological capability at the national level and manufacturing performance were then analyzed quantitatively. The Mexican performance was also compared with its peer developing countries, the United States, and Japan. The quantitative analyses identified important factors of general technological capability acquisition and anomalies in Mexico, which warranted in-depth analysis. Three case studies of environmental technology introduction in the Mexican auto sector were subsequently conducted. A conceptual model of environmental technological change was then developed, based on the common elements abstracted from the case studies, and informed by theories and concepts of general technological change. Because the research question is concerned with environmental outcomes, i.e., emission reduction, an emission projection model was developed and applied to analyze future technology and behavior options.

Each research step contained sub-tasks, which utilized different quantitative and qualitative methods. They are described in detail in the following sections. Figure 1, attached at the end of this chapter, shows a schematic of the methodology and research steps.

The time frame for the profile, comparative analysis, and case studies was from 1980 to present, which corresponds to the introduction of the three technologies analyzed as case studies. This time frame also captures changes in environmental policy and general shifts in industrial development strategies that have taken place in Mexico. The time frame for the scenario analysis was from 2000 to 2025, which allowed me to analyze scenarios that contain advanced technologies with longer-term introduction projections.

2.2.1 Step 1: Sector and Country Profile Development

The objectives of the first research step included the following:

- To characterize air quality in the Mexico City Metropolitan Area (MCMA) and to analyze the role of automobiles in air pollution
- To describe legal and institutional frameworks for air quality management in Mexico
- To characterize the auto sector development in Mexico

This analysis was based on literature review, using the process-tracing approach. The research step contained two main tasks, as described below. This research step is described in Chapter 3.

Task 1–1: Environmental Profile

The first task was to develop the country profile to characterize Mexico in terms of the following from 1980 to the present:

- Air pollution problem definition, contributing factors, role of automobiles
- Institutional and legal frameworks for air quality management
- Vehicle emission control policies and standards, technologies adopted for air pollution mitigation

Task 1-2: Economic and Industrial Profile

The second task ran parallel to the first task, and focused on the economic and industrial profile of Mexico. In particular, the economic performance and development strategies that Mexico has taken in the past 30 years were examined, as well as the structure and performance of the automobile sector.

2.2.2 Step 2: Comparative Quantitative Analyses of Technological Capabilities

The second research step had the following objectives:

- To analyze how indicators of technological capabilities of Mexico compare with other countries
- To describe what parameters explain manufacturing performance in Mexico and other countries
- To identify anomalies in Mexico (if any) that may influence the understanding of technological change, which merit in-depth investigation in the next step

The two main tasks described below were carried out quantitatively by statistical and econometric analyses. This research step is described in Chapter 4.

Task 2–1: Statistical Profile of Technological Capability

The first task was a comparative analysis of indicators of national technological capability in Mexico, its peer nations, Japan, and the US, during the case study period (1980–2000). Mexico's peer nations included: Argentina, Brazil, India, South Korea, Singapore, and Thailand. Indicators were selected from the literature on technological capability, building on the analysis by Lall (Lall, 1992). The statistical assessment was conducted on following indicators, with data obtained from the World Bank (World Bank, 2000) to ensure consistency.

Table 1: Categories of technological capability indicators

Science and Technology	Economic Structure	Human Capital
R&D expenditure, scientists, engineers, technicians in R&D, journal articles, patent applications, high tech exports	Manufacturing value added, gross domestic investment, manufactured exports, foreign direct investment	Education expenditure, labor force with various levels of education, school enrollment

Task 2-2: Analysis of Manufacturing Value Added and Influencing Factors

The second task was to examine how manufacturing sector performance of Mexico and eight other countries listed in Task 2-1 could be explained by other parameters of technological capability. Manufacturing value added was used as a proxy for automobile sector performance. A regression analysis was carried out at the country level to evaluate how the Mexican case has compared with other countries, and to identify any anomaly in Mexico that should be explored further in this research.

2.2.3 Step 3: Case Studies of Environmental Technological Change

The objectives of the third research steps were the following:

- To identify and analyze various factors that have influenced the introduction of air pollution mitigation technologies in the Mexican automobile sector
- To examine the role of policies, particularly in environmental policy, in the introduction of environmental technologies
- To find observations that characterize differences and similarities in environmental versus general technological change in the Mexican automobile sector

The three technology cases were: catalytic converter introduction in 1993, Tier 1 vehicle technology introduction in 1999, and on-board diagnostic (OBD) system introduction from 2002. The case analysis required primary data collection, which was carried out through interviews and a survey. The data were also supplemented with literature review. This research step contained three tasks, as described below. This research step is described in Chapter 5.

Task 3–1: Identification of Factors Specific to Automobile Sector for Air Pollution Mitigation

A preliminary list of factors of general versus environmental technological change for the sector was developed, based on the findings from the quantitative analyses, described in Research Step 2, and the literature.

Task 3-2: Interviews and Survey with Policymakers and Automakers

This task required primary data collection, which was conducted through a survey of automakers and focused interviews with industry representatives and policymakers. They were asked to analyze the factors and the processes delineated so far, and to identify more specific determinants. They were also asked to differentiate between general versus environmental technological change. The interviewees included policymakers from the 1980s and 1990s to get historical perspectives. The MIT Program on Urban, Regional, and Global Air Pollution provided a high-visibility platform to gain access to key industry and government representatives.

Task 3–3: Cross Analysis of Three Cases of Environmental Technological Change

2.2.4 Step 4: Development of Conceptual Model

The objective of this research step was to develop and refine a conceptual model that analyzes environmental technological change. There were three tasks in this step, and first two were somewhat iterative as the model was refined with observations from specific applications. This research step is described in Chapter 6.

Task 4–1: Conceptual Model Development

This task involved building a conceptual model of the process of environmental technological change. The process stages were identified in the theories and concepts of general technological change. The factors were synthesized and articulated from the case studies, quantitative analysis, and past analyses of environmental technological change.

Task 4–2: Model Application to Three Cases

The survey and interviews generated information on the relative importance of different factors to explain the three cases. The explanatory power of the conceptual model was enhanced with specific descriptors that link factors and process stages in each case. The model application also highlighted the general trend in changes in factor importance that emerged during the analysis period.

Task 4–3: Analysis of Policy Implications

The conceptual model is based on policy-relevant factors, as the factors of technological change it postulated are at least partially susceptible to policy interventions. Thus, the policy implications of the model could be analyzed. Such analysis included implications of environmental regulation, industrial policy, trade-related policy, and their interactions. This analysis also generated insights for future policy making in these areas. Also, the differences in general versus environmental technological change were articulated.

2.2.5 Step 5. Scenario Analysis of Emission Reduction Options

This research step analyzed the effect of technology-related options on the overall air pollution mitigation in the Mexico City Metropolitan Area (MCMA). An emission projection model to analyze future technology and behavior options for passenger vehicles was developed. The model application provided quantitative estimates of emission reductions expected from various policy measures that influence the adoption of air pollution mitigation technologies. The analysis period was from 2000 to 2025. This research step is described in Chapter 7.

Task 5-1: Model Development

An emission projection model for the MCMA was developed, based on assumptions and methods used in the 1998 MCMA Emissions Inventory. The model was built using Microsoft Excel, and was linked to socio-economic projections for the MCMA (Dodder, Galindo et al., 2001) to evaluate option performance under different plausible futures.

Task 5-2: Scenario Formulation and Model Analysis

Future scenarios of policy implementation for air pollution reduction were constructed. They included technology-oriented options, such as more stringent emission standards, as well as non-technology options, such as driving restrictions for older vehicles. The emission projections were then linked to a cost model to analyze total costs of policy options to analyze policy efficacy.

The results of this step have been used in the on-going multi-attribute trade-off analysis, within the framework of the Mexico City project, which was described in Chapter 1. Projected emissions for automobile-related scenarios are combined with additional scenarios on freight, public transportation, as well as industrial and residential activities to carry out trade-off analysis of emission reduction options in the MCMA. Total emission projections are also used for atmospheric modeling and health-based cost-benefit analysis.

Section 2.3: Rationale, Validity, and Reliability of Research

2.3.1 Rationale for Methodology

While technological change is a well-studied subject, the availability of scholarly output on environmental technological change specifically remains limited. The limited availability of scholarly output relevant to my questions necessitated the in-depth case study approach. In addition, the case study approach enabled me to analyze policy outcomes and processes by which such outcomes are achieved. The merits of sector- and firm-level inductive analyses have also been recognized in the literature on general technological change.

There are potential disadvantages to the case study approach, including the indeterminacy of the causal mechanism. George and McKeown (George and McKeown, 1985) recommended a set of measures to strengthen small-n studies: increasing the number of cases, reducing the number of variables considered, focusing on the cases that are comparable, and by working with and attempting to construct simple theories of few variables.

Following these recommendations, my research included a number of observations within the 20-year time frame to analyze temporal changes. The comparability of cases in research step 3 was addressed by focusing on technologies in one field (automobile sector) with a similar objective (air pollution mitigation). Individual case analysis used the process tracing procedure, which is a method of identifying causal mechanisms by investigating the process of how various initial conditions cause the observed outcomes (George and McKeown, 1985). The quantitative analysis in research step 2 compared countries with similar levels of development, all with significant automobile sector importance in the national economy, across the same time period.

2.3.2 Validity and Reliability

In order to ensure the quality of data and analysis, it is important to maximize validity, reliability, and replicability of data (King, Keohane et al., 1994). Validity refers to measuring and analyzing the parameters of interest. Reliability means the use of the same procedures and data by different researchers will yield same measures and same results.

To improve my research validity, I have used variables that have been identified and accepted as effective indicators in existing literature. The use of multiple indicators increases the comprehensiveness of analysis. To maximize the reliability of my research, a wide range of materials were used, both from primary and secondary sources. Primary sources included policy documents, interviews, and questionnaire responses from the industry, government, academic institutions, and other stakeholders. Secondary sources included journal articles, reports and analyses from the World Bank, the Mexican government, and other sources.

Questionnaire responses and interview transcripts may be made available with adequate provision to protect the privacy of individual respondents, if appropriate, and other sources are readily accessible. The replicability of my research is supported by footnotes and bibliographic essays, and providing records of methods, rules, and procedures for data collection.

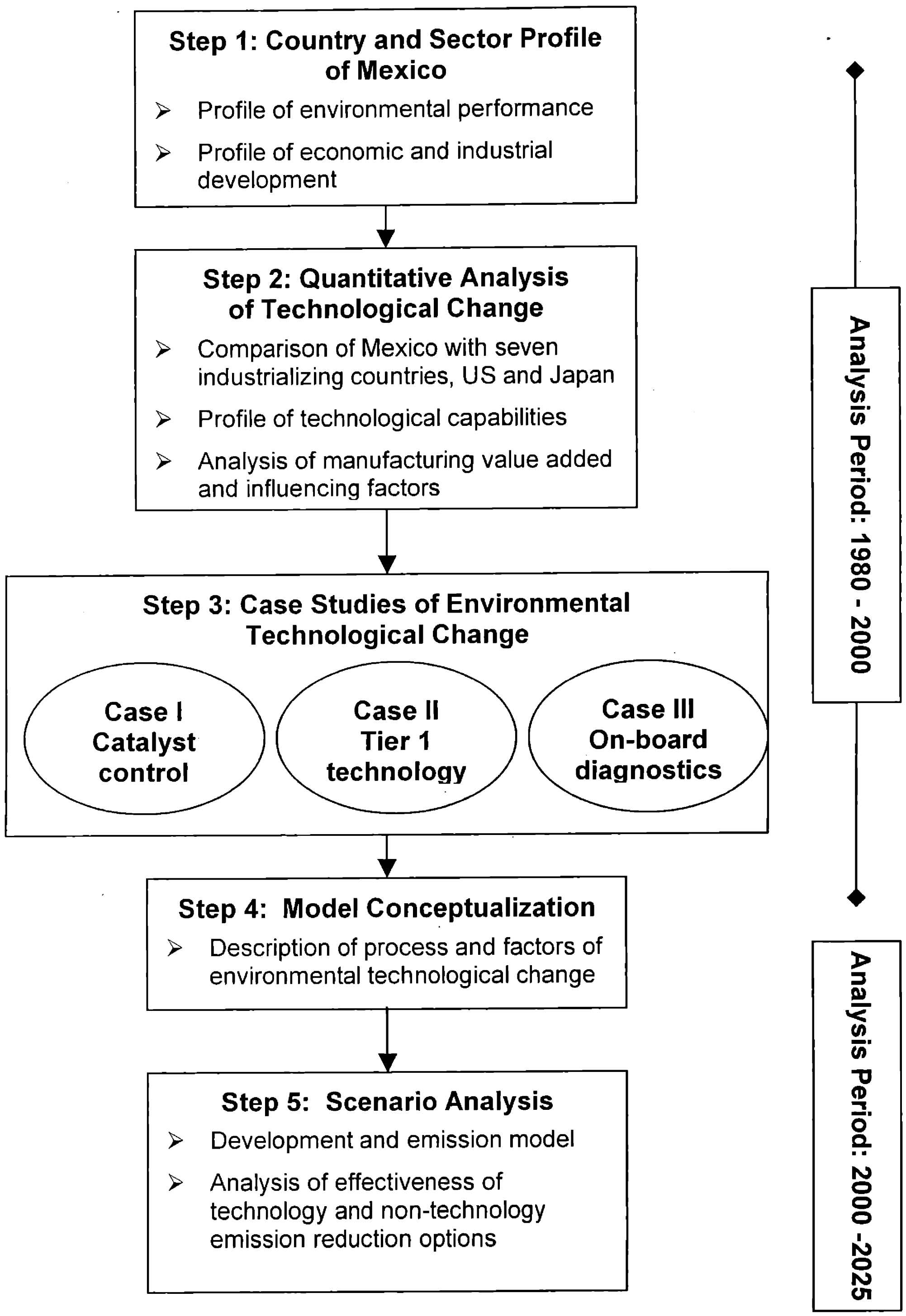

Figure 1: Research steps

Chapter 3.
Environmental and Industrial Profile

While the link between air quality and effects on human health and the environment has long been recognized, serious government interventions to control air pollution did not begin until the 1970s in industrialized countries. Many developing countries, including Mexico, lagged behind in undertaking control measures, although their citizens and government officials were becoming increasingly aware of the problem. By the 1980s, the Mexico City Metropolitan Area (MCMA) had become one of the most polluted areas in the world, with pollutant emissions exceeding the air pollution standards on a regular basis.

This chapter consists of five parts. The first section presents the historical and current states of air pollution in the MCMA. The second section describes the main contributing factors of air pollution and sources, which highlight the role of transportation. The third section summarizes the current and past legal and institutional frameworks for air quality management. The fourth section describes the evolution of policies and strategies for air pollution mitigation for the Mexican automobile fleet, with an emphasis on technological responses. The fifth section summarizes the economic and industrial profile of Mexico, focusing on the development of the automobile sector.

Section 3.1: The Air Pollution Problem

The air quality today in the MCMA is far from adequate, despite some tangible improvements that have been achieved in the past decade. Concentration limits, or criteria, have been established in Mexico for six pollutants that have been found to have adverse effects on humans and the ecosystem. These six criteria pollutants are: carbon monoxide (CO), nitrogen oxides (NO_X), sulfur dioxide (SO_2), ozone (O_3), particulate matter smaller than 10 micrograms (PM_{10}), and lead (Pb).[14]

To evaluate the severity of air pollution at present, three indicators that show trends in the pollutant concentration levels are examined in this section. These indicators are: peak concentrations of pollutants, the number of standard violations of pollutants, and the frequency of air pollution contingency episodes. In addition, major health effects and sources of pollutants are presented.

3.1.1 Peak Concentrations

The peak concentration levels of the five criteria pollutants are indicative of worst-case scenarios of the air pollution severity. Table 2 summarizes the air quality standards and peak pollutant concentrations from 1988 to 1999. While the peak concentrations in general have declined in the past decade, recent peaks are still in violation of standards,

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[14] While this research is concerned with all six pollutants, the scenario analysis does not include lead, as lead pollution has been adequately addressed by the phase-out of leaded gasoline.

particularly for O_3, PM_{10}, and NO_x. SO_2 is the only pollutant whose peak concentration has fallen under the standard.

Table 2: Standards and peak annual concentrations from five measurement stations

	CO (ppm)	NO_x (ppm)	SO_2 (ppm)	O_3 (ppm)	PM_{10} (ug/m^3)
Standard (duration)	11 (8 hr)	0.21 (1 hr)	0.13 (24 hr)	0.11 (1 hr)	150 (24 hr)
1988	29.5	0.327	0.183	0.405	-
1991	15.9	0.370	0.192	0.404	-
1995	14.9	0.296	0.081	0.349	241
1997	9.8	0.274	0.099	0.309	324
1999	12.1	0.216	0.094	0.311	184

(INE, 2000)

The data have been obtained from five measurement stations that are located in different geographical zones in the MCMA and therefore considered to be reasonable representations of the variability within the metropolitan area. Also, these five measurement stations have the most comprehensive data, starting from 1988 (INE, 2000).[15]

3.1.2 Standard Violations

The number of days with concentrations above the ambient air quality standards is an indicator of average emission levels compared to the standards, and summarized in Table 3. The data are from the five measurement stations from which the peak concentration data (Table 2) have been collected. While the days of standard violation have decreased for CO and SO_2 in the 1990s, the violation days for other key pollutants, particularly O_3, remain quite frequent. The percentage of O_3 standard compliance is at best 24% of days in 1999, and as low as 7% in 1991.

15 The five measurement stations are: Tlalnepantla (TLA) in the northwestern zone, Xalostoc (XAL) in the northeastern zone, Merced (MER) in the central zone, Pedregal (PED) in the southwestern zone, and Cero del la Estrella (CES) in the southeastern zone (INE, 2000).

Table 3: Number of standard violation days from five measurement stations

	CO	NO_x	SO_2	O_3	PM_{10}
1988	56	27	42	314	-
1991	159	19	18	339	-
1995	4	19	0	315	78
1997	6	13	0	303	145
1999	2	2	0	277	2

(INE, 2000)

The Mexican ambient air quality standards are in general comparable to the US national standards and standards set by the World Health Organization (WHO) (Molina and Molina, 2002a).[16 17]

3.1.3 Contingency Periods

Another measure of air pollution in the MCMA is the frequency of contingency episodes. The contingency program has been established to reduce emissions and exposure when very high pollution levels are observed, through various compulsory measures and public warning. It goes into effect when the metropolitan index of air quality, called IMECA, registers above a certain level of O_3 or PM_{10} concentrations separately or combined. Because the emission reduction measures are implemented one day after the contingency declaration, the program is aimed at addressing high emission levels that are expected to last over multiple days. This necessitates an analysis of meteorological forecasts prior to declaring the contingency.

The contingency program has two phases. The current threshold level for phase I contingency is 240 IMECA points (0.28ppm equivalent) for O_3, or 175 IMECA points for PM_{10} (300ug/m^3 equivalent), or combination of 225 IMECA points for O_3 and 125 IMECA points for PM_{10}. Phase II contingency is declared when the Phase I contingency is in effect for three consecutive days, or when the IMECA index exceeds 300 points for

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16 The Mexican CO standard (11ppm in 8 hours) is slightly more lax than the American and WHO standards, which are 9ppm in 8 hours. For O_3, the Mexican standard (0.11 in 1 hour) is more stringent than the US national standard (0.12ppm in 1 hour), yet higher than WHO (0.08ppm in 1 hour) and Los Angeles (0.09ppm in 1 hour). The Mexican SO_2 standard (0.13ppm in 24 hours) is equivalent to the WHO standard, and slightly lower than the US national standard (0.14ppm in 24 hours). NO_2 and PM_{10} standards are identical for WHO, US, and Mexico (Molina and Molina, 2002a).

17 Since the PM measurements began in 1995, standard violations have been observed as follows: 78 days (1995), 186 days (1996), 145 days (1997), 117 days (1998), and 2 days (1999). The low number of standard violations in 1999 is an anomaly and may be attributed to meteorological conditions, and not necessarily to pollution abatement measures (INE, 2000).

O_3, or 250 points for PM_{10}. When the O_3 IMECA points go below 180 and/or PM_{10} IMECA point is below 150, the contingency is de-activated (Molina and Molina, 2002a).

Measures for Phase I contingencies include: circulation restriction on 50% of older vehicles and freight vehicles, 50% reduction in the operation of thermoelectric plants in the MCMA, closure of gasoline stations without vapor recovery systems, restrictions on paving and maintenance, notice to the public to avoid outdoor activities, termination of school outdoor activities, as well as epidemiological surveillance. Measures for Phase II contingencies include: 60% reduction in industrial activities, circulation restriction on all older vehicles, as well as all measures for Phase I. Table 4 shows the number of contingency periods and days from 1993 to 2000. Contingency periods have been declared at least once annually since 1993. The data do not show a clear decreasing or increasing trend.

Table 4: Contingency periods from 1993 to 2000

Year	Number of contingency periods	Number of days*	Year	Number of contingency periods	Number of days
1993	12	15	**1997**	3	6
1994	1	3	**1998**	5	12
1995	5	7	**1999**	3	5
1996	3	9	**2000**	1	2

*A contingency period goes into effect one day after the announcement is made. For the purpose of counting the number of days, the count begins one day after the initial high IMECA levels have been recorded (Molina and Molina, 2002a). For example, the contingency was declared at 15:00 on 15 October 1996, and lifted on 17 October 1996 at 15:00. For this contingency period, the duration was 2 days, i.e., 16 and 17 October. **(CAM, 2002a)**

The social and economic costs of contingencies are significant, as the compulsory measures summarized above necessitate disruption of industrial, commercial, transportation, and otherwise regular human activities. The premise of the contingency program is that the health effects of exposure to very high concentrations are so serious that minimization of emissions and exposure is necessary and warranted to protect the health of the MCMA citizens.

3.1.4 Sources and Effects of Pollutants

The analysis of the three indicators has shown that substantial challenges still remain to reduce air pollution in the MCMA. Table 5 summarizes major sources of air pollution and effects on human health and the environment. Pollutant sources are discussed in more detail in Section 2 of this chapter. The effects of pollutants are divided into acute health effects, chronic effects, and other effects. Acute health effects are experienced shortly after exposure, and tend to affect organs that have contact with the pollutant(s). Chronic health effects are experienced long after exposure, and may manifest in a wider range of organs or functions (Molina and Molina, 2002a). Other effects include environmental degradation that does not directly affect human health, such as damage to vegetation, materials, and reduced visibility.

Table 5: Sources and effects of pollutants

Compound	Sources and effects	Compound	Sources and effects
CO	Sources: Incomplete combustion of fuels and fire Acute effects: Alters nervous system, cardiac & pulmonary functions (headache, drowsiness, death) Chronic effects: Other effects: reduced visibility	HC	Sources: Incomplete combustion of fuels, processing, distribution, use of oil, solvents, chemical reaction in atmosphere Acute effects: Alters respiratory system Chronic effects: carcinogen Other effects: ozone precursor, reduced visibility
SO_2	Sources: Combustion of sulfurous fuels (gas, diesel, coal) Acute effects: eye & respiratory irritant Chronic effects: immune system suppression, susceptibility to bronchitis Other effects: acid rain component reduced visibility	O_3	Sources: Atmospheric reaction b/w HC and NO_x, under sunlight Acute effects: eye & respiratory system irritation Chronic effects: loss in immune system functions, aging, susceptibility to infection Other effects: reduced visibility, vegetation damage
NO_2	Sources: High temperature combustion in vehicles & industry Acute effects: lung irritation, cardiovascular & respiratory effect Chronic effects: aggravation of chronic respiratory disease and symptoms for susceptible population (eg., asthmatics), necrosis Other effects: reduced visibility, ozone precursor, material corrosion	PM	Sources: Carbon in industrial & domestic combustion as well as fuel, industrial processes, erosion, fire, volcanic eruptions Acute effects: respiratory irritant, aggravation of asthma & cardiovascular disease Chronic effects: chronic bronchitis Other effects: reduced visibility

(CAM, 2002a, Evans, Levy et al., 2002, Molina and Molina, 2002a)

Section 3.2: Contributing Factors of Air Pollution

Environmental problems in mega-cities are closely associated with social, demographic, economic, and industrial changes that are taking place in the local area and at the national level. Specific factors that have contributed to the degradation of air quality in the MCMA can be categorized as: (1) population growth, (2) enlargement of the metropolitan area (sprawl), (3) geographic and topographic condition, (4) increase in emission sources, and (5) lax emission control and standards.

Some factors, such as population growth and sprawl, tend to be universal and observed in both developed and developing countries. Other factors, such as lax emission standards, tend to be observed more in developing countries. Some factors, such as geographic and topographic conditions, are unique to the MCMA and may not be mitigated directly by policy measures. The five factors are described in further detail in this section.

3.2.1 Population Growth

The MCMA has experienced a 20-fold increase in the population level since 1900. The population in MCMA reached 17.9 million in 2000, accounting for approximately 18% of the total population in Mexico. The population level is expected to further increase to 20.7 million by 2010, and 22.5 million by 2020. The percentage of the national population living within the MCMA has stabilized at about 20% since the 1970s, as shown in Figure 2.

The MCMA is comprised of the Federal District, or DF, and urbanized municipalities in the State of Mexico, or EdM, that surrounds the Federal District.[18] By the mid 1990s, the population share of the State of Mexico in the MCMA has become greater than that of the Federal District. The DF population has stabilized since the 1980s at about 8 million inhabitants, while continuing to increase in EdM, as shown in Figure 3. The population growth in MCMA is influenced by the concentration of political institutions, economic investments, and industrial, service, and financial infrastructure in the metropolitan area. Such concentration of wealth, infrastructure, and opportunities, coupled with regional income disparity, has continued to attract migration from other parts of the country towards the MCMA (Lezama, Favela et al., 2002).

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[18] The current definition of the MCMA is presented in Section 3.2.2.

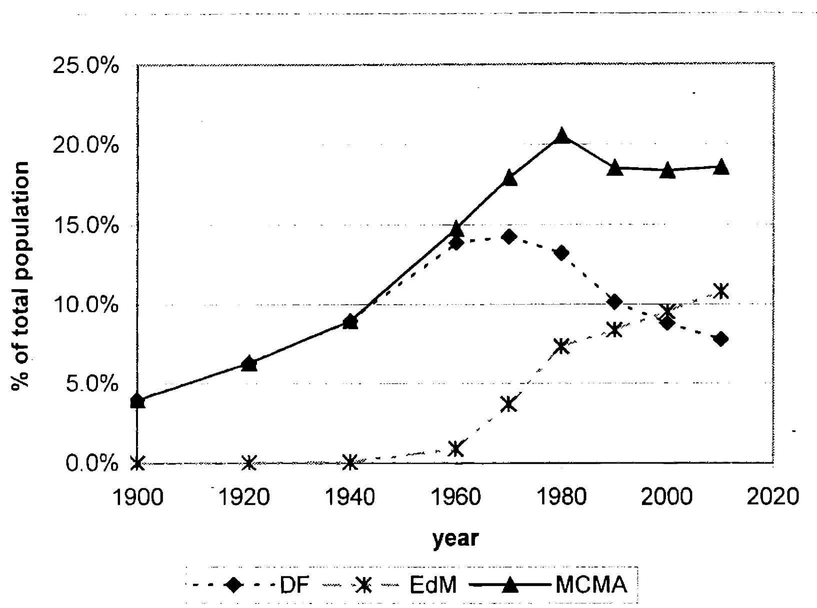
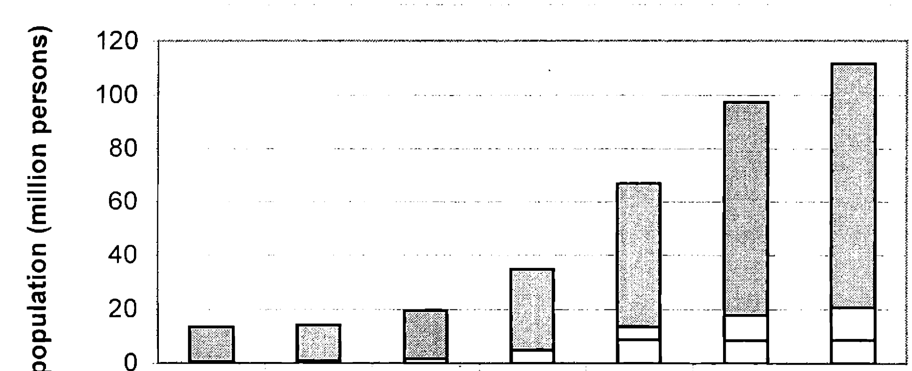


Figure 2: Percent share of national population in MCMA

(INEGI, 1997)



	1900	1921	1940	1960	1980	2000	2010
rest	13.07	13.44	17.89	29.76	53.12	79.48	90.94
EdM			0.01	0.31	4.9	9.28	12.07
DF	0.54	0.9	1.76	4.85	8.83	8.59	8.67

Figure 3: Historical and projected population growth in Mexico and MCMA

(INEGI, 1997, INEGI, 2000)

3.2.2 Enlargement of the Metropolitan Area

Like many mega-cities experiencing population growth, the MCMA has experienced suburbanization, or sprawl. Specifying the actual size of the MCMA is a challenge, due to different interpretations of what constitutes a metropolitan area, and increasing urbanization of the surrounding areas, which requires changes in the MCMA delineation. The definition of the MCMA used by the Mexico City project includes 16 delegations, or *delegaciones*, in DF, 37 urbanized municipalities, or *municipios*, in EdM, and one *municipio* from the State of Hidalgo (Lezama, Favela et al., 2002). Currently covering 5,295 km^2 in surface area, the metropolitan area has grown 10-fold in the past 40 years.

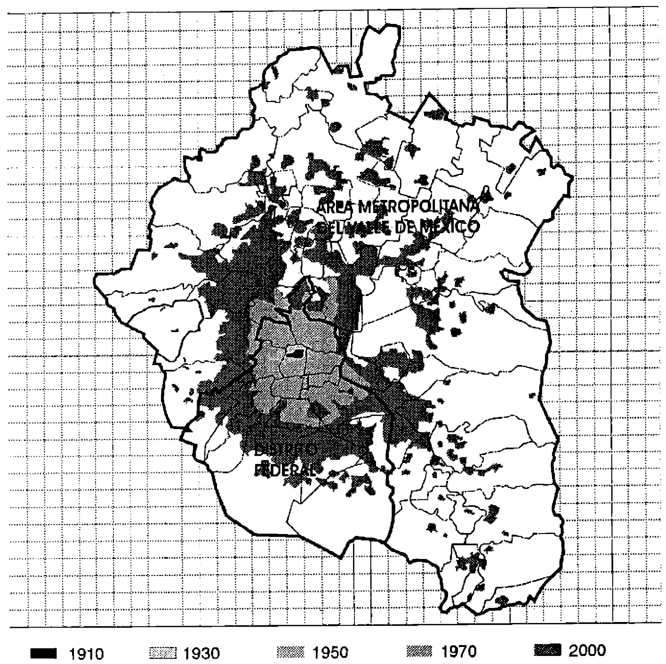


Figure 4: Historical urbanization trend in MCMA
(Covarrubias, referenced in Molina and Molina, 2002a)

While the urbanization and population growth have stabilized within DF, EdM continues to experience growth in population and urbanization, particularly in the peripheral areas. Figure 4 shows the historical urbanization trend. The growth trend from 1950 to 2000 summarized in Figure 3 and Table 6 shows that expansion of the metropolitan area since the 1970s have been due to the additions of municipios in the EdM. Irregular settlements for the poor and real estate development for the rich have overtaken protected natural areas in the peripheral areas, due to weak enforcement of laws that control growth and urban sprawl (Schteingart, 2000).

Table 6: Number of local districts included in historical MCMA definition

	1950	1960	1970	1980	1990	2000
Federal District (Delegaciones)	11	15	16	16	16	16
State of Mexico (Municipios)	2	4	11	17	27	37
State of Hidalgo (Municipio)	0	0	0	0	0	1

(Lezama, Favela et al., 2002, from INEGI, 1997, INEGI, 2000,CONAPO, 1998)

The average population density of the MCMA is approximately 12,000 inhabitants per km^2, which is higher than the density in most mega-cities in Latin America, the United States, and Japan, yet lower than India (Calcutta and Bombay) and Hong Kong. The DF population density has fluctuated from 15,000 inhabitants per km^2 in 1940, dropping to 10,500 inhabitants per km^2 in 1960, and rising again to over 12,000 inhabitants per km^2 more recently. The EdM population density has varied from 2,300 inhabitants per km^2 in 1960, to12,400 inhabitants per km^2 by 2000. In general, more recently established settlements tend to have lower population densities (Ward, 1998).

3.2.3 Geographic and Topographic Conditions

The unique geographic and topographic conditions of the MCMA have had compounding negative effects on the air quality. Mexico City is located at 2,240m (7,350 feet) above mean sea level. At this altitude, the air oxygen content is approximately 23% less than the ground level. The lower oxygen content makes the internal combustion process from vehicles and industrial sources less efficient, resulting in higher emission generation if not carefully controlled. Photochemical reactions, such as the formation of ozone and smog, tend to occur faster in higher altitude.[19] In addition, humans may inhale larger quantities of air to compensate for the lower oxygen content, resulting in more pollutant inhalation (Garza, 1996). The subtropical latitude also creates favorable conditions for ozone formation throughout the year (Molina and Molina, 2002a).

The MCMA is also surrounded in three directions (east, south, and west) by mountains, which form a physical barrier at 3,600m (11,800 feet) above mean sea level. The barrier protects the MCMA as a basin that is 800 to 1,000m deep, shielding it from wind circulation, which in turn decreases the speed at which pollutants are dispersed in the

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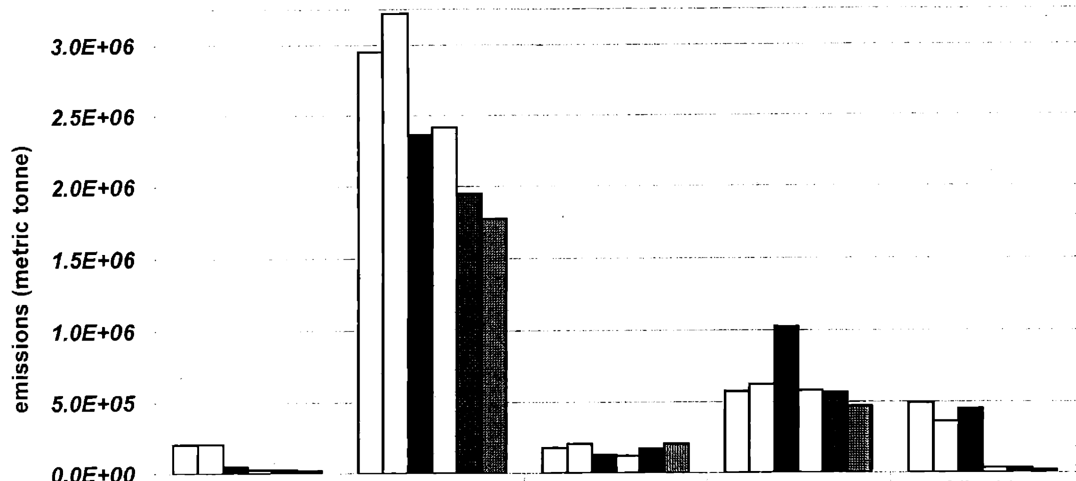
[19] Ground level ozone is formed with the following reaction (CARB, 1999): $VOC + NO_x + Sunlight \rightarrow O_3 + NO_2 + PAN + HNO_3 + particles, etc.$

atmosphere. In addition, the mountains contribute to thermal inversion, which occur frequently during the dry season from October to March. With thermal inversion, a stable layer of colder air is formed at night, trapped near the ground by a layer of warmer air. The inversion lasts for several hours after sunrise until the ground is heated by sunlight, and the two layers mix. The high level of emissions and strong solar radiation in the morning hours create favorable conditions for photochemical reaction, resulting in high levels of ozone (Molina and Molina, 2002a).

3.2.4 Increase in Emission Sources

The growth in urban areas and population has occurred as Mexico experienced industrial and commercial development, and corresponding income growth. Such increase in economic activities and demand for resources have translated to more emissions from a larger number of sources. However, quantification of emissions from various sources did not begin until 1986, when the first emissions inventory for the MCMA was compiled with technical assistance from the Japan International Cooperation Agency. Successive emissions inventories were published in 1989, 1994, 1996, and 1998. Comparable historical data on emission sources and their quantities are limited. Figure 5 shows the changes in total emission levels as reported in these five emissions inventories. Recent analyses have attributed differences among the inventories to methodological differences or emissions factors (Molina, Molina et al., 2002). The historical changes as shown in the figure below therefore may not accurately convey real changes in emissions or emission sources during the time period of analysis.



	SO2 (metric tonnes)	CO (metric tonnes)	Nox (metric tonnes)	HC (metric tonnes)	TSP/PM10 (metric tonnes)
1988	206,000	2,951,000	177,000	572,000	491,000
1989	202,000	3,226,000	203,000	625,000	366,000
1994	45,468	2,358,141	128,646	1,025,760	452,000
1996-a	24,414	2,414,907	121,459	579,043	31,854
1996-b	29,000	1,948,000	174,000	569,000	31,000
1998	22,466	1,768,836	205,885	475,021	19,889

Figure 5: Total emissions reported in various emission inventories (CAM, 1996, CAM, 2001, INE-CENICA-JICA, 1997)

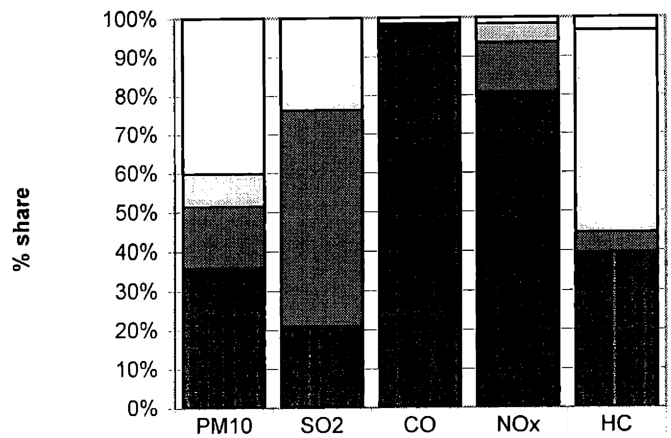
While the quantification of historical emission trends may be hampered by data limitations, other observations, such as energy demand and car ownership, allude to a society with increased production and consumption of goods and services, and resulting emissions. The demand for gasoline in the MCMA has grown 26% in 12 years, from 14.0 million liters per day in 1986 to 17.6 million liters per day by 1998. The MCMA electric power demand has grown at 3.5 to 4% annually, from approximately 5,600 megawatts in 1994 to 6,848 megawatts in 1998 (Morales, 2001). The new car sales in the MCMA have increased from approximately 158,000 units in 1990 to over 220,000 units in 1999 (AMIA, 1999).

The current major sources of emissions in the MCMA include mobile sources, industry, households and services, as well as biogenic sources. These four major sources of pollution are described below, as presented in the most recent and comprehensive emissions inventory from 1998:

- Mobile sources: private vehicles, road-based public transportation, freight, and motorcycles
- Point sources: industrial sources, such as electricity generation, manufacturing, and –chemical industry

- Area sources: household combustion, airplane operations, services such as dry cleaning, and other commercial activities
- Vegetation and soil: disturbed vegetation, land erosion such as drying of lakes and deforestation, unpaved and paved roads (CAM, 2001)

The contributions of the four emission categories are shown in Figure 6.



	PM10	SO2	CO	NOx	HC
vegatation and soil	40%	0%	0%	2%	3%
area sources	8%	24%	1%	5%	52%
point sources	16%	55%	1%	13%	5%
mobile sources	36%	21%	98%	81%	40%

pollutant

Figure 6: Major sources of emissions in MCMA in 1998

(CAM, 2001)

Transportation Sources

The transportation sector is a major source of air pollution, accounting for 90% of CO, 81% of total NO_x emissions, and 40% of hydrocarbons. Among the transportation sources, passenger vehicles make up a significant of emissions. 46% of CO, 23% of NO_x, and 17% hydrocarbon emissions from the MCMA are attributed to passenger vehicles as of 1998 (CAM, 2001). As indicated from these figures, emission reduction from transportation sources, especially passenger vehicles, is a priority for air quality management in the MCMA and needs to be pursued further.60% of all energy in the MCMA is consumed by the transportation sources. Vehicle ownership has grown to 3.3 million vehicles in circulation by 1998, with 2.3 million private vehicles. The metropolitan area expansion has also resulted in an increase in vehicle kilometers traveled and demand for faster modes of travel. Table 7 summarizes the vehicle age distribution and emission shares in the MCMA.

Table 7: Vehicle age distribution and emission shares in MCMA

	Private vehicles		Taxis		Buses		Cargo trucks	
	% vehicle	% emission	% vehicle	% emission	% vehicle	% emission	% vehicle	% emission
91 and newer	57	25	86	74	58	54	42	40
1981 – 1990	29	41	14	36	33	36	38	41
1980 and older	14	34	-	-	9	10	18	19

(CAM, 2001)

There is a general shift from high-occupancy modes, such as buses and Metro, to medium-occupancy modes, such as microbuses, and low occupancy modes, such as private vehicles and taxis. This modal shift is a major contributing factor to congestion, with increased travel time and emissions from stop-and-go driving cycles (Molina and Molina, 2002a). The modal changes have occurred both from technical and socio-cultural reasons. The technical reason may be that the higher occupancy modes have not improved their coverage and service to meet the changing transportation demands of the growing MCMA and population. The socio-cultural reason may be that cars are considered as a status symbol as well as more secure mode of personal transportation. As such, once citizens own or have access to private vehicles, they are less likely to user other modes of transportation.

Non-Transportation Sources

Non-transportation sources refer to area sources, point sources, and soil and vegetation. The non-transportation sources accounted for 40% of all energy consumed in the MCMA as of 1998 (CAM, 2001). Point sources, particularly industry, are large emitters of SO_2 and PM_{10}, contributing 55% of SO_2 emissions, and 16% of PM_{10}. Area sources account for 52% of total HC emissions, which are generated from solvent usage, fuel leakages and incomplete combustion in the storage, distribution, and usage of liquid petroleum gas (LPG). Vegetation and soil are a major source of PM_{10} emissions in the MCMA, accounting for 40% of total emissions. The drying of lakebeds and deforestation began in the colonial period, as efforts to reclaim land from waterlogged areas intensified. Despite various programs to recover and protect conservation land and to increase the vegetation cover in the last 30 years, soil erosion and resulting emissions are still a major problem (Molina and Molina, 2002a).

3.2.5 Lax Emission Control and Standards

For transportation and non-transportation sources, emission control measures have historically been limited, similar to other developing countries. This is largely due to lax emission standards and poor enforcement of standards. Specific policy measures introduced to control mobile source emissions are discussed in more detail in Section 3.3 and Section 3.4 of this chapter and Chapter 5.

Section 3.3: Institutions and Legal Framework for Air Quality Management

Air pollution mitigation in the MCMA is addressed within a complex legal and institutional framework. Institutions with responsibilities for air pollution mitigation in the MCMA are located at federal, state, metropolitan, and local levels, with individual legal frameworks and jurisdictions. This section presents an overview of institutions and legal frameworks that are currently implemented. Historical development of institutions and air quality management programs is described at the federal, state, and metropolitan levels. Figure 7 shows the major current laws and jurisdictions for air quality management and institutions responsible for their implementation at different levels.

3.3.1 Federal Institutions and Legal Framework

Current State

At the federal level, the Secretariat of Environment and Natural Resources (SEMARNAT) is responsible for the establishment and enforcement of environmental law, as well as management and protection of natural resources, waste and pollution control, and administration of national parks and other protected areas.[20] Two semi-independent institutions under SEMARNAT are also directly involved in air pollution control. They are National Institute of Ecology (INE) and the Federal Attorney for Environmental Protection (PROFEPA). INE coordinates environmental research, including urban, regional, and global air pollution. PROFEPA is the inspectorate responsible for enforcing environmental laws and regulations at the federal level.

The principal legal framework for air quality management at the federal level is the General Law of Ecological Balance and Environmental Protection (LGEEPA), specifically articles 110 through 116. LGEEPA was adopted in 1988 and amended in 1996. LGEEPA assigns the following responsibilities for air pollution management to SEMARNAT and its semi-independent institutions:

1. Establish emission standards for mobile sources (new and used)
2. Establish emission standards for stationary sources (new and existing)
3. Establish ambient air quality criteria
4. Issue air emission permits for stationary sources under federal jurisdiction[21]

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20 SEMARNAT, through the presidency of the Mexican Republic, submits laws to Congress. In addition, Congress can approve laws proposed by itself. The final decision is an attribution of Congress (Lezama, 2002).

21 Stationary sources under federal jurisdiction include facilities for chemicals, oil and petrochemicals, electric power generation, vehicle manufacturing, paint and dye, metals, glass, asbestos and cement, and hazardous waste treatment plants. These facilities are required to make annual compliance report, including stack monitoring data (OECD, 1998).

5. Establish fuel standards for transportation, industrial, commercial, and domestic usage, in coordination with Secretariat of Commerce and Secretariat of Energy

6. Enforce federal standards and permits, or delegate some or all of its functions to states or municipalities

In the 1990–1995 period, total investment in the main federal air pollution programs amounted to $2.33 billion (OECD, 1998). In addition to the above federal responsibilities, the 1996 LGEEPA amendments clarified responsibilities at the federal, regional, and municipal levels:

1. Assign greater responsibility for air quality management at state and municipal level

2. Allow SEMARNAT to issue air quality standards by region, area, or zone, or allow the implementation of alternative air pollution programs developed by state and municipal governments. Such programs must comply with federal standards, and may be more stringent

3. Develop economic instruments at the federal, state, and local levels to encourage compliance (OECD, 1998)

Historical Development

Since the 1970s, the institutional and legal frameworks for air quality management at the federal level have changed significantly, reflecting growing concerns for environmental problems and evolving institutional needs.

In 1972, the Under-Secretariat of Environmental Improvement was created within the Secretariat of Health and Public Assistance, partly in response to health concerns over air pollution. In 1982, the first institution with environment as one of its major mandates was created when the Secretariat of Urban Development and Ecology (SEDUE) was established. In 1992, SEDUE was transformed into the Secretariat of Social Development (SEDESOL), which was given the mandate for social development policy formulation, including environmental aspects. The National Institute of Ecology (INE) and the Federal Attorney for Environmental Protection (PROFEPA) were created at the same time to provide assistance on environmental matters to SEDESOL. In 1994, the environmental functions were separated from SEDESOL to form the Secretariat of Environment, Natural Resources, and Fisheries (SEMARNAP). SEMARNAP was given the responsibility to promote sustainable development. INE was responsible for setting technical ambient standards and emission limits for stationary and mobile sources, as well as vehicle emission standards and criteria for operating air quality monitoring systems. In 2000, SEMARNAP was reorganized as the Secretariat of Environment and Natural Resources (SEMARNAT). The fishery management functions were reassigned to the Secretariat of Agriculture. INE's responsibility of standard setting was transferred to the Under-Secretary of SEMARNAT (OECD, 1998, Molina and Molina, 2002c).

Each of these institutional changes has signified a change in scope of environmental public policy. Within the Secretariat of Health, environmental policy tended to be framed within the context of health effects. With SEDUE, policy frameworks tended to be based on health and urban development. Policy frameworks under SEDESOL encompassed social development. Finally, with the establishment of SEMANAT, resource management began to be viewed within the framework of sustainable development.

Compared to the institutional structural change, the legal framework has not undergone as many changes. The first general environmental legislation, called the Law for Environmental Pollution Prevention and Control, as adopted in 1971. More comprehensive environmental law titled the Federal Law on Environmental Protection was introduced in 1982. However, these early legal frameworks did not contain standards, regulations, or enforcement mechanisms. Hence, LGEEPA was the first "real" environmental law with enforceable standards and regulations. LGEEPA, discussed above, superseded the 1982 law in 1988, and was amended in 1996. The prospect or threat of enforcement became more credible with the establishment of PROFEPA in 1992.

3.3.2 State and Local Level Institutions and Legal Framework

Current State

State and local governments have considerable responsibility in air quality management, partly due to the decentralization efforts of the federal government. The Secretariat of Environment of the Federal District is the institution responsible for environmental management for the DF. Within the State of Mexico, The Secretariat of Ecology is the responsible institution.

The legal framework for the DF Government is the Federal District Environmental Act, which was most recently amended in 1999. For the State of Mexico, the Protection of the Environment for Sustainable Development Act of 1998 provides the regulatory framework. The following list summarizes air quality management responsibilities that fall under state and local jurisdictions. Responsibilities that are applicable to either state or municipal governments, but not both, are specified as such. Otherwise, they are applicable at both levels:

1. Establish emission standards for commercial and industrial facilities outside the federal jurisdiction (state level)

2. Establish emission standards for service sector facilities (municipal level)

3. Issue air emission permits for commercial and non-federally regulated industrial facilities (state level) and for service sector facilities (municipal level)

4. Implement a specific air pollution program, as approved by the federal government Establish an environmental emergency, or contingency, program

5. Apply general air quality criteria in urban development planning

6. Maintain emissions inventory
7. Operate air quality monitoring program
8. Enforce state or local standards and permits, as well as federal standards that have been delegated to state or local levels

Historical Development

As mentioned previously, the responsibility for air quality management at the state and local level has grown in the last decade, due to the decentralization process by the federal government. As a result, institutions and legal foundations were newly created or strengthened in the 1990s. When the first metropolitan air quality control plan (PCMCA – described in more detail in Section 3.3.3) was introduced in 1979, an environmental authority existed in EdM but not in the DF. By the time the next program (PICCA – also described in more detail in Section 3.3.3), was introduced in 1990, the General Coordination of Urban Reorganization and Environmental Protection for the DF government was established as an institution directly concerned with environmental issues (Lezama, 2000). Generally speaking, many states and municipalities do not have technical and financial capabilities for adequate air quality management. Specifically, disparities in institutional capacity and infrastructure provision exist between the DF and EdM environmental secretariats (OECD, 1998, Molina and Molina, 2002d).

3.3.3 Metropolitan Level Institutions and Legal Framework

Current State

The current institution for air quality management and program coordination at the MCMA level is called the Metropolitan Environmental Commission (*Comisión Ambiental Metropolitana*, or CAM). The CAM has been established within the constitutional framework that entitles the creation of metropolitan commissions within the purpose of addressing problems that affect multiple areas within the MCMA, such air pollution, transportation, water, and waste management (Lezama, 2000). The CAM provides a mechanism for administrative coordination among various levels of governments. The CAM is comprised of 17 stakeholder institutions at the federal and state levels, as follows:

- <u>Governmental institutions at federal level (11):</u> SEMARNAT, Secretariat of Energy, Secretariat of the Interior, Finance Secretariat, Secretariat of Social Development, Secretariat of Economy, Secretariat of Agriculture, Secretariat of Communication and Transport, Secretariat of Administrative Development, Secretariat of Public Education, Secretariat of Health
- <u>Governmental institutions at state/local level (2)</u>: State of Mexico, Federal District
- <u>State enterprises and commissions (4):</u> PEMEX, Mexican Petroleum Institute (IMP), Federal Electricity Commission, Central Light and Power (*Luz y Fuerza del Centro*)

Among these entities, SEMARNAT, DF government, and EdM government are the permanent members. The CAM presidency rotates every two years between the DF and EdM governors, and the technical secretary post also switches between the environmental ministers of the two governments. The technical secretary organizes the activities of working group on various issues, such as air quality, natural resources and protected areas, soil quality and resource management, and environmental education (CAM, 2002b).

The current air quality management framework at the metropolitan area is titled "Program for Air Quality Improvement in the MCMA 2002 – 2010," or PROAIRE 2002 - 2010 (CAM, 2002a). This plan was published in early 2002, and includes the following major options:

- Vehicles and transport (38 options): establish more stringent emission limits, reduce sulfur content of gasoline to 50 ppm, improvement of inspection program (described in Section 3.4.3), modernization of driving restriction program called *Hoy No Circula* (described in Section 3.4.2), scrappage, retrofit, introduction of alternative fuel vehicles and buses and expansion of fueling stations, Metro and light rail expansion, program integration, infrastructure improvement
- Industry (7 options): control emissions, introduce cleaner production, strengthen voluntary management, reduce emissions from electric generation facilities
- Services (9 options): reduce hydrocarbon emissions from laundry and dry cleaning, introduce self regulation and improvement mechanisms in small and medium sized establishments, reduce liquid petroleum gas (LPG) emissions from residential installations, promote the use of solar energy, develop and promote economic instruments for industrial and service sector
- Conservation of natural resources (15 options): develop a program to reduce soil erosion, protect and monitor natural resources, develop a demonstration and capacity building and financing scheme to introduce sustainable forestry and agriculture, improve forest fire prevention measures.
- Protection of health (8 options): update the contingency program, better communication of risk, conduct an economic assessment of health effects, create and revise ambient air quality standards, investigate the health effects of air pollution
- Environmental education (4 options): develop a formal and informal environmental education program, develop a training and capacity building program on environmental issues, develop a program on communication and dissemination of environmental education
- Institutional strengthening (8 options): characterize and diagnose industrial, commercial, and service establishments, develop regulations for stationary and mobile sources of the DF Environmental Act, reactivate the environmental trust fund (see footnote 22 and description on PROAIRE 1995 - 2000 for detail) modernize the monitoring network, conduct emissions inventories, integrate a working group on new technologies for air pollution control

The total estimated cost is $6.5 billion dollars for public investments, and $7.7 billion for private investments. All combined, the measures are expected to reduce NO_x emissions by 43%, PM_{10} by 18%, and HC by 17% (CAM, 2002a).[22]

Historical Development

Institutional arrangements have evolved considerably in the past 20 years, with successive introductions of air quality improvement programs. The creation of an intergovernmental institution at the metropolitan level was first contemplated in the 1970s, as the awareness for the necessity to manage air pollution as a cross-boundary issue began to emerge. The first such entity, the Inter-Secretarial Commission for Environmental Sanitation in the Mexico Valley (CISA), was established in 1979. As environmental policy formulation during this period was the responsibility of the Secretariat of Health, the chair and members were affiliated with the Secretariat of Health. Programs were analyzed based on health and sanitary implications, and tasks were assigned to ministries as well as state departments.

The Metropolitan Commission for Pollution Prevention and Control (CMPCCA) was established in 1992 under the leadership of the DF Mayor named Manuel Camacho, and was instrumental in implementing the PICCA air quality program, which is discussed in more detail below. The CMPCCA comprised of representatives from various EdM and DF agencies, and federal institutions such as the Secretariat of Urban Development and Ecology, PEMEX, Federal Energy Commission. The CMPCCA went beyond the health and sanitary perspective of CISA for a broader interpretation of environmental issues, yet it was somewhat constrained to pollution, according to Lezama (Lezama, 2000). The most recent institutional change came in 1996, when the Metropolitan Environmental Commission (CAM) was established, as discussed earlier in this section.

Prior to the current PROAIRE 2002 - 2010 program, three air pollution management programs at the metropolitan level have been introduced since 1979. The first program at the metropolitan level called Coordinated Air Quality Improvement Program for the Valley of Mexico (PCMCA) was introduced in 1979. The PCMCA's primary objective was to prevent further environmental degradation, with an emphasis on immediate actions for emergency situations. The program components included the following:

- <u>Emergency measures</u>: establish public alert systems and increase monitoring network

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[22] The extent of CAM project implementation has been limited, due to financial and human resource constraints. The financial support for the CAM project implementation has come from domestic governmental sources as well as international cooperation. The Environmental Trust Fund for the Valley of Mexico, or *Fideicomiso Ambiental del Valle de México,* was established to support CAM projects in 1995 with a 2-cent gasoline tax. The trust fund has been suspended since 1998. In terms of human resources, the 2-year rotation of personnel disrupts policy continuity and longer-term planning. Staff members must also balance responsibilities at the CAM as well as their regular appointments at the DF or EdM government (Molina and Molina, 2002d).

- Prevention and control of vehicle pollutants: revise HC and CO regulation for new vehicles, inspection and testing of new and in-use vehicles, fuel reformulation, synchronized traffic lights, increased electric transport
- Prevention and control of industrial pollution: promote fuel switching to gas, encourage industrial relocation and modernization, step up surveillance
- Prevention and control of natural sources: substitute crop, expand woodland areas, control dust from mining, paving, street cleaning, solid waste management
- Prevention and control of noise contamination: reduce vehicle noise, establish land use regulation related to noise
- Support measures: promote urban development through diversification of land use and self-sufficient metropolitan centers to reduce auto use, conduct education and awareness raising in citizens, educators and students, carry out research on health, physical, and chemical aspects of pollution, introduce legislation
- Inter-ministerial relation: establish Inter-Ministerial Commission to supervise diagnosis and coordination, and technical evaluation

The PCMCA was not successfully implemented, as evidenced by a significant increase in air pollution. The failure has been attributed to the voluntary nature of the program options, lack of analysis on institutional strength and viability, and financial constraints (Lezama, 2000).

In 1990, the second program, titled the Integral Program to Combat Air Pollution (PICCA), was introduced. The PICCA program elements included the following:

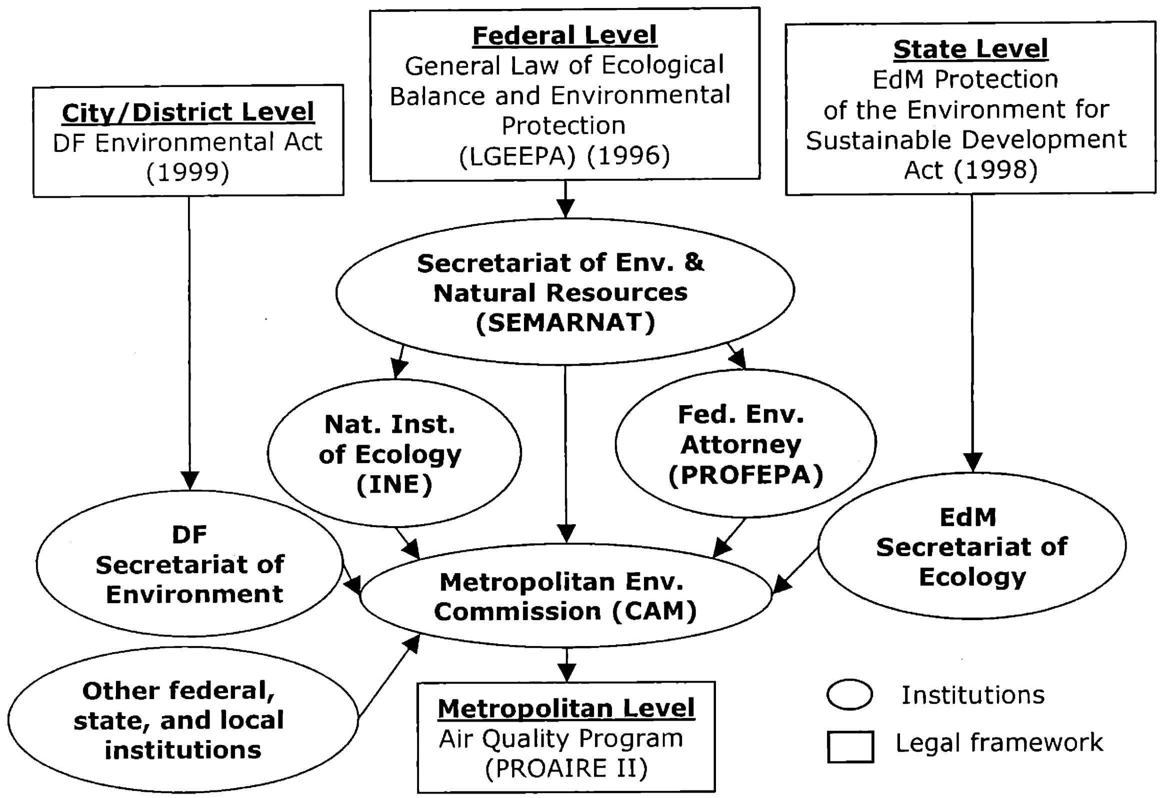
- Improve fuel quality: introduce reformulated and oxygenated gasoline, reduce SO_2 in diesel and gasoline, phase out leaded fuel, install vapor recovery
- Rationalize and restructure transport: introduce catalytic converters in 1991 and later models, expand underground, electric, and public transport, renovate *Ruta 100* bus engines, continue *Hoy No Circula* (described in Section 3.4.2), expand verification program
- Modernize industrial technology: change fuel oil for gas, control emissions, prohibit polluting industries, carry out monitoring, improve combustion processes in services
- Prohibit new pollution industries and relocate thermoelectric industries: use natural gas, suspend operations of two electricity generating plants during winter months, conduct continuous monitoring
- Recover, protect, and restore affected natural areas: implement an urban reforestation program
- Control and disposal of solid wastes:
- Education, communication and civic participation: support scientific and technical research, provide information on environmental issues, train professionals, conduct dissemination campaigns on problems and solutions (Lezama, 2000)

The program was developed during a period of high public awareness of lead and ozone problems. The program development benefited from the sense of priority and professionalism among the actors, and better access to scientific and technical information. The main objective of the PICCA program was to limit the increase of pollutant emissions. Specific goals were: (1) not to exceed international lead norms, (2) not to exceed national and international SO_2 norms, (3) reduce particulates and NO_x, (4) to reduce hydrocarbons and use better combustion systems in industry and services, and (5) to reduce total emission to 2.8 million tons. While many, but not all, of the measures were introduced, the specific objectives were not totally met, as the review of the historical parameters in Section 3.1 shows.

The third program was the 1995 – 2000 Air Quality Improvement Program for the Mexico City Area (PROAIRE). Within this text, the 1995 – 2000 PROAIRE will be referred to as PROAIRE 1995 - 2000. PROAIRE 1995 - 2000 set policy objectives to promote clean industry, switch to cleaner fuels, upgrade and improve mass transport, promote environmentally sensitive urban development, and encourage erosion control. PROAIRE 1995 - 2000 contained specific measures under the following categories:

- Improvement and incorporation of new technologies: modernize driving restriction program (*Hoy No Circula* - described in Section 3.4.2), revise evaporative emission standard, introduce more stringent emission standards for new and in-use vehicles, improve inspection and maintenance program, harmonize inspection program in DF and EdM
- Improvement and substitution of fuel: introduce more stringent fuel standard, phase out of leaded fuel, progressively reduce sulfur content, establish a program to introduce hybrid and electric vehicles in both passenger and freight vehicles
- Inspection and vigilance (enforcement): improve standard enforcement for inspection and maintenance, improve fuel quality, and modernize vehicle fleet
- Economic incentives: include environmental costs for fuel pricing, change pricing of two types of gasoline, change new vehicle tax to provide incentives for fleet turnover, reduce tariff for importation of key environmental technologies that are not manufactured in Mexico, apply a 2-cent surcharge for environmental trust fund, or *Fideicomiso Ambiental del Valle de México*
- Environmental information and education and social participation: study development and introduction of methane vehicles for passenger and freight vehicles, starting with official government vehicles, identify low emission vehicles in windshields, establish a permanent mechanism to get public input for new ideas for emission reduction (CAM, 1996)

While some of the above measures were fully or partially implemented, little or no progress was made on others. The total estimated public investment for this program was $10.5 billion, including PEMEX investments for equipment to produce high quality fuel for the whole country, and by electricity and public transport enterprises. Private investment of $2.8 billion for industry, service sector, and private cars was also envisioned (CAM, 1996, COMETRAVI, 1999b, Lezama, 2000).



Municipal or Local Jurisdiction

- Air pollution program (must be federally approved)
- Emission permits for service sector facilities
- Vehicle emission verification program
- Environmental emergency (contingency) program
- Enforcement

Federal Jurisdiction

- Emission standards for fixed sources
- Vehicle emission standards
- Ambient air quality standards by region/zone, or approve air pollution programs developed by state and municipal governments
- Fuel quality standards
- Air emission permits for facilities that produce chemicals, oil and petrochemicals, electric power, cars, paint and dye, etc.
- Enforcement

State Jurisdiction

- Air pollution program (must be federally approved)
- Emission permits for commercial and industrial facilities outside federal jurisdiction
- Vehicle emission verification program
- Environmental emergency (contingency) program
- Enforcement

Figure 7: Current legal and institutional framework for air pollution management

(Lezama, 2000, OECD, 1998)

3.3.4 Other Institutions

In addition to the environment-oriented institutions discussed above, numerous other institutions share responsibilities related to air quality management. These institutions have their primary organizational mandates in transportation, land use, health, and economic management. Table 8 presents some of the key institutions and their jurisdictions.

Table 8: Institutions with air quality management responsibilities

Institution	Responsibilities related to air pollution
Federal Institutions	
Secretariat of Environment and Natural Resources (SEMARNAT)	Sets standards and issues air permits, including vehicle and fuel standards, coordinates enforcement
National Institute of Ecology (INE)	Coordinates research, including air pollution. Used to be responsible for setting emission and ambient standards, and monitoring systems
Federal Attorney for Environmental Protection (PROFEPA)	Inspectorate responsible for enforcing and encouraging compliance with environmental laws, norms, regulations and programs in industrial activities. Carries out environmental audits.
Secretariat of Finance (SHCP or Hacienda)	Establishes economic instruments and levies taxes, including environmental trust fund, new vehicle tax
Federal Secretariat of Communication and Transport (SCT)	Enforces inspection and maintenance programs for federally registered vehicles
Secretariat of Economy (SE or SECOFI)	Promotes and regulates automobile sector development, such as People's Vehicle program. Oversees trade-related issues, including vehicle importation, technology availability. Manages program for environmental protection and industrial competitiveness
Secretariat of Energy (SENER)	Oversees PEMEX operations, manage programs on energy conservation and minimizing environmental effects on energy production and transport
Petróleos Mexicanos (PEMEX)	State oil company responsible for drilling, refining, and transport. Responsible for 25 – 50% of federal government income in the 90s
Secretariat of Social Development (SEDESOL)	Develops, manages, and evaluates policies on social development and land use
Secretariat of Health	Involved in setting contingency IMECA levels, conducts risk analysis
Metropolitan Institutions	
Metropolitan Environment Commission (CAM)	Coordinates environmental programs that are implemented in the metropolitan area, such as Emissions Inventory and PROAIRE

Institution	Responsibilities related to air pollution
Metropolitan Commission on Transport and Roadways (COMETRAVI)	Coordinates programs related to transportation in the metropolitan area
Metropolitan Commission for Human Settlement (COMETAH)	Coordinates urban planning and integrates local plans
	Local Institutions
DF and EdM Secretariats of Environment, Secretariat of Ecology	Establishes local environmental law and enforces standard, oversees inspection and maintenance program for locally registered vehicles
DF and EdM Secretariats of Transportation (SETRAVI, SCT)	Manages transportation operations, manages public transport system directly and in concessions
DF and EdM Secretariats for Land Use (SEDUVI, SEDUOP)	Responsible for zoning, and monitoring of real estate development
DF Metro system (STCM)	Operates the Metro system, develops and carries out expansion

(CAM, 2002b, Molina and Molina, 2002c, OECD, 1998)

Section 3.4: Policies for Mobile Source Emission Control

Section 3.3 introduced the institutions and legal frameworks for air quality management in the MCMA. This section focuses on mobile source emission control, and provides an analysis of how standards and technological regimes for air pollution mitigation have changed in the past 30 years. Table 15, attached at the end of this section, presents a timeline of control measures that have been introduced, as well as institutional and legal changes. Air pollution mitigation from mobile sources involves technological change, behavioral modification, infrastructure development, and other factors. Within the MCMA context, this analysis focuses on mitigation options that involve technological change and behavior modification for private passenger vehicles. Factors that influenced the introduction of these technologies are presented and analyzed in more detail in Chapter 5.

3.4.1 Vehicle Emission Control: Technology-Oriented Options

Mexico has implemented progressively more stringent emission standards that required more sophisticated technologies in the past 30 years. Emission standards in Mexico have been introduced after technologies that comply with more stringent standards have already been developed in other countries, such as the United Sates, Europe, and Japan. Mexico has thus implemented technology-following standards, where technology availability and effectiveness have been demonstrated elsewhere, particularly in the US.

Non-Catalyst Control: 1975 - 1990

Emission standards to control vehicle emissions were first introduced in Mexico in 1975 at the federal level. The Mexican emission standards from the 1980s were equivalent to the 1972 US standards. The standards were lax enough to be met without catalyst control. Limited technologies, such as charcoal canisters, were used for compliance. Hydrocarbon and CO exhaust emission levels from new vehicles were reduced, but not the NO_x emission level.

Oxidation Catalyst Control: 1991 - 1992

In 1991, 2-year interim standards that required the use of oxidation catalyst went into effect. The two-year interim period was negotiated by the automakers, as some manufacturers needed additional time to make significant investments, conduct training, and find necessary technology suppliers to produce cleaner vehicles. The process leading up to the catalyst control introduction is described in detail as a case study in Section 5.2. Oxidation catalyst control further reduced HC and CO emissions from new vehicles, but NO_x emission levels remained the same. While the standard only required oxidation catalyst control, some manufacturers began installing three-way catalytic converters starting 1991. The emission standards were introduced at the federal level, and endorsed in the PICCA program at the metropolitan level, as explained in the previous section.

Three-Way Catalyst Control (Tier 0 Standards): 1993 - 1998

In 1993, more stringent emission standards that included NO_x emission control went into effect. The 1993 Mexican standards were largely equivalent to the 1981 US standards, which are referred to as Tier 0 standards. Tier 0 vehicles were equipped with three-way catalytic converters. The introduction of three-way catalytic converters required the introduction of unleaded gasoline, as lead poisons and permanently damages the catalysts. Consequently, the introduction of the Tier 0 standards contributed to the emission reduction of NO_x, HC, CO, as well as lead.

Tier 1 Standards: 1999 and Beyond

In 1999, emission standards were tightened again, to reduce the maximum emission limits by 2001 to the levels mandated in the US from 1994, which are referred to as Tier 1 standards. The introduction of Tier 1 standards is described in detail as a case study in Section 5.3. There are some differences in Mexican and US Tier 1 vehicles. Tier 1 vehicles sold in the US are typically equipped with three-way catalysts, electronic fuel injection, and exhaust gas recirculation (EGR). However, some new automobiles sold in Mexico are apparently not equipped with EGR, despite its use in American cars since 1972 (IMP (Instituto Mexicano del Petróleo), 2000). Also, Mexican vehicles did not have emission warranties until this year, while American Tier 1 vehicles have emission warranties up to 5 years or 50,000 miles, and to 10 years or 100,000 miles. Emission warranties are discussed in more detail below.

The emission standards were introduced at the federal level by SEMARNAT and INE. At the metropolitan level, PROAIRE 1995 - 2000 contained an incentive measure to promote the phase-in of the Tier 1 vehicles ahead of the 2001 requirement. Specifically, vehicles meeting Tier 1 standards are eligible for inspection stickers that remain valid for

2 years, as opposed to 6 months for other inspection stickers. In addition, Tier 1 vehicles are exempt from *Hoy No Circula* restrictions (Aoki, 2000, Molina and Molina, 2002b). *Hoy No Circula* and inspection programs are described in more detail in Section 3.4.2 and Section 3.4.3.

On-Board Diagnostics (OBD)

Despite the rapid progression of emission standards, two technical measures that have had major effects on maintaining the level of emission control in the US have not been made mandatory in Mexico. They are on-board diagnostics (OBD) and emission warranties. The OBD systems are useful in maintaining emission levels, as they monitor emission performance of various vehicle components that can affect the emission characteristics of the vehicle, alert the driver of malfunctions, and provide information on problem diagnosis and repair solutions to technicians. An upgraded OBD system, referred to as OBD II, has been mandated and phased in the US from 1994. In Mexico, OBD systems have not been mandated, although some vehicles developed for the US market and also sold in Mexico have been equipped with one since the mid 1990s to comply with the US mandate. A voluntary agreement to phase-in the OBDII system was reached in late 2000 between the CAM and the auto manufacturers. According to the agreement, automakers will start to install OBD in 20% of cars sold in 2002, and increasing by 20% annually to full implementation by 2005 (CAM-AMIA, 2000). The introduction of OBD is described in detail as a case study in Section 5.4.

Emission Warranties

In Mexico, vehicles were not sold with emission warranties until 2002. Auto manufacturers have stated in the past that the quality of gasoline in Mexico is low and variable for emission control systems to function property on the long run, and warranties would place undue burden on the auto manufacturers. Also, some firms have argued that costs for warranties and would be too expensive. Without the sector-wide participation, firms did not provide warranties voluntarily, for lack of competitive advantage. Nevertheless, some manufacturers have been selling cars in Mexico that are designed to meet the US durability and warranty guidelines.

The voluntary agreement between the CAM and the auto manufacturers discussed above also stipulated the phase in of emission warranties. According to the agreement, automakers will provide warranties up to 80,000 km (50,000 mi), starting with 20% of cars sold in 2002, and increasing by 20% annually to full implementation by 2005 (CAM-AMIA, 2000).

Evaporative Emission Standards

Evaporative emission standards were not introduced until 1995, when all cars, light commercial vehicles and light trucks were required to meet an evaporative emission standard of 2.0 grams per test.[23] The similar standard was initially introduced in the

[23] While evaporative emissions were not formally regulated, the Mexican car manufacturers equipped vehicles with evaporative emission control systems under government supervision until 1995 (COMETRAVI, 1999a).

United States in 1972. Evaporative emission control was included in PROAIRE 1995 - 2000.

Table 9 summarizes the emission reduction level, required technologies, and when they became available in the US and Mexico.

Table 9: Timeline of US and Mexican emission standards and technologies

Emission Reduction Level	Emission Level* (grams per km) HC	CO	NO_x	Required Technology	Technology Availability in US	Technology Availability in Mexico
No control	5.5	54.0	2.3	n/a		
Initial reduction (non-catalyst control)	2.2	24.2	2.3	EGR Air injection Air-fuel ratio Ignition timing	1972	1977
Oxidation catalyst control	0.94	15.0	1.94	EGR Oxidation catalyst Ignition timing	1975	1991
1977 CAA Amendment	0.94	15.0	1.25	Three way catalyst Electronic fuel injection or closed loop carburetor	1978	
Tier 0	0.25	2.11	0.62	Electronic fuel injection Oxidation catalyst Fast-burn combustion chamber (lean burn engine) EGR	1980	1993
Tier 1 at 80,000km	0.16	2.11	0.25	Three way catalyst Electronic fuel injection EGR	1994	2001
Tier 2 at 80,000km	0.036	1.55	0.037	Advanced catalyst, EGR, low sulfur gasoline	2004?	2006?
Tier 2 at 192,000km	0.041	1.80	0.044			

* The emission levels are those achieved by different technologies, and are not in all cases equal to earlier Mexican emission standard specifications.

(Faiz, Weaver et al., 1996, US EPA, 1999b)

3.4.2 Vehicle Emission Control: Options to Reduce Vehicle Km Traveled

Hoy No Circula

The *Hoy No Circula* (No Driving Today) program began in 1987 as a voluntary measure spearheaded by an environmental group to restrain traffic volume and to reduce emissions and fuel consumption. The program premise is quite simple: vehicles are not allowed to circulate one weekday, depending on the last digit of the license plate. The program became mandatory in November 1989 when it was incorporated into the contingency program, which was explained in Section 3.1. The program resulted in fuel consumption decrease, increased average traffic speed, and increased subway ridership. The positive results compelled the policymakers to include it in the PICCA program, which was deployed from 1990. However, the program began to experience less support and unintended consequences, as citizens were unwilling to change their behavior on a permanent basis and took measures to circumvent inconveniences associated with the program.[24] The program is currently administered at the metropolitan level, and enforced by the police force of DF and EdM.

Significant modifications have been made to the program to improve its efficiency, and to shift the program objective towards encouraging fleet turnover. Since 1991, public transport vehicles, namely taxis and microbuses, have been subject the restrictions. The program is also now tied to the vehicle inspection and maintenance program and additional driving restrictions for the contingency program (*Double Hoy No Circula*), which was introduced in 1995 in the PROAIRE 1995 - 2000 program.

3.4.3 Inspection and Maintenance Program

The vehicle inspection and maintenance (I&M) program became mandatory in the MCMA in 1988. The enhancement of the program has been included in PICCA and both PROAIRE 1995 - 2000 and PROAIRE 2002 - 2010 programs. The system was centralized and updated with advanced technologies throughout the 1990s. Vehicles that circulate in the MCMA must be inspected every six months, unless they are Tier 1 vehicles, which have been granted a 2-year exemption.

Despite its administrative and technical problems, the inspection and maintenance program is an integral part of the *Hoy No Circula* program. Vehicles obtain different inspection sticker types, ranging from 00 for the cleanest to 2 for the least clean, according to differentiated emission and technology standards and model years. The 00 stickers, which require compliance with Tier 1 standards for model year 2000 and beyond, are exempt from *Hoy No Circula* restrictions, and also valid for 2 years. The 0

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[24] Originally, the *Hoy No Circula* program was supposed to be implemented only in the winter months when climate conditions were not favorable to pollutant dispersion. In general, the public was receptive towards complying with the program, as it was a temporary measure. However, the authorities decided to make it a year-round program when an initial program review yielded positive results (Molina and Molina, 2002b). Some have argued that this decision, similar to other measures, was made unilaterally and suddenly without public input, resulting in implementation difficulties.

stickers, which require original emission control system for model year 1995 and beyond, are also exempt from circulation restrictions, but are required to undergo biannual inspections. The 0 stickers can also be obtained if 1993 to 1995 vehicles have replaced catalysts, or for CNG and LPG vehicles of any model year. Passenger vehicles older than 1993 are given number 2 stickers, which are subject to additional restrictions during contingency periods (Molina and Molina, 2002b, OECD, 1998).

3.4.4 Fuel Quality Improvement

Fuel quality is an important element in air pollution mitigation for two reasons. The first reason is that fuel reformulation directly reduces emissions of certain pollutants, such as lead, CO, HC, and SO_2. The second reason is that advanced emission technologies require cleaner fuel to function properly. For example, three-way catalysts require unleaded gasoline to prevent catalyst poisoning, and Tier 2 technologies require low-sulfur gasoline to avoid long- and short-term reduction to the emission reduction potential. Due to its importance, fuel quality improvement has been stipulated in LGEEPA as well as PICCA, PROAIRE 1995 - 2000, and PROAIRE 2002 - 2010. Refinery upgrades for over US$7 billion in the past decade have enabled the provision of unleaded and reformulated gasoline. In addition, the upgrades reduced the sulfur contents of diesel to permit the operations of buses with current US emission technologies.

Unleaded Gasoline

The introduction of unleaded gasoline from 1991 was first stipulated in LGEEPA. Unleaded gasoline blend called Magna Sin was introduced in the early 1990 as part of PICCA. Price incentives were introduced in 1996 to lower the price of unleaded fuel to promote its use, as outlined in the first PROAIRE. Leaded gasoline was phased out completely in 1997 in the MCMA and early 1998 in the rest of the country (COMETRAVI, 1999a). It is estimated that more than 1,000 tonnes of lead and sulfur emissions have been reduced annually, due to the phase-out of leaded gasoline. The highest three-month average lead concentration from five measurement stations has been reduced from 6.13 ug/m^3 in 1988 to 0.91 ug/m^3 by 1999, below the standard of 1.5 ug/m^3 over 3 months (CAM, 2000).

Reformulated Gasoline

PEMEX currently supplies two gasoline blends in the MCMA, named Magna and Premium. Premium, which was introduced in the MCMA in late 1996, is higher in quality and price compared to Magna. Magna sales accounted for over 90% of total fuel consumed in the MCMA in 1998. The gasoline reformulation in the past 10 years has been carried out with the following objectives:

- To limit the contents of reactive compounds (olefins and aromatics)
- To lower evaporative emissions of hydrocarbons by reducing the vapor pressure
- To reduce ozone formation potential and other pollutant emissions by requiring a 1% minimum of oxygenate content

- To reduce benzene emissions

Their specifications are summarized in Table 11, compared with the US specifications. The current oxygen content is 1.6%, 0.6% of which is added to mainly fulfill the octane needs at the lowest cost. This oxygen content can reduce emission of CO by 15 percent and HC by 12%. Mexico imports MTBE and other oxygenates to increase the octane value, which requires allocation of approximately 10% of its crude export revenue. PEMEX may face oxygenate deficiency in the near future if the new investments in several refineries are further delayed or not approved. PEMEX is currently evaluating technology investment options for its refineries and attempting to maximize output from existing facilities. Refinery upgrades are carried out by purchasing available technology, and by using the PEMEX Technology Group for installation (Favela, 2000a, Molina and Molina, 2002c).

Low-Sulfur Gasoline

The use of fuel oil with sulfur content higher than 2% was banned in Mexico City in 1991. The Premium blend contains much less sulfur than Magna but more than the US reformulated gasoline, as shown in Table 11.[25] The provision of low sulfur gasoline will become more important in this decade, as the sophisticated emission control equipment to meet the Tier 2 standards requires sulfur level at 30ppm to achieve full emission reduction potential. To produce low sulfur gasoline domestically using the high sulfur Mexican crude (770ppm average), changes in refining technologies and reconfiguration of refineries with substantial investments, up to US$2 billion, will be required. As PEMEX is currently importing high quality gasoline to meet the domestic demand, continued importation may also be considered as a tangible option.

[25] PEMEX data shows that average quality of gasoline is better than the official specifications (Molina and Molina, 2002c).

Table 11: Comparison of gasoline specifications

Fuel Parameter	PEMEX Magna Sin/Reformulada	PEMEX Premium	US reformulated gasoline average
Reid Vapor Pressure (psi)	6.5–7.8	6.5-8.5	7.2 – 8.1, summer 11.5, winter
Aromatics (max % by volume)	25	30	23.4
Benzene (max % by volume)	1.0	2.0	1.0 (1.3 max)
Oxygen (% by weight)	1-2	1-2	2.0
Sulfur (ppm)	500	280	200

(Favela, 2000a, Molina and Molina, 2002c)

Diesel Reformulation

Diesel with 1% sulfur, which had a market share of 79% in 1991, has been replaced by another blend that contains lower than 0.5% sulfur (5,000 ppm). Diesel Sin, which was introduced in 1995, contains a maximum 0.05% (500 ppm) of sulfur with a 75% market share (OECD, 1998). The fuel standards of Mexican diesel are comparable to the US standards, as shown in Table 12. Quality improvement is accomplished by technology investments as discussed above, and possibly changing the crude slate.

Table 12: Comparison of diesel specifications

Fuel Parameters	Diesel Sin	US Standards	CARB
Sulfur (ppm)	500	500	500
Cetane (minimum)	48	40	48
Aromatics (% by volume)	30	35	10

(CARB, 1997, COMETRAVI, 1999a)

3.4.5 Alternative Fuels and Vehicles

CNG Vehicles

The use of CNG in the MCMA has been promoted in PICCA and both PROAIRE programs. CNG has been increasingly accepted as viable alternative fuel, and the number of CNG vehicles is increasing. From 1992, a natural gas pilot program converted 50 police patrol cars to CNG. Diesel-CNG hybrid garbage trucks have also been introduced in the MCMA. CNG-powered buses are being used for longer city routes, but there remain ample opportunities for further emission reduction from the city's older bus fleet (OECD, 1998).

Funds from the Environmental Trust Fund, *Fideicomiso Ambiental del Valle de México,* have been made available to provide financial assistance for vehicle conversions (OECD, 1998). Dedicated or converted CNG vehicles can be exempt from *Hoy No Circula* restrictions regardless of their model year, as long as they are equipped with certified conversion equipment including closed loop and three-way catalysts (Molina and Molina, 2002b).

Approximately 1,200 CNG vehicles were in circulation in the MCMA as of 2000. The Mexican CNG conversion cost estimates range from \$5,000 per vehicle, up to 10% of the original purchase cost for heavy vehicles. A private firm called Combustibles Ecológicos Mexicanos (Ecomex) has carried out the conversion of private and government vehicles. Ecomex also provides a financing program for conversions, and has developed a system to allocate savings from fuel price differences for a down payment of new CNG vehicles. The system, in operation in the Federal District, is aimed at sustaining the number of CNG vehicles in circulation. Ecomex also owns and operate CNG filling stations within the MCMA. A small-scale fill station cost US\$800,000 to build, and a larger fast-fill station cost approximately US\$3 million. Ecomex projects to operate 35 to 40 small and medium sized filling stations by 2003 (Ecomex, 2000, Ecomex, 2002).

The availability of CNG had been limited until recently for two reasons. First, Mexico has historically imported CNG from Texas, although natural gas reserves are found domestically. Second, there remained substantial concern over the effect of seismic activity on a natural gas pipeline system. Limited CNG delivery and distribution infrastructure had thus curtailed its applicability in Mexico. The construction of one refueling station was halted due to neighborhood oppositions (COMETRAVI, 1999a). These factors are now getting mitigated substantially, as the CNG infrastructure development has become a priority for the Mexican energy and economic development policy.

LPG Vehicles

An LPG conversion program in public transportation vehicles and delivery fleets was introduced in the 1990s for both environmental and safety reasons. Initially, conversions were done by imported kits, and only for public transport, private cargo transport, and government vehicles. Fuel recharging was done at controlled stations. LPG converted vehicles are subject to more stringent emission standards and certification, requiring the use of catalytic converter and close loop systems for air-fuel ratio control (Díaz, 2000).

Today, 23,000 to 28,000 LPG converted light duty vehicles, light, medium, and heavy-duty trucks are estimated to be in circulation in MCMA.[26] There are 11 LPG fueling stations in MCMA. The use of LPG as motor fuel has grown due to its lower cost compared with gasoline. Gasoline has been an important source of revenue for the federal government, and as a result is priced higher. LPG is priced lower as it is predominantly used for home. The fuel price difference and low conversion cost (up to $8,000 pesos) has resulted in illegal LPG conversion. Today, private car owners are switching to LPG, using improvised technology, recharging at clandestine recharging stations (i.e., gas truck on the street, or in vacant properties). Such illegal conversions often result in vehicles with higher NO_x emission levels, up to 4 times the standards. The loss of fiscal revenue associated with the widespread LPG conversion could also be significant, as Mexico is an LPG importer (Favela, 2000b).

The quality of LPG may not be optimized for emission reduction in the MCMA. LPG composition in MCMA is similar to domestic fuel composition, at 60% propane and 40% butane, with a considerable variation in propane volume from 40% to 60%. Tests using representative vehicles in MCMA by IMP showed that LPG with 70% propane had the best emission characteristics (Díaz, 2000).

Electric Vehicles

PROAIRE 1995 - 2000 promoted a strategy to promote new technologies for cleaner vehicles, including the production and use of hybrid and electric vehicles. PROAIRE 2002 - 2010 also includes an option to introduce electric vehicles as demonstration project and for road-based public transport.

Fuel Pricing

One way to encourage the use of alternative fuel is through preferential pricing. The CNG price has been set at 34% of the price of gasoline on an energy equivalent basis. This price difference can off set the higher CNG vehicle cost for vehicles that use more than 60 liters of CNG on a daily basis. The LPG pricing, on the other hand, has generated unintended incentives for illegal conversions, as discussed above.

3.4.6 Fuel Economy Standards

Fuel economy standards are a tangible instrument in managing or reducing greenhouse gas emissions, particularly CO_2 from the transportation sector, which is a major greenhouse gas emitter in many countries. Fuel economy improvements also may contribute to air quality improvements, for example through alternative fuel technologies. In Mexico, the transportation sector accounted for approximately 20% of CO_2 emissions in 1998 (CAM, 2001).

Currently, there is no vehicle fuel efficiency standard in Mexico. In the past, corporate fuel economy standards called PREMCE (*Promedio de Rendimientos Minimos de*

[26] The total number of CNG and LPG powered vehicles are not well known. Other sources state 35,000 LPG vehicles and 1,100 natural gas vehicles in MCMA.

Combustible Por Empresa) were applied until the late 1980s or early 1990s, but were abolished to avoid NAFTA infringement. PREMCE was similar to the US Corporate Average Fuel Efficiency standard (CAFE). A comparison of fuel efficiency figures for ten vehicle models sold in Mexico and US from 1996 (Table 13) shows that the fuel efficiency figures for these particular vehicle models appear to be comparable. Real fuel efficiency figures in Mexico may not correspond to these figures, depending on local driving cycles and congestion.

Table 13: Comparison of fuel economy of select new vehicles from 1996 model year

Model	Mexico (km/l)	US (km/l)	Mexico (mi/gal)	US (mi/gal)
VW sedan	12.3	9.7 - 13.1*	28.9	23 - 31
VW Golf	11.3	10.2 - 11	26.5	24 - 26
VW Jetta	10.7	10.2 - 11	25.1	24 - 26
VW Jetta VR-6	8.8	8.9	20.7	21
Dodge Neon	11.0	11.9 - 13.6	25.8	28 - 32
Dodge Stratus	10.7	9.4 - 12.3	25.1	22 - 29
Dodge Intrepid	7.7	8.5 - 9.4	18.0	20 - 22
Plymouth Grand Voyager	6.4	7.6 – 10.6	15.0	18 - 25
Chevy Cavalier	10.9	11.1 - 12.3	25.5	26 - 29
Chevy Cutlass	9.6	8.5 - 9.8	22.4	20 - 23

* US VW Sedan fuel economy figures are for 2002 models

(COMETRAVI, 1999a, US DOE, 2000)

The lack of fuel efficiency standards in Mexico may be linked to its status in the UN Framework Convention on Climate Change (UNFCC). While it is the 14th highest CO_2 emitter in the world as of 1994, Mexico is a non-Annex I country and is therefore only required to report its emission levels, with no emission reduction or stabilization obligations.

Recently, some measures have been introduced or pledged to reduce fuel consumption and greenhouse gas emissions. For example, PEMEX has pledged to reduce greenhouse gas emissions. The National Energy Efficiency Commission (CONAE) have begun a voluntary program since 2001 to disseminate information on fuel efficiency, such as providing information on vehicle windows at dealerships and creating a central database available to the public.

Section 3.5: Economic and Industrial Development— Automobile Sector

3.5.1 Automobile Sector Profile

The automobile sector represents one of the most important industrial sectors for Mexico in terms of its contribution to the national economy and employment. The sector has played a significant role in the increased national export drive, capitalizing on the comparative advantages of Mexico, such as its close proximity to the United States, trade liberalization, as well as moderate labor costs. The percent share of automobiles in total export has risen from 15% in 1986 to 20% in 1996, during the time period in which the total export grew significantly. It is the second leading export sector, following the electrical machinery, equipment, and parts sector (US Department of State, 1999).

The sector has also created significant employment opportunities in Mexico. The number of jobs generated by the sector has increased significantly to approximately 200,000 jobs by the mid 1990s, from 60,000 jobs in 1970 and 100,000 in the early 1980s (Morris, 1998, OECD, 1990).[27]

The automobile sector in Mexico consists of multinational production and assembly firms as well as parts and component manufacturers. Multinational firms have dominated the production and assembly of vehicles. Currently, there are eight firms that are based in Germany, France, Japan, and US that have established passenger vehicle manufacturing operations in Mexico. They are described in more detail in the following section. For the truck and bus manufacturing, domestic and multinational firms are present. As the focus of this research is on passenger vehicles, the term auto sector hereon refers to the manufacturers of passenger vehicles.

Mexico has an active parts and components manufacturing sector, with over 1,000 firms. As a separate sector, its trade balance is negative, and it imports more than it exports. In 1998, the sector's export performance was approximately US$7.5 billion, while it imported US$16.3 billion, $10.6 billion of which from the United States (US Department of State, 1999). The sector is strong in engine parts, brakes, oils and lubricants, and some electronic components, but weak in emission control components, accessories, and security devices. Fuel injection systems, computer control systems, sensors, air condition controls and compressors, electronic equipment and accessories, and automotive parts are mostly imported. The Mexican government has promoted foreign direct investment (FDI) in this sector. Currently, foreign investment accounts for approximately 40% of the total parts production.

One sub-sector of importance for air pollution mitigation is the emission control technology suppliers. Currently, catalytic converters are both imported and manufactured

[27] The impact of the transportation related industry on employment is also significant in the US. The number of transportation-related employment in the US has grown from approximately 66 million workers in 1960 to 130 million by 1997. The % share of transportation-related employment has gradually declined from 13.5% in 1960 to 11.1% in 1997 (US DOE, 1999).

in Mexico, as discussed in the following section. While the technology availability has increased with firms establishing manufacturing facilities in Mexico, a large share is still imported, particularly from the US. The demand for pollution control equipment in Mexico is quite significant; the sector is the sixth leading sector for US exports and investment.[28][29] The US is the strongest exporter in this sector, with 70% of the import market share. The dominance of the US emission control technologies can be attributed to the tightening emissions standards, which have spurred innovation and creation of the industry in the US. The technology-forcing standards in the US have given the US firms a head start on development and production of emission control technologies. The local production of pollution control technologies reached US$1.2 billion (estimated) by 1999, US$520 million of which was exported. US$1.1 billion was imported, US$790 million from the US. The export performance of this sector has grown from US$286 million in 1996 to US$491 million in 1998, and US$520 million in 1999 (US Department of State, 1998, US Department of State, 1999).

3.5.2 Industry Development and Policy Frameworks

This section describes the development of the automobile sector and policy instruments that have been used to shape the sector growth. Table 17, attached at the end of this chapter, summarizes the historical development of the Mexican automobile sector, with a timetable of policy and industry initiatives.

Current State

Nine American, Japanese and German firms are active in the passenger vehicle sector. These firms are: BMW, DaimlerChrysler, Ford, General Motors, Honda, Nissan, Peugeot, Renault, and Volkswagen. Toyota is in the process of establishing a production facility in northern Mexico. General Motors, Volkswagen, and Ford have been operating in Mexico longer than other firms, with considerable presence in the country. As of 1995, General Motors had over 30 plants in Mexico, followed by Ford with over 24 plants. BMW, Honda, Renault, and Peugeot are relatively new entrants into the market, and have established manufacturing plants in Mexico.

In 2000, the sector produced approximately 1.9 million passenger vehicles in Mexico. Of these, slightly above 70% were exported. The US-based multinational firms are geared towards exporting, primarily to the United States. Volkswagen and Nissan, on the other hand, are more oriented towards the domestic market, and hold approximately 50% of the total automotive market in Mexico. As a sector average, 90% of the exported vehicles go to the United States, as shown in Table 13. Table 13 also shows that the export destinations differ among firms. The export destinations of Volkswagen and Nissan are

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[28] The sector includes equipment and technologies for air pollution, solid, industrial, remediation, and medical wastes (US Department of State, 1999).

[29] The leading sectors for US exports and import identified by the US State Department are as follows: (1) Automotive parts and supplies, (2) building products, (3) franchising, (4) telecommunications equipment, (5) computers and peripherals, (6) pollution control equipment, (7) water resources equipment and services, (8) food processing and packaging equipment, (9) general industrial equipment and supplies, and (10) security and safety equipment (US Department of State, 1999).

more varied, including Europe and other Latin American countries (AMIA, 2001).[30] The sector has experienced strong growth after the 1994 economic recession, largely due to its export performance. The growth rate has increased from 8% in 1997 to 25% in 1998 (US Department of State, 1999). The export performance indicates that all of the exporting firms are capable of producing vehicles and accessing key technologies that comply with emission standards of the exporting markets.

Table 13: Export destinations by producers in February 2001

Firm	Car destination	% share	Firm	Car destination	% share
DaimlerChrysler	North America	100%	**Nissan**	North America Central America South America	91% 6% 4%
Ford	North America	100%	**VW**	North America Europe South America Central America	78% 19% 2% 1%
GM	North America Central America	99% 1%	**Sector average**	North America Europe South America Central America	90% 7.5% 1.4% 1.1%
Honda	North America	100%			

NOTE: BMW is not listed as its assembly operations are exclusively for the domestic market

(AMIA, 2001)

In terms of emission control technologies, catalytic converters are currently imported and manufactured in Mexico. Multinational producers in Mexico include: Allied Signal Environmental Catalyst, Arvin Exhaust, Bosal International, CarSound, Cartec, Equipo Industrial Automotriz, PEASA, and Tenneco Automotive. CarSound and Engelhard technologies are also imported to Mexico. Most firms established Mexican

[30] The difference in export destination is more pronounced for trucks. For example, Nissan exported 55% of its truck exports to South America, and 45% to Central America, and 0% to the US (AMIA, 2001).

manufacturing facilities to meet the local demand, i.e., for cars being manufactured in Mexico for the domestic and export markets (MECA, 2000).

The industry association for the manufacturers of passenger vehicles is the Mexican Association of Automobile Industry (AMIA). AMIA has played an active institutional role in building consensus among the member firms, and negotiating and consulting with the government agencies on various policy matters, including environmental regulations. AMIA also has collected historical and current statistical data on vehicle import and export. The parts and component sector has a separate industry association named National Autoparts Association (INA).

From the public sector, the Secretariat of Economy, SE or formerly known as SECOFI, has the legal mandate to monitor and facilitate the development of the automobile sector. The Mexican government has had a long history of using industrial policy instruments to build competitiveness in the automobile sector in terms of production technologies, product quality, and local capacity.[31] The development of the automobile sector is currently guided through the 1994 Automobile Decree. While the extent of industrial policy application has decreased in the past 10 years with the liberalization of the Mexican economy under NAFTA and deregulation of the automobile sector, the sector is still subject to various policy measures. For instance, imports of new or used vehicles are restricted – assembly plants are allowed to import vehicles based on the trade balance requirements. Passenger vehicles must contain at the minimum 62.5% worth of North American parts and components to be meet the rules of origin requirements to be eligible for reduced tariff, which will be phased out as of January 2003. Specific measures are explained in more detail in Appendix A. In addition, the Secretariat of Economy participates in the environmental standard setting procedure, primarily to ensure that the principle of free trade is not infringed upon by proposed standards.

Role of MCMA

The Mexico City Metropolitan Area is a significant market for domestic vehicle sales. Of the total vehicles produced in Mexico, from one third to nearly one half has been sold in the MCMA, as shown in Table 14. This implies that the domestic market may be strongly influenced by the conditions set forth in the MCMA market, including environmental conditions. The local and state level institutions do have jurisdictional

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[31] There are many definitions of industrial policy. The following are two representative examples:

- Policy aimed at particular industries (and firms as their components) to achieve the outcomes that are perceived by the state to be efficient for the economy as a whole (Chang, 1993)
- Policies that favor promising industries, creating skilled work forces, developing infrastructure, and regional policy (Reich, 1983)

For detailed analysis of economic impacts industrial policy, see Itoh, 1991.

Instruments of industrial policy for developing countries encompass technology-oriented tools, capacity and linkage building tools, and market development programs. Specific instruments include technology importation and acquisition programs, R&D support, technical assistance, foreign direct investment, local contents requirement, export promotion, financing programs, and information and support mechanisms.

authority to set air quality standards as well as in-use vehicle emission standards, as summarized in Section 3 of this chapter. On the other hand, the MCMA share of the total domestic production has been under 20% since 1993. This implies that the MCMA market conditions may have relatively weak influence over the production sector compared with the export market conditions. These points are explored further in the case study analysis in Chapter 5.

Table 14: MCMA share of domestic sales and total domestic production

	1993	1994	1995	1996	1997	1998	1999
MCMA share of domestic sales	33%	38%	45%	40%	39%	45%	53%
MCMA share of total domestic production	18%	18%	8%	8%	10%	15%	16%

(AMIA, 2002b, Rogers, 2000, Studer-Noguez, 1999)

Historical Development

The sector development of the automobile sector in Mexico was influenced by various factors from both the industry perspective and the government perspective. From the industry perspective, its presence in Mexico can be attributed to four main reasons as follows:

- Sourcing of labor intensive components in Mexico
- Geographic proximity to the North American market
- Domestic market growth prospects, leading to an interest in securing a long-term position in Mexico (Womack, 1986)
- Integration of the Mexican market into the regional market, and integration of North American production (Morris, 1998)

The sector development has also been influenced by government policy applications, as well as the structure of the auto industry at the global level. From the Mexican government's perspective, the auto sector development was attractive for the following reasons:

- Development of advanced industry with substantial technological capacity
- Employment opportunities
- Foreign currency conservation and generation

The relative importance of these factors has changed as the sector developed. This section traces the development of the Mexican automobile sector in five phases with distinct differences in industrial policy tool applications and industry response.

Initial Phase (1920 - 1962)

The Mexican automobile sector began its development with the establishment of a Ford plant in 1926. In the early period, the Mexican automobile sector was focused on assembly-type industry using imported assembly (CKD) kits.[32] Local assembly was initiated to offset shipping costs and tariffs (Womack, 1986).[33] Drivers for the sector included the international strategy of leading US automakers and anticipated growth of domestic market. The Mexican government encouraged the sector establishment by reducing tariffs on assembly materials.

During this phase, the production of domestic parts and components remained small, below 20% of total inputs (Moreno, 1987, OECD, 1990). As a consequence, the auto sector accounted for a significant share of total imports by the 1950s. Vehicle and part imports accounted for 11% of Mexico's total imports (Jenkins, 1977). Factors that limited the sector growth included the relatively small size of the domestic market and high vehicle prices. The Mexican market in the early 1960s was only large enough to support five or six models, if production economies of scale were to be exploited. By the end of this phase, twelve assembly plants had been established, with increasing prominence of US firms such as Ford, GM, and Automex (Chrysler) (OECD, 1990).

Import Substitution Phase (1962 - 1977)[34]

In the import substitution era, the sector moved away from simple assembly towards manufacturing. Changes in the Mexican industrial policy contributed to the transformation of sector towards manufacturing. The Automobile Decree of 1962, issued by the Secretariat of Economy and Industrial Development (SECOFI), included several measures to increase domestic production and to reduce importation of vehicles, parts, and components. For example, the decree required 60% of direct costs of vehicles to come from domestic production, including mandatory use of Mexican made engines and transmission systems by 1964. The decree also defined a dual industrial structure, i.e., allowing foreign ownership in assembly activities, limiting the vertical integration of foreign firms to the production of engines, and obliging the firms producing parts to have a minimum of 60% Mexican capital. Car imports were reduced, and production quotas were set up (OECD, 1990). To provide incentives for the auto sector to switch to manufacturing, another Automobile Decree in 1963 exempted import duties on

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32 CKD stands for completely knocked-down.

33 The history of industrial policy application also goes back a long way. By the early 1930s, Mexico and other Latin American countries provided some degree of protection to promote local assembly, by providing lower tariff on imports of unassembled cars, compared to assembled vehicles (Jenkins, 1977).

34 The MIT Dictionary of Modern Economics provides a rather lengthy definition of import substitution. It defines import substitution as "...one of the main development strategies chosen by developing countries. In the early post-war years it was thought... that a policy of industrialization was the best strategy by which to attain economic progress. The most obvious route a through import substitution. This entailed establishing domestic industries behind tariff and quota barriers... It was hoped that imports would be replaced and internal growth fostered. It was hoped that the costs of the strategy would be borne by the advanced countries supplying the manufactured consumer good. Experience with the strategy has turned out to be disappointing for most developing countries." (Pearce, 1995)

machinery and equipment for five years, and import duties on raw materials, parts, and components for four years. The exemption was phased out to 50% and 25% over two three-year periods. In addition, the government production quotas were lifted if the level of local integration was over 70% (Jenkins, 1977).

The government's adoption of import substitution policy was motivated foremost by the need to save foreign exchange, followed by the desire to create new employment opportunities. In addition, the sector development in Brazil and Argentina indicated the possibilities of industrial development to the Mexican government. The Brazilian and Argentinean development also pressured Mexico to develop its own sector to avoid opening the market to exports from these countries within the Latin American Free Trade Area (LAFTA). The Mexican economic authorities practiced some control over the number of entries and investment projects during this period, with limited success (Jenkins, 1977).[35] Finally, the government aimed to resolve the growing conflict between the terminal industry, dominated by the multinationals, and the auto parts industry, dominated by domestic firms (Morris, 1998).

The automakers were willing to make defensive investments to accommodate import restriction measures, primarily due to the increased competition the sector faced in both developed and developing countries, and projected market expansion in Mexico. During this phase, the GNP per capita had increased by almost 50%, from \$2,091 in 1962 to \$3,028 in 1972, both in constant 1995 US dollars (World Bank, 2000). This rise in income warranted the expansion of the domestic market for automobiles. Another important reason was that the firms were faced with the choice of investing or leaving the market, due to increasingly strict import restrictions measures. Those firms with Mexican presence determined that remaining in the market was preferable than leaving and then facing higher entry barriers at a late date to a market dominated by its competitors.[36]

During this phase, the market dominance of the US firms began to diminish, in competition with non-US firms. At the beginning of the import restriction phase in 1963, Automex (Chrysler), Ford, and General Motors dominated the sector with 21%, 24%, and 22% market share respectively. By 1973, Volkswagen had the largest market share of 27 %, followed by Automex, Ford, and General Motors at 19%, 17%, and 13 %. Nissan had increased its market share to 9% by then (Jenkins, 1977).

The overall effect of this phase was a substantial increase in the economic output from the sector. The demand for car in Mexico grew to approximately 160,000 vehicles in

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[35] Major firms that submitted proposal to the Mexican authorities but did not start production include Peugeot, Volvo, Hillman, Citroen, Toyota, and Mercedes-Benz. On the other hand, the authorities appeared to have faced pressure to allow some existing firms, such as GM and Ford, to continue production. The authorities may also have faced pressure to accept investment proposal from Nissan. The authorities had limited control over firm entry, due to their underlying concern to maintain favorable conditions for foreign investment (Jenkins, 1977).

[36] Despite the import substations strategy, Mexico continued to import some foreign cars and commercial vehicles. The exact number of such importation, however, is unknown (Jenkins, 1977).

1970 and over 210,000 vehicles in 1973, compared to 64,000 vehicles in 1960 and 35,000 vehicles in 1955 (Jenkins, 1977). The auto sector became the largest manufacturing activity, accounting for over 5% of total manufacturing value by 1973. Foreign direct investments during this period totaled approximately $500 million (Morris, 1998). The sector generated over 60,000 jobs by 1970. The degree of local integration increased significantly. By 1973, the average local content of Mexican vehicles was 65%, measured by direct cost.[37] Domestic production included motors and transmissions, and local production capability in casting and machining of engine parts, such as crankshafts, intake and exhaust manifolds, and their assembly were developed (OECD, 1990, Jenkins, 1977).

Despite the initial success, several limitations for further development of the sector began to emerge. The first limiting factor was the sector's focus on the domestic market, which required significant importation of parts ad vehicles, and limited export performance. In 1970, the passenger vehicle export was zero, and parts export was $26.4 million only, yet the sector imported $256.7 million worth of parts and vehicles. By 1975, the sector export performance of less than $5 million for cars and over $100 million for parts and components was dwarfed by its importation worth $750 million. The second limiting factor was the small domestic market and corresponding production scale that restricted true import substitution. For example, the total Mexican annual production in 1970 was less than an average output from one US plant. As a result, the sector generated a large foreign trade deficit, in contradiction to the policy objective of foreign exchange savings, and faced performance and development limitations.

Faced with these negative effects, the economic authorities began to change its policy direction from import substitution. For example, the Automobile Decrees that were introduced in 1969 and 1972 fixed production quotas based on the export performance and required exportation of parts to offset imports to develop the parts and component manufacturing. The foreign exchange crisis of 1976 further highlighted the need for change in sector development and policy direction (OECD, 1990).

Export Promotion Phase (1977 - 1982)[38]

Faced with the constraints of the import substitution era, the Mexican auto sector began to evolve towards export promotion in the late 1970s. The Automobile Decree of 1977 included specific measures to increase export. First, the requirement for domestic part

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[37] The Mexican local content was lower than in Argentina and Brazil, which achieved 96% and 85% of local content by value. In the three countries, the engine, parts, and subassemblies were procured locally. Mexico imported body stampings, which enabled the Mexican firms to follow the annual model changes of the parent companies. In Argentina and Brazil, firms produced the same models for several years (Jenkins, 1977).

[38] Export promotion is the development of industries whose main markets are overseas. According to the MIT dictionary of modern economics, export promotion strategy is considered to be the main alternative to import substitution in less developed countries. The success of the strategy is dependent on several factors to enable production and distribution at low cost. Such factors include efficient infrastructure in transport and communications, availability of low cost raw materials, as well relatively open trade policy (Pearce, 1995).

integration was changed to 50% of the cost of production, not including labor, and the value of imported components was subtracted in the local content calculations. Second, the foreign exchange budget of vehicles, including direct and indirect imports as well as payments abroad, were determined for each producer. The firms were held responsible for correcting the deficit in the balance of payments. Third, the production quota system and price control were phased out to foster productivity improvements and competition.

The economic authorities provided a number of incentives, including tax incentives, subsidies, credits, and infrastructure development. For example, tax incentives decreased the price of Mexican engines by approximately 30% lower than Japanese and US engines (OECD, 1990). During this period, 23% of subsidies for manufacturing capacity installation, totaling $245 million, was allocated to the auto industry. Local credits were made available for plant installation, sometimes for up to 80% of the total investments. State governments facilitated land acquisitions and provision of water and other infrastructures (Arteaga and Micheli, 1987, OECD, 1990).

The government's motivation in this policy shift was to complement the domestic market growth with stronger export performance to balance the trade deficit.

The auto sector responded positively to this change in government policy direction, primarily as the change coincided with the major sector transformation at the global level and corresponding changes in the Mexican production strategy. At the global level, the sector faced changing demand for cars, incorporation of new technologies, as well as increasing competition from the Japanese manufacturers (OECD, 1990). The sector viewed Mexico favorably, due to its proximity to the US, its cost advantage related to government support as well as manufacturing experience, and its economic prospect.[39] Strong domestic demand for automobiles complemented the drive for expansion. The per capita income increased by 6% annually, from $3,353 in 1977 to $4,269 by 1981, but declined to $4,013 in 1982 due to the economic crisis (in 1985 US$) (World Bank, 2000). As a result, firms began to establish engine and assembly plants, mainly for export, with state of the art production facilities. Six firms in operation in Mexico were: GM, Ford, Chrysler, Volkswagen, Renault, and Nissan (Womack, 1986).

While the overall sector performance was positive, short-term results were not in line with the policy objectives of the 1977 Automobile Decree. The domestic demand during this period was quite strong, ranging from over 194,000 units in 1977 to approximately 290,000 units by 1982. The export performance increased from 5,200 vehicles in 1977 to over 14,000 vehicles in 1982 (OECD, 1990). The production capacity of engines increased to over 1 million during phase, mainly for export to the US. The expansion of engine production helped the US-based multinationals to meet the foreign exchange budget requirement, and allowed them to respond to growth of the lower-cost Japanese vehicles in the US (Morris, 1998). While the investments increased significantly during this period, the trade balance did not turn positive until 1983, as plant investments typically took a few years to be completed and fully functional, and due to stronger than

[39] Mexico's positive economic prospect during this time period is frequently attributed to the oil boom of the late 1970s.

expected domestic demand. The sector generated over 120,000 jobs, and accounted for over 7% of manufacturing production by 1980.

The economic crisis that began in 1982 had strong negative impacts on the sector performance, and illuminated a number of problems. For example, the sector was still limited by the small production scale, due to an excessive number of production lines and models. In 1977, there were 7 carmakers with 15 lines and 36 models. By 1981, there were 19 lines with 47 models. In 1981, only 18,000 cars were produced per production line, in contrast to 100,000 to 150,000 cars per line in developed countries, and 45,000 cars per line in Brazil. In addition, the vehicle prices were not competitive – prices were more expensive than the US, as 30% to 100% was added onto the consumer price. The domestic car sales dropped by 16% between 1981 and 1982. The authorities also started to feel the high cost of economic incentives, especially during the economic crisis. These issues eventually led to a shift in policy direction.

Liberalization Phase (1982 - early 1990s)

The 1983 Automobile Decree included measures to address various problems highlighted in the previous section. First, subsidies were phased out, except for the import tax exemptions on machinery and equipment not produced in Mexico, which were maintained until 1985. Second, the number of lines and models were gradually reduced from 3 lines with 7 models per firm in 1984 to 1 line with 5 models per firm by 1987, to reach the minimum number for scale economies, estimated at 50,000 units per line. Third, the foreign exchange budget offset was tightened, so that only 20% of foreign currency spending could be offset with exports from outside the automobile branch. 8-cylinder engines were prohibited for the domestic market in order to save energy, and 25% of passenger vehicles were supposed to be lower-priced models with no optional equipment.

More importantly, the Decree introduced some key measures to support the integration of Mexican auto sector into the evolving regional production system. The automakers were given an option to build additional lines, provided that they were self sufficient in foreign exchange and that they export more than 50% of their output as cars or equivalent assembly material for each line, and maintained at least 30% local contents. 20% of vehicles from new production lines could be sold in the domestic market (Morris, 1998). The national integration requirement for existing models was increased by 10% to 60% by 1987, which could be offset by export performance. The sector was to "...achieve international price and quality levels, without resorting to mechanisms that would go against the policy of price regulation (OECD, 1990)." In addition, the Consultative Committee for the Automotive Sector was established, allowing the industry to participate in the decision-making process related to the sector.

The 1989 Automobile Decree, under the Salinas administration, set out steps towards gradual liberalization of the sector. Under the Decree, the importation of completed vehicles was allowed, subject to trade balance and export requirements. Assemblers with positive trade balances could import vehicles up to 15% of their domestic sales. They also had to match every dollar in the import value with $2.50 in export performance in 1991, $2.00 in 1992 – 93, and $1.75 in 1994. The domestic content requirement was reduced to 36% for domestic models, but remained at 30% for export models. The restrictions on models and obligatory use of some domestic parts were eliminated (Morris, 1998).

The 1989 Decree also introduced the People's Car Program, *Auto Popular*, which promoted the production and sales of accessible vehicles. Vehicles are offered at lower prices, exempt from new car tax (ISAN), and with financing program through authorized dealers. As vehicle financing was difficult to obtain until very recently, this programs facilitated vehicle ownership for citizens with medium income level. The manufacturers are given a tariff exemption on importation of parts and component, and must produce at least 40,000 units per year. Volkswagen sedan was the first model in this program, followed by GM Chevy, which entered the program in 1995. This program, which is still in operation as of 2002, greatly expanded the market for these two entry-level vehicles. In 1989, the sales volume of VW sedan increased by 70 percent, from 20,000 units a year before to over 32,000 units. By 1990, the figure was over 84,000 units. The program remains very popular, and sales figure in 1998 was 91,300 units. These two models account for approximately 10% of total vehicle sales in Mexico today, and 30% in the mid 1990s (SE, 1999). In terms of environmental performance, while the program stipulates that cars incorporate emission reduction technology within the effective legal limits, there are no additional requirements to reduce emissions or promote cleaner vehicles.

The primary motivations for the government were to manage the foreign exchange budget, and to achieve scale economies by reducing production line differentiation. Considerations for the domestic sector development remained important, as reflected in the local integration requirements, and the aim to supply competitive vehicles in the domestic market through efficiency improvements. The force of sector globalization and Mexico's role was increasingly recognized by the policymakers, as evidenced by the support measures for integration in the 1983 Decree, as well as deregulation embodied in the 1989 Decree (OECD, 1990, Morris, 1998).

From the industrial perspective, the sector performance was profoundly influenced by its own structural changes, and less by government interventions. Unlike the previous phases where policy shaped the industry, the industry began to influence policy. During this phase, the auto sector experienced structural changes both at the global and local contexts. Domestic contexts include the changes in the domestic demand, and evolving labor relations, which compelled firms to establish plants in new locations. From the regional context, a North American production framework that encompassed production facilities in Mexico, US, and Canada was beginning to emerge (Studer-Noguez, 1999). From the global context, the increased importance of the foreign market, particularly the US market, led to changes in the sector structure in Mexico.

The supply structure in Mexico during this phase experienced growth and diversification for exports, as well as greater geographic concentration of production facilities. Numerous new plants for multinational firms were established during this period, with state-of-the-art, capital-intensive technologies. Many of these facilities were located in the north and in the border region, to be closer to the main export market. The new locations were selected also to avoid areas with active trade unions to attract labor with new contracts and lower wages, and in response to decentralization policies. At the same time, some older, technologically obsolete plants were shut down while others were modernized and expanded. Some firms exited the market and ceased production, such as Renault and VAM.[40]

The possibility to sell vehicles in both domestic and export markets for firms that met the 1989 Decree requirements led to further integration into the North American operations by consolidating the Mexican operations into their regional strategies (Morris, 1998). Some scholars speculated that production lines for the foreign and domestic markets were being consolidated, due to the increasing number of new and modernized plants (OECD, 1990). Yet others thought that the two-tiered production system, with newer facilities in the north for the export market, and older, centrally located facilities for the domestic market, would remain in effect (Morris, 1998, Mortimore, 1995).[41] From the environmental perspective, the continued existence of the two-tiered production system well into the late 1990s was confirmed when emission differences for certain vehicle models available both in Mexico and the US was discovered. This observation will be described in more detail in Chapter 5.

While the auto manufacturers enjoyed greater flexibility, the auto part manufacturers, including emission equipment manufacturers, remained under more controlled policy environment.[42] The legal limit on foreign direct investment (FDI) was set at 40%, discouraging multinational firms to establish manufacturing facilities in Mexico. In addition, the vertical integration for firms producing vehicles was not encouraged. The export performance of parts and components was promoted in the 1977 and 1983 Decrees, which included specific local content targets for vehicle exports. The international competitiveness of the parts and components sector during the liberalization phase varied according to the level of technology. In general, firms producing low technology goods were export intensive and competitive. Firms producing medium technology goods were not competitive internationally, and more than 70% of output was for the domestic market. The performance of high technology goods were insignificant,

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40 Unlike South Korea and Japan, Mexico did not develop a national passenger vehicle company. Vehiculos Automotores Mexicanos (VAM) was the only firm with Mexican majority ownership, set up as a joint venture. Its predecessor was set up in 1946 to import assembled Jeeps and for their distribution. The company established an assembly operation in the 1950s for different makes, including Datsun and Peugeot. Following the 1962 decree, the company changed its name to VAM as a joint venture with Jeep and American Motors. Its market share was consistently small, 7% at maximum. The Mexican government sold off its majority share in VAM in 1983, and the firm was eventually shut down by 1984 (Jenkins, 1977, OECD, 1990).

41 Both the government and industry had reasons to support the older production facilities. For the government, protecting thousands of relatively well-paid manufacturing jobs in these facilities was a priority during the economic crisis. For industry, these plants could continue to service the domestic demand without substantial investments, as most of the production machinery and equipment were fully depreciated (Morris, 1998).

42 The 1983 Decree defines auto parts firms as those whose sale of component destined for motor vehicles is greater than 50% of their total sales. The definition does not include firms that manufacture both finished vehicles as well as components (OECD, 1990).

as such goods, if produced in Mexico, were produced directly by car manufacturers, and not be independent firms (Booz Allen and Hamilton, 1987).[43] The mixed performance of the auto parts sector was attributed to the delay in restructuring and modernization programs in the sector. The future competitiveness of the sector became a serious concern for the policymakers around this time (OECD, 1990).

During this phase, the domestic market contracted as a result of the fall in per capita income from the economic crisis. GNP per capita decreased by 6% annually in 1982 and 1983 to $4,013 and $3,768 in 1995 US dollars, stagnated and then decreased by 6% again in 1986 (World Bank, 2000). The domestic sales decreased by 33% in 1983, increased above 10% in 1984 and 1985, then decreased again in 1986 and 1987. The overall market contraction led to changes in the market structure, including demand segments and dominant players. The sales of low priced vehicles under $10,000 including VAT increased, while the mid-level vehicles priced from $10,000 to $15,000 declined. The dominant players in the low-price vehicles were Volkswagen, Nissan, and Renault in 1984. By 1987, Renault exited the market, and Nissan had the largest share of the low price market, followed by Volkswagen. Nissan offered its low price model, Tsuru, at a price lower than the Volkswagen beetle, increasing the market share. The average units per production line for Tsuru was approximately 60,000 units by 1987, far greater than the industry average of 15,000 units and the only model that met the minimum production set forth by the 1983 Decree (OECD, 1990).

On the other hand, the export production increased dramatically, and surpassed the domestic sales by 1993. The foreign exchange balance turned positive by 1993, initially supported by a substantial increase in engine export, and later with passenger vehicle export (OECD, 1990). There were differences in export orientation among the firms. While the share of export in total vehicle production for Chrysler, Ford, and General Motors was 61%, 60%, and 44% respectively, Nissan and Volkswagen was more focused on the domestic market. Nissan exported 19% of its production, while Volkswagen exported almost zero. Both firms focused on supplying the domestic market with low priced cars. Nissan's export market was Central America, and not the United States.

One analysis found that the competitiveness of Mexican-made vehicles in the export market was inversely proportional to the percentage of local contents. The local content offset enabled the exporting firms to be competitive by optimizing the more competitive production factors in Mexico, such as labor and domestically produced parts that are cheaper than in the US, and avoiding the less competitive domestic factors, such other domestic parts that were at least 20% more expensive than in the US. This study found that vehicles with 30% domestic integration were totally competitive in the international market, while 40 to 50% domestic integration was fairly competitive. In contrast, the 1983 Auto Decree required 60% integration for existing models in the domestic market. The export drive and domestic requirement offset was thus mutually reinforcing: firms needed to export to offset the national integration requirement, and the more offset the

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[43] Examples of low technology goods include windows, stamped articles, and small plastic parts. Medium technology goods include plastic panels for bodywork, fuel injection components, and driving wheels. High technology goods include automatic transmissions and condensers (OECD, 1990).

firms could use, the more competitive the vehicles became (Booz Allen and Hamilton, 1987, OECD, 1990). On the other hand, domestically oriented firms did not have access to offsets, which meant that their access to competitively priced parts and technologies, including environmental technologies, was also limited. This observation is elaborated in more detail in Chapter 5.

The overall policy effect was mixed at best, as the sector performance was influenced not only by policy intervention, but more so by structural changes initiated by the sector and facilitated by past policy applications. While some (Mortimore, 1995, Scheinman, 1993) suggested that the Salinas administration was able to direct the auto sector to better serve the needs of the Mexican economy, others (Jenkins, 1977, OECD, 1990) concluded that the industry had become too dynamic to be steered into a different direction by Mexican policy. The establishment of plants in northern states generated employment opportunities, albeit at lower wages.[44] While the goal of foreign trade and exchange balance has been met, the other main policy objective of rationalization of domestic supply was not been achieved. The competitiveness of Mexican vehicles in the export market was influenced by access to parts and components procured abroad, due to the sub-optimal performance of the domestic parts and component sector. The production scale did not increase to the level prescribed in the Automobile Decree. The industry maintained that it could not produce at the competitive capacity or scale economy, partially due to the high level of indirect tax on car sales of 20 to 40% and VAT of 15%. The high level of tax has persisted until today. It also continues to be blamed for slowing down the vehicle turnover rate by the industry.

Further Liberalization/Free Trade Phase (early 1990s to present)

Following the liberalization trend in the late 1980s, NAFTA established a regional trade framework in the auto sector and the Mexican economy as a whole. The following is a summary of Mexico's commitment:

- Phase out of tariffs on cars and lights trucks that meet rules of origin by 2003
- Phase out of trade balance requirements by 2004
- Phase out of import restrictions on non-Mexican producers by 2004
- Elimination of market share restrictions immediately
- Reduction and elimination of local content requirements by 2004
- Phase in of rules of origin requirement
- Phase-out of embargo on used vehicles that meet the NAFTA rules of origin starting in 2009 over 10 years
- Use of import licenses to monitor NAFTA provisions until 2004 only

[44] Labor supply and cost has an impact on the economic performance of manufacturing plants, and thus is a source of comparative advantage for Mexico. In the late 1980s, the cost of labor was estimated to be 5% of the total production costs, compared to 15% in the US. Assuming lower productivity, the OECD estimated that locating in Mexico would lower the total production cost by 9%, which corresponds to about 70% of the share of business profits (OECD, 1990).

- Use of import licenses to restrict used vehicle entry until 2009
- Use of import licenses to monitor the age of vehicle imports during the used vehicle restriction phase-out (2009 – 2019)

Details of tariffs, regional content, and import restrictions are presented in Appendix A.

The auto sector was highly involved in shaping the NAFTA provisions related to the sector. Rather than a comprehensive deregulation mechanism, NAFTA is viewed by some as a regulatory framework to limit competition from new entrants for 10 years (Morris, 1998). Environmental concerns were addressed by the side agreements on the environment and labor rights, which underlined harmonization of environmental standards and enforcement mechanisms for standard violations.

In addition to NAFTA, the legal framework for international capital participation was modified to facilitate foreign direct investment (FDI). The Foreign Investment Law of 1992 provides national treatment for most FDI, including the equal national treatment for most foreign investment, elimination of performance requirements, as well as liberalized criteria for automatic approval of foreign investment proposals. Investors from NAFTA nations also receive both national and Most Favored Nation (MFN) treatment in establishing operations or acquiring firms, except where reservations have been established separately. The National Program for Development Finance (PRONAFIDE) was developed for the period 1997 – 2000 to achieve 5% annual GDP growth and employment generation, supported by growing domestic savings, FDI, and responsible monetary and fiscal policy (US Department of State, 1999).

BMW and Renault entered the market during this phase. BMW's entry was to supply high-end luxury vehicles to the domestic market, and not for export. BMW's assembly operations use imported kits from Germany. Renault re-entered the market in 1999, taking advantage of the alliance with Nissan, which enabled them to manufacture Renault vehicles in Nissan plants. Currently, Renault sells two models for medium and high-end market, and will be in all market segments in the future. Cars are imported and manufactured in Mexico, depending on the model.

The auto sector significantly increased investments towards plant and product modernization, quality and productivity improvements. Between 1995 and 2000, investments totaling $5.2 billion were realized or envisioned. The production volume increased significantly, particularly for the export. Accordingly, the total production in Mexico reached 1.9 million units by 2000, compared to 1.1 million units in 1994. By 2000, over 70% of the domestic production was for export. With the phase out of import restrictions, the share of imported vehicles for the domestic market increased to approximately 60% by 2001 (AMIA, 2001). The financial crisis of December 1994 resulted in an abrupt drop in domestic sales, hurting national auto parts industry that catered towards the domestic market. However, the 50% devaluation of peso and favorable exports markets enabled the auto manufacturers to rebound by 1996. Forecasts for the sector by the government and industry remain quite positive.

Section 3.6: Summary and Observations

This chapter presented the key factors that have in contributed air quality degradation in the MCMA, such as population growth, expansion of the urban area, geographical and topographical characteristics, increase in emission sources, and lax emission standards. The institutional, legal, and technological responses for air quality management were also described. The transportation sector has been a significant source of pollution, and technological options have been used extensively to reduce emissions. The introduction of these options required acquisition of technological capability in the automobile and petroleum sectors, as well as different policy support not related to the environment. These factors are explored further in the next chapters.

Table 15: Timeline of laws, policies, and corresponding technologies

Period	Laws, Policies, and Programs	Technology level
1971	Federal Law for the Prevention and Control of Environmental Pollution passed	
1972		Control of evaporative emissions
1973-1977		Electronic ignition system in Chrysler cars (1974 model year); in GM cars (1976 model year)
1976 – 1982	Sub-secretariat of Environmental Improvement (SMA) created in Secretariat of Health	
1978	Inter-ministerial Commission for Environment established	
1979	First MCMA air quality management program (PCMCA) introduced	Altitude control in carburetors introduced
1982	Federal Law of Environmental Protection introduced Secretariat of Urban Development and Ecology (SEDUE)	
1983	Operation of the diagnostic system and verification of mobile sources in DF (10 centers)	
1985	National Commission on Ecology (CONADE) established to define environmental priorities and for coordination	Manufacturing of 8-cyclinder automobiles prohibited, per SECOFI decree
1986	RAMA ambient air quality monitoring network introduced 21 measures to control air pollution in MCMA introduced	Fuel injection systems introduced in 1986 GM models Sulfur reduction from diesel fuel
1988	General Law of Ecological Equilibrium and Environmental Protection (LGEEPA) introduced at the federal level	
1989	Operation of car verification program became obligatory	NOx certification included for new automobiles
1990	Comprehensive Program Against Air Pollution in the MCMA (PICCA) implemented at the metropolitan level Biannual verification of vehicles in DF, and biannual verification of trucks that circulate in federal highways began	Unleaded gasoline (Magna Sin) introduced
1991	Interim emission standards for 91 and 92 model years introduced	Oxidation catalysts in new gasoline vehicles mandated
1992	National Institute of Ecology (INE) established to set environmental regulations and management and protection of environment and natural resources Attorney General for Environmental	Liquefied petroleum gas (LPG) conversion program for cargo and passenger cars started Pilot natural gas conversion program for police cars started

Period	Laws, Policies, and Programs	Technology level
	Protection (PROFEPA) established to enforce environmental laws and regulations SEDUE reorganized into Secretariat of Social Development (SEDESOL) Metropolitan Commission for Pollution Prevention and Control (CMPCCA) created for PICCA implementation Annual I&M program began in DF	
1993	Tier 0 standards introduced Semiannual vehicle verification computerized in DF	Three-way catalytic converters in all new gasoline vehicles mandated New vehicles manufactured with LPG motors made available
1994	Secretariat of Environment, Natural Resources, and Fisheries (SEMARNAP) established to incorporate all federal environment functions	
1995		Low sulfur diesel (Diesel Sin) introduced
1996	Metropolitan Environmental Commission (CAM) established to coordinate policies and programs at the metropolitan level, succeeding CMPCCA PROAIRE introduced by CAM	Vehicles with on-board diagnostic system first appear (select Ford models) Low sulfur gasoline (Premium) introduced
1998		Leaded gasoline phased out from MCMA
1999	Tier 1 emission standards introduced Voluntary agreement between INE and auto industry to phase in OBD and warranty from 2002 and to introduce technologies 2 years after US and Europe signed	Vehicles with Tier 1 technologies available
2002	PROAIRE introduced in MCMA by CAM	Phase-in of OBDII and vehicle warranty begins

(COMETRAVI, 1999a,OECD, 1998)

Table 17: Timetable of policy actions and sector response

Year	Government Action	Industry Action
1925		Ford opened first Mexican assembly plant
1930	High import duties on finished vehicles assessed	US producers established assembly plants for Mexican demand
1947	Import of assembled vehicle prohibited, Annual assembly quotas and import bans on parts manufactured locally (mainly tires and tubes)	Increase in number of autos assembled in Mexico
1951	Price control system established for low-priced cars and all trucks	
1954	Import quotas for assembly plants made contingent upon equivalent cotton export	
1959	Import licenses on small finished cars granted Increase of model numbers permitted	
Early 1960s	Import substitution strategy	20 to 25% of vehicle costs by Mexican made parts
1961	Highest price cars eliminated (close to 30 brands and 70 models)	
1962	Automotive Decree established Integration programs for local production of motors and parts by 1964 required	Firms remain in the Mexican market
1963	Automobile Decree introduced Exemption of import duties on machinery and equipment, raw material, parts and components	
1969	Automobile Decree introduced Fixed production quota based on export performance of each enterprise Partial offset of imports by parts export	
1972	Automobile Decree introduced Fixed production quota based on export performance of each enterprise Imports partially offset by parts export	Negligible export performance Net importer
1973	Law to Promote Mexican Investment and Regulate Foreign Investment introduced Maximum FDI capital requirement for auto components set to 40%, and 40% for secondary petrochemicals Restricted FDI in petroleum and other hydrocarbons, basic petroleum products	Average local content of 65% measured by cost
1976	Foreign exchange crisis	Attention to foreign trade deficit in the sector
1977	Automobile decree introduced Raised the national part integration requirement and modified how local contents were calculated (subtracted imported components from parts bought locally)	Strong domestic demand

Year	Government Action	Industry Action
	Included all payments abroad (repatriation of profits and other factor payments) and raised the foreign exchange requirement through exporting parts to 50% from 40% Eliminated production quotas and price controls to increase competition and encourage productivity gains	
1982	Economic crisis	
1983	Automobile Decree introduced Phase out of subsidies Reduced number of car lines and models, unless the line is balance-of-payment neutral 60% LCR for finished cars, or compensation by increasing export balance-of-payment neutrality on yearly basis protected domestic market through import licenses	Re-organization and re-privatization Decreased models and production lines Government equity in VAM sold Renault sold
1984	Guidelines for Foreign Investment and Objectives for its promotion released: Encouraged foreign ownership in high technology and export oriented products	Establishment of plants for export in Northern Mexico
1989	Automobile Decree introduced Gradual trade liberalization to allow passenger car imports based on export performance LCR reduced to 35% Export-import index requirements reduced No national integration requirement *Auto Popular Program* introduced	Structural change at global sector level Integration into regional production network
1992	Foreign Investment Law National treatment for FDI Elimination of performance requirements Most Favored Nation treatment for NAFTA investors	
1994	NAFTA introduced Elimination of market share restrictions Agreement on Currency crisis	Sharp decline in domestic demand, strong export performance
1999	Phase out of industry protection measures per NAFTA	Renault re-enters Market >70% of production for export

(OECD, 1990, Morris, 1998)

Chapter 4. Comparative Quantitative Analyses of Technological Change

The overall objective of this research is to analyze the process and determinants of environmental technological change. In this, the research faces one of the major challenges of interdisciplinary research on sustainability: obtaining policy-relevant results and insights from both quantitative and qualitative research methods. The experience of researchers in area of technological change and industrial development has been that quantitative analysis alone may not provide sufficient insight to illuminate the causal mechanisms of change, understanding of which is required for effective policy intervention. This inadequacy reflects both poor data availability and consistency, especially from developing countries, and the nature of econometric analysis itself, which tests correlation rather than causality. My research methodology argued these two points, and called for both qualitative and quantitative analysis—each necessary but neither sufficient on its own.

This chapter presents the results of my quantitative analysis of widely used indicators of technological change for a set of nine countries of interest, including Mexico. First, a comparative analysis of indicators of technological change was conducted with data from nine countries. Second, an econometric analysis of manufacturing value added for these nine countries. Manufacturing value added is the best available proxy for technological progress in industrial development in general, and for the automobile sector specifically.

The following two sections describe the methodologies and results of these analyses. The results indicate that while quantitative analysis did yield insight into the significance of some variables that are thought to be susceptible to policy manipulation, findings are not sufficient to construct a model for policy intervention. The results, however, can inform the qualitative analysis, which yields additional knowledge for the model conceptualization. The qualitative analysis is presented in Chapters 5 and 6.

Section 4.1: Statistical Analysis

4.1.1 Introduction

A comparative analysis of technological capability indicators was conducted to evaluate and compare Mexico's technological capability with other countries. Seven rapidly industrializing countries were included in the analysis, namely Argentina, Brazil, India, Singapore, South Korea, and Thailand. The experiences of these countries were also compared with those of the United States and Japan, which have served as models of industrial development to many of these countries. The analysis covered 19 years, from 1980 to 1998.

While such analysis does not take into account country-specific comparative advantages, such as geographical proximity to major markets, it does present some quantitative evidence on how countries at comparable levels of industrialization have maintained and/or gained technological capability. Many of these countries may be competing against each other for potential manufacturing investments, as increasing globalization (and free trade) allows firms to seek out favorable locations worldwide.

4.1.2 Indicator Categories

Literature on industrial development and technological change has identified a number of variables that influence technological capability acquisition. In particular, analyses by Lall identified different categories of national technological capability indicators for developing countries. The following table summarizes the indicators selected for further analysis, taken from Lall's analysis as well as the indicators of human development indexed by the World Bank (Lall, 1992, World Bank, 2000).[45]

Table 17: Categories of indicators on national technological capability

Science and Technology	Human Capital	Economic Structure
R&D expenditure (%GNP, 95US$)	Labor force with primary, secondary, and tertiary education levels (% labor force)	Manufacturing value added (%GDP, US$)
Scientists and engineers in R&D (per million persons)	School enrollment at primary, secondary, and tertiary levels (% of appropriate age group)	Gross domestic investments (% GDP, 95 US$)
Technicians in R&D (per million persons)	Literate workers (number of workers)	Domestic credit (% GDP, 95 US$)
Patent applications (resident, non-resident, resident share)	Education expenditures (% GDP)	FDI net inflow (% GDP, 95US$)
Science and technology journal articles (number of articles)		Manufacturing exports (% GDP, 95 US$)
High technology exports (% GNP, 95US$)		Telephone line (per 1,000 persons)

To maximize comparability, all national data were obtained from the World Bank Development Indicators Database (World Bank, 2000). When possible, data were compared in (1) absolute monetary or other numeric terms, and (2) normalized by GNP and/or population. In some cases, the absolute level of technological effort is an indicator of competitiveness, while in other cases the level of national capability is better reflected

45 Lall conducted in-depth qualitative policy case studies in different countries, and used statistical analysis as evidence on the role of policy instruments for technological development. However, his quantitative work was limited to basic statistical analysis, such as averaging and growth rate comparisons (Lall, 1992). Riedel, on the other hand, focused on a quantitative analysis on the nature and determinants of export-oriented foreign direct investment in a developing country context (Riedel, 1975).

by normalized indicators. Average figures and standard deviations for the analysis period were calculated and ranked among the nine countries. For indicators with significant value changes during the time period of analysis, average annual growth rates (%) were also calculated and compared. The data were also normalized for comparison, meaning all numbers have been divided by the highest average figure in each category. The normalization allows readers to visually scale different country performance compared to the best performer. Summary tables of data for the three categories are attached as Appendix B.

4.1.3 Observations

Science and Technology Category

Overview: The role of science and technology in economic development and policy-making has been gaining better recognition in both developed and developing economies. Access to information, as well as ability to generate and apply relevant scientific and technical knowledge is particularly important to developing countries. While the complexity and the broad nature of science and technology elude simple quantification, parameters listed under this category is thought to provide insight for what the World Bank refers to as the technological base of countries (World Bank, 2000). Figure 8 compares the normalized nineteen-year national averages of twelve indicators in the science and technology category. The top performer is shown above each indicator column.

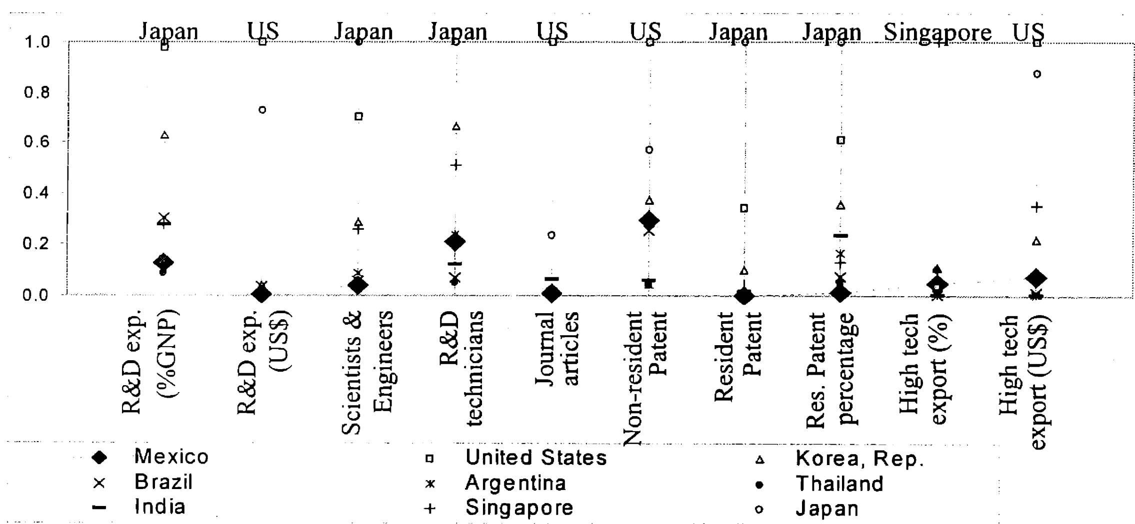

Figure 8: Normalized 19-year average comparison: science and technology indicators

Category summary: As the above figure illustrates, the United States and Japan continued to dominate in this category, ranking first and second in most of the indicators. The performance gap between the developed versus developing countries could be observed in many indicators. The strength of the developed countries was especially pronounced in indicators measured in monetary units, such as R&D expenditures and high technology exports, as well as innovation-related indicators, such as the number and share of resident patent applications, science and technology articles, and R&D expenditures. South Korea and Singapore appeared to have caught up, or narrowed the gap, in high technology exports (in 1995 US$ and % GNP) and the % of national resources allocated to R&D (% GNP). While most countries experienced some level of growth, others experienced declining or stagnating performance in a number of indicators. In particular, innovation-related indicators for Mexico either declined, such as R&D expenditures (in 1995 US$ and % GNP), or showed stagnation, such as the resident patent application rate. The tendency to rely on foreign sources of innovation and invention was observed from the high rates of non-resident patent applications in most developing countries, particularly in Mexico, Thailand, and Brazil. Yet the Mexican high technology export grew steadily. These observations indicate that countries with the ability to manufacture and export high technology goods may not necessarily have the innovation capabilities embodied in R&D, patents, and publications. Performances of individual indicators are summarized below.

R&D expenditure: This parameter is defined as current and capital expenditures on creative, systematic activity intended to increase the stock of knowledge, including fundamental and applied research and experimental development work leading to new devices, products, or processes (World Bank, 2000). This parameter was compared as the percentage of GNP and in 1995 US dollars. The data in both % and dollar values showed a clear division between the industrialized economies and the developing countries. Japan and the United States ranked as the top and second best performers of the 19-year averages in both % of GNP and 1995 US$. On average, both countries have allocated approximately 2.7% of GNP to R&D, or US$163 billion in the US and US$118 billion in Japan (1995US$). The R&D allocations in the two countries showed an increasing trend in both metrics.

The R&D expenditures in the developing economies showed more variations, increasing in both percentage and monetary values in some countries, while declining in others.[46] Among the developing countries, South Korea showed the most significant growth, starting from mediocre performance in 1980 to advance to the level comparable to the two industrialized economies in terms of % of GNP by the mid 1990s. Singapore had the highest average annual growth rates in both metrics, improving its performance from the lowest in actual expenditures (1995 US$) in 1981 to a level comparable to other developing countries by the mid-1990s. Other countries, such as Thailand and India, showed moderate increases in the actual expenditures. For Mexico, the actual value and percentage share of R&D expenditures declined by 7% as an annual average. While its level of expenditure appears to have rebounded somewhat during the mid-1990s, it was still below the expenditure level of the early-1980s. Mexico's 19-year average figures in

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46 The limited data availability from Brazil and Argentina hampered the analysis. Brazil had three data points in the 1990s, while there was only one data point for Argentina in 1995. The availability of data from other countries ranged from full availability to five data points spread over the analysis period.

% of GNP and dollar values were 0.35% (ranked 8th) and US$1.1 billion (ranked 6th) respectively.

Scientists and engineers in R&D: This parameter counts persons trained to work in any field of science who are engaged in professional R&D activity (World Bank, 2000). As most such jobs require completion of tertiary education, it is an indicator of the availability of high-level human resources in R&D. The data are presented as the number of such persons per million people.[47] Similar to the R&D expenditure performance, Japan and the United States showed the highest number of scientists and engineers, with an increasing trend overall. On average, 4,881 scientists and engineers per million persons have been engaged in R&D in Japan, and 3,420 in the United States. The differentiation between the developed and developing economies could be observed again, with growth in some developing countries to narrow the gap. Singapore and South Korea experienced significant growth, from under 500 in the early 1980s to over 2,000 by the mid-1990s. While these two countries experienced growth, the rest of the developing nations appeared to have stagnated. The 19-year average figures of the three lowest countries were 197 in Mexico, 140 in India, and 105 in Thailand.[48]

R&D technicians: This parameter counts the number of persons in professional R&D activity, who have received vocational or technical training in any branch of knowledge or technology (World Bank, 2000). As most such jobs require three years beyond the first stage of secondary education, the parameter is an indicator of the availability of middle-level human resources in R&D. The data are presented as the number of technicians per million people.[49] Japan and South Korea ranked first and second, with the average of 3,420 and 1,394 technicians per million people respectively. Mexico was ranked fifth with 172 per million people, ahead of India, Brazil, and Argentina.

Scientific and technical journal articles: This parameter is defined as the number of scientific and engineering articles published in the fields of physics, biology, chemistry, mathematics, clinical medicine, biomedical research, engineering and technology, and earth and space sciences. These articles are published in approximately 4,800 journals that have been selected by the Institute of Scientific Information as the base of its Science Citation Index as of 1981, and published by the National Science Foundation (World

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47 While the data availability from some developing countries were sporadic, sometimes with only 4 observations, the general tends could nevertheless be observed.

48 The data series for Mexico was limited to four observations from 1986, 1993, 1994, and 1995. The observation from 1993 (161 per million) is significantly lower than the 1986 data (226 per million). The three-year series from 1993 to 1995 shows a gradual increase, but below the 1986 level.

49 Similar to the indicator on scientists and engineers, data availability was limited. The data series was not available in the US, and only 1 data point was available in Brazil.

Bank, 2000).[50] It is an indicator of the availability of written information and scholarly output, and is compared in the numbers of articles.[51]

Similar to the R&D expenditure parameters, there was a clear stratification between the developed and developing countries. The United States had by far the largest number of articles, with 139,370 articles on average. The US performance exceeds the Japanese performance (32,888 articles) by a factor of four. For the developing countries, India came in third overall with 9,210 articles, followed by Brazil with 1,993 articles. Mexico ranked seventh with 931 articles, ahead of Singapore with 458 articles. The developing countries had an increasing trend, except for India, whose numbers decreased by 2.5% (annual average equivalent). Mexico ranked third in the annual average growth rate with 6.7%, behind South Korea (30.4%) and Singapore (18.4%).

Patent applications (resident): Patent-related parameters have often been used as a measure of innovation and invention. Of the three patent-related parameters, domestic innovative capacity may be best reflected in the number of resident patent applications.[52] Some variations in patent application rates may be related to the reliability of the patent system, lack of which has been identified as a potential block for technology cooperation in developing countries. Resident patent applications showed a significant difference between developed and developing countries. Japan ranked first (346,174 applications), followed by the United States (118,876 applications) on average between 1996 and 1997. South Korea was the top performer for the developing countries, with the annual average of 34,255 resident applications between 1996 and 1997, third overall. India (5,908), Singapore (4,202), and Brazil (1,816) followed. The average number of resident applications for Mexico was 409, eighth overall. Only Thailand ranked below Mexico, with 221 applications.

Patent applications (non-resident): The number of non-resident patent applications can be an indicator of availability of (and need for) innovation from foreign sources.[53] The United States and Japan ranked first and second, with 111,210 and 63,439 applications respectively on average between 1996 and 1997. The high levels of both resident and non-resident applications in the developed economies can be interpreted as indicative of technological sophistication, needs and opportunities for innovative ideas, and/or openness/reliability of the patent system. For developing countries, non-residents were shown to hold a large share of patent applications, ranging from 41,366 applications in South Korea (3rd overall) to 4,780 in India (9th overall). Mexico ranked 5th overall with

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50 The World Bank states that the index may not include journals of regional and local importance, and may also reflect bias towards journals published in English (World Bank, 2000).

51 The data were available in all countries, in 1981, 1985, 1989, 1992, and 1995, except for Thailand. No data were available in Thailand.

52 The data availability was limited to 1995 to 1997. Data from developing countries were somewhat suspect, as data from South Korea, India, and Singapore showed drastic changes between 1996 and 1997, which were not explained in the database.

53 Similar to the resident patent applications, the availability and reliability of data appeared to be limited.

32,904 applications, slightly behind Singapore (33,935, 4th overall), and ahead of Brazil (28,145, 6th overall), India (6,632, 7th overall), Argentina (5,035, 8th overall), and Thailand (4,790, 9th overall).

Percentage of resident patent applications: The percentage of resident applications in total patent applications describes the relative contribution of domestic innovative capacity to address the need for such information in each country. In developed economies, the resident share of patents was larger than the non-resident share, indicating the strength of the domestic innovative capacity. The share of resident applications in Japan was the highest at 84.5%, while the figure for the US was second highest at 51.6%. All developing countries, on the other hand, had a larger number of non-resident applications than resident applications, alluding to the reliance on foreign innovative capacity, despite the data fluctuations described in the footnote. In particular, Mexico showed the lowest share of resident sources, with only 1.2% of total patent applications attributed to residents. Thailand had the second lowest level, with 4.4%. The high number of non-resident applications and the low number of resident applications in Mexico indicates that Mexico is virtually dependent on international sources to meet the innovation needs, the level of which is considered relatively high for developing countries.

High technology export: High technology exports are defined as products with high R&D intensity, including products in aerospace, computers, pharmaceuticals, scientific instruments, and electrical machinery (World Bank, 2000). Data on high technology exports were available between 1991 to 1998, and compiled as % of GNP and in 1995 US$. Singapore outranked other countries with the high technology export average value of over 50% of GNP. Despite steady growth, exports from other countries averaged below 10% of GNP. South Korea ranked second with 6.0%, followed by Thailand with 5.6%. In terms of the actual monetary amount of high technology exports, the United States ranked first, followed closely by Japan in second, and Singapore in third. Mexico compared favorably with other developing countries, ranking fourth in the % of GNP, and 5th in 1995 US dollars. Mexico also had the highest average growth rates in both units. The analysis alludes that the capacity to export high technology goods may be somewhat different from other capacities linked to R&D and innovation. The R&D embodied in the high technology goods can be done outside the producing country, which requires only the manufacturing capability.

Human Capital

Overview: Human capital development is often cited as a necessary condition for improving the base for technological capability (Lall, 1992). Human capital development can be reflected in various indicators on education, such as expenditures on various levels of education and the size of literate labor force. As the human resource needs range from those with basic skills to highly trained professionals, education indicators encompass different levels of education, from primary to tertiary. Analysis of such indicators, however, needs to be interpreted with caution, as national statistics on education generally do not convey accurate or complete picture of educational systems (World Bank, 2000). Figure 9 compares normalized nineteen-year national averages of eight human capital indicators.

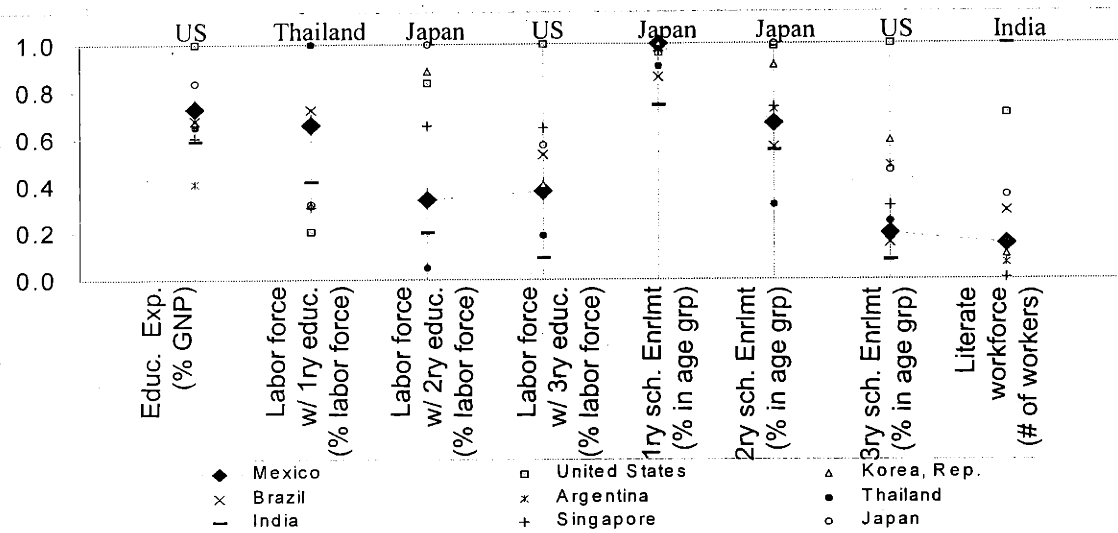

Figure 9: Normalized 19-year average comparison: human capital indicators

Category summary: Indicators in this category showed smaller disparities between the developed and. developing countries, especially in school enrollment figures (primary and secondary), and the % GDP share on education spending. Due to the decline in the illiteracy rate and general population growth, the size of literate workforce has grown more rapidly in developing countries, compared with Japan and the US. India ranked first in the size of the literate workforce. There remained, however, a disparity in indicators on tertiary education between the developed and developing countries, and also among developing countries. While South Korea, Singapore, and Brazil had a relatively high percentage of labor force with tertiary education that was comparable to Japan at above 20%, Thailand and India had a much smaller group of workers with tertiary education, at 8.1% and 4%. In addition, the actual monetary resources allocated to education in each of the developing countries were less than 10% of the average Japanese or American education expenditures. Mexico's education expenditures have been comparable to peer countries on average, although the limited and stagnant level of tertiary school enrollment and of labor force with tertiary education allude to the scarcity of highly trained personnel (or opportunities for such workforce).

Education expenditure: Education expenditure is defined as the amount of public spending on public education and subsidies to private education at the primary, secondary, and tertiary levels, expressed as the percentage of GNP (World Bank, 2000).[54]

[54] The expenditure data generally exclude foreign assistance for education, and also may not include expenditures for religious schools (World Bank, 2000).

While the United States and Japan still averaged first and second, there was little difference in the % of GNP allocated to education between the developed and developing economies.[55]

Literate workforce: This indicator combines the size of the total labor force and the literacy rate of adults above 15 years of age. Literacy is defined as the ability to read and write a short, simple statement with understanding (World Bank, 2000). It is measured in the number of literate workers. India had the highest number of literate workers, averaging approximately 176 million workers over the analysis period, with the highest annual growth rate of 3.7%. The large number of literate workers in India is due to the growing number of adult population and the 15% drop in the adult illiteracy rate between 1980 and 1998. The United States and Japan scored second and third after India, with 124 million and 63 million literate workers. As the literacy rate in these two countries has not changed (assumed to be near 100%), the growth is directly attributed to the increase in the adult population size, which has not grown significantly in these two countries. Consequently, the average annual growth rates for Japan and the United States are the lowest and the second lowest, at 1% and 1.3% respectively. The 19-year average for Mexico was 26 million people, which ranks fifth. Mexico's average annual growth rate is relatively high at 3.6%, influenced by the decline in the adult illiteracy rate (19% to 9%) and adult population growth.

Labor force with primary, secondary, and tertiary education: This set of indicators measures the proportion of the labor force that has primary, secondary, or tertiary education, as a percentage of the total labor force (World Bank, 2000). The proportion of the labor force with primary education is thought to be non-skilled labor, while the labor force with tertiary education is considered to take professional or highly skilled positions.[56] The proportion of the labor force with primary education is expected to decrease over time, as social and economic development tends to extend the formal years of schooling. However, as the data series only contained at most three observations in

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[55] When expressed in 1995 US dollars, a significant difference could be observed between the United States, Japan, and the rest of the countries. On average, the United States have spent approximately US$330 billion annually on education in 1995 dollars, while the figure for Japan is approximately US$190 billion. The developing countries allocated more than one order of magnitude less than the two industrialized countries, ranging from US$23 billion in Brazil to US$1.7 billion in Singapore. Mexico ranked fourth, with US$13 billion. Education expenditures increased in all the countries between 1980 and 1998, with developing countries having larger rates of growth.

[56] Three levels of education are defined by the World Bank, based on the International Standard Classification of Education as follows: primary education provides children with basic reading, writing, and mathematics skills along with an elementary understanding of such subjects as history, geography, natural science, social science, art, and music. Secondary education completes the provision of basic education that began at the primary level, and aims at laying the foundations for lifelong learning and human development, by offering more subject- or skill-oriented instruction using more specialized teachers. Tertiary education, whether or not to an advanced research qualification, normally requires, as a minimum condition of admission, the successful completion of education at the secondary level (World Bank, 2000).

each country, the analysis only provided a snap shot look.[57] The labor force in the US had the smallest proportion of elementary educated workers (17%) and the largest proportion of tertiary educated workers (43%). Singapore followed the US with 26% with primary education (ranked seventh), 31% with secondary (ranked fourth), and 28% with tertiary education (ranked second). In contrast, the labor force in Thailand had 83% of labor force with primary education (ranked first), 2% with secondary education (seventh), and 8% with tertiary education (seventh). Mexico also had a large share of primary and secondary educated workers, with 55% with primary (third), 16% with secondary (fifth), and 16% with tertiary education (sixth). As expected, the workforce from developed countries appeared to be better educated.

Primary school enrollment: The school enrollment figures are given as the percentage of the number of children of official school age (as defined by the national education system) who are enrolled in school. This indicator appeared to have the highest degree of convergence among the countries. Among the nine countries, six countries, including Mexico, had the primary school enrollment rate of over 95%. Thailand's enrollment rate was 90.2%, Brazil with 86%, and India with 74.1%. The primary school enrollment figures improved or were maintained at over 99% in all countries except for Thailand and Singapore, where the enrollment figures declined.

Secondary school enrollment: Compared with the primary school enrollment figures, the secondary school enrollment figures had greater variations among the countries. The United States and Japan had high and stable enrollment rates, averaging over 95%, while South Korea improved the enrollment rate from approximately 75% in 1980 to 99.9% by 1997. While all other developing countries saw improvements in the enrollment rate, Mexico's performance fluctuated, and the enrollment rate in 1997 at 66% is slightly less than the rate at the beginning of the analysis period, at 67%.

Tertiary school enrollment: The tertiary school enrollment figures differed significantly between the United States and the rest of the countries. The US enrollment percentage grew from about 55% in 1980 to over 80% by 1996, averaging at 75%. The next highest enrollment rate was in South Korea, averaging at 44%, having increased from 15% in 1980 to 68% by 1997. Argentina, Japan, and Singapore ranked third, fourth, and fifth, with enrollment figures reaching approximately 40% in 1996. Thailand ranked sixth with the average rate of 18%. Mexico was ranked seventh, followed by Brazil and India. While some developing countries, such as South Korea, Argentina, and Singapore, experienced significant growth, others, such as Mexico and Brazil, stagnated. As expected, such observations on national differences were also applicable to the R&D scientists and engineers indicator, which was described earlier.

Economic Structure

Overview: This category included indicators on the availability of financing and investments from domestic and foreign sources, on the performance of overall and

[57] There were no data points available for Argentina. Only one data point was available from the US, Brazil, Thailand, and India.

export-oriented manufacturing, and on infrastructure readiness. Due to differences in the methods used to deflate consumption and investments, cross-country comparisons and interpretations of these indicators require caution (World Bank, 2000). Figure 10 shows normalized nineteen-year national averages of eleven indicators in the economic structure category.

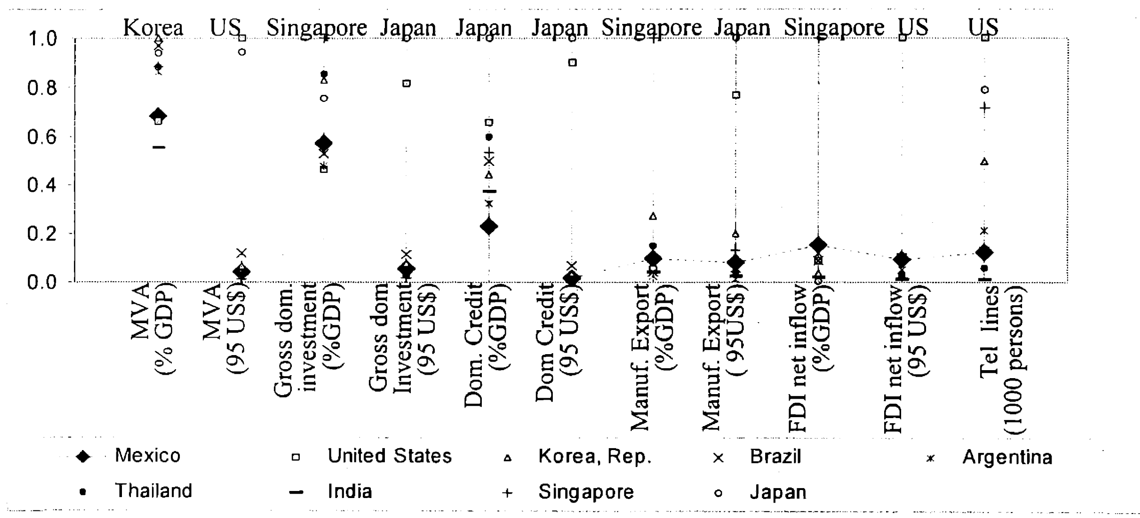

Figure 10: Normalized 19-year average comparison: economic structure indicators

Category summary: The level of financing and investments available to Japan and the United States significantly exceeded their availability to the developing countries in terms of actual monetary values. Japan and the US ranked first and second in average values of gross domestic investment (US$1.2 trillion in Japan, US$1 trillion in the US) and domestic credit (US$5.7 trillion in Japan, US$5.2 trillion in the US). In comparison, Brazil, the best performing developing country in these two indicators, had only 12% of the amount of domestic investment available in Japan, and 7% of Japanese domestic credit. Some country differences were also evident in the source(s) of financing and investments. While the United States had the largest net inflow of foreign direct investment, Japan relied predominantly on domestic sources and thus had the second lowest FDI inflow. Mexico and Singapore, on the other hand, relied more heavily on foreign investments, as they both had relatively modest levels of domestic credit and gross domestic investments. In terms of infrastructure readiness, which could be estimated by the number of telephone lines as well as gross domestic investment, Japan and the United States appeared to be better equipped than the developing countries. Among the developing countries, South Korea and Singapore showed strong growth in the two indicators.

For manufacturing performance indicators, countries with strong financing and investment availability, such as Japan and the United States, had high levels of manufacturing exports and manufacturing value added. For developing countries, South Korea and Singapore had very strong manufacturing export performance, followed by Mexico.

Manufacturing value added: Manufacturing value added is the net output of a number of key industries, and is evaluated further in an econometric analysis in the following section. In % of GDP, most countries experienced very minor fluctuations in the output throughout the 1980s and 1990s. The average figure of manufacturing value added was between 25 to 30% in South Korea, Brazil, Japan, Singapore, Thailand, and Argentina. Mexico averaged 20% (7th overall), followed closely by the United States. India had the lowest figure, at 16.3% on average.

In actual monetary value (1995 US$), a wide gap between the developed and developing economies could be observed, where the developed economies outperformed the others by one to two orders of magnitude. The US had the highest 19-year average figure of 1.14 trillion dollars, followed by Japan with 1995 US$1.1 trillion. Both countries had positive average annual growth rates. The US performance was steady until the early 1990s, and increased substantially since then, while the Japanese growth in the 1980s stagnated by the early 1990s. The outputs showed significant variations among the seven developing countries, all of which had positive average annual growth rates. Brazil maintained the highest level of manufacturing value added among the seven countries, but its performance fluctuated significantly, twice experiencing a decrease over 10%. South Korea experienced very steady and high growth, increasing its output by 9.5% on average. Mexico and Argentina had relatively low rates of growth, and were outperformed by South Korea by the mid-1980s and caught up by India by 1995. The 19-year average value of manufacturing value added was approximately 1995 US$500 billion.

Manufactures exports: Manufactures exports refer to exported share of chemicals, basic manufactures, machinery and transport equipment, and miscellaneous manufactured goods excluding non-ferrous metals (World Bank, 2000). This indicator and the high technology export explained above describe the export performance of sectors with technological capability. Like others, this indicator was evaluated in %GDP and in 1995 US dollars.

In % GNP, Singapore maintained the highest level over the analysis period, 62% in the lowest year. While the high volume of manufactures exports is a reasonable general observation, the actual figures are suspect, as some are above 100%.[58] South Korea's manufactures exports ranged between 20 and 30%. Mexico's performance soared from below 10% in 1993 to above 25% in 1998, corresponding to the onset of NAFTA. Thailand experienced a growth pattern somewhat similar to Mexico's. Brazil, India, and Argentina had low export shares, all averaging below 5%. Japan's average was 9.8%, while the US average was 5.2%.

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[58] This data series required several conversion steps to be described in the desired units. Errors may have been introduced and/or compounded in the conversion process.

In actual dollar values, the differentiation between the developed versus developing countries could be observed. Of the two developed countries, the United States experienced rapid growth in the 1990s, with four years of above 20% growth. Since 1994, the US export exceeded the Japanese figure, which experienced more fluctuations. The US exported approximately US$540 billion. South Korea and Singapore ranked third and fourth, reaching US$194 billion and US$111 billion respectively. Mexico's manufactures export had the highest average annual growth rate of 30.5%. With a high rate of growth in the 1990s, Mexico exported US$108 billion in 1998, which is 40 times more than the 1980 export figure.

Gross domestic investment: Gross domestic investment consists of outlays on additions to the fixed assets and net changes in the level of inventories. Fixed assets include land improvements, such as fences, ditches, and drains; plant, machinery, and equipment purchases; and the construction of roads, railways, and the like, including commercial and industrial buildings, offices, schools, hospitals, and private residential dwellings. Inventories are stocks of goods held by firms to meet temporary or unexpected fluctuations in production or sales (World Bank, 2000). Data have been converted to % GDP and in 1995 US dollars.

In % GDP, this indicator had one of the narrowest differentials between the top and bottom ranks, with Japan in the fourth place and the US ranked ninth. The top three performers on average terms were Singapore, Thailand, and South Korea, all with over 30% of GDP. In terms of dollars, Japan and the United States outperformed all others by one order of magnitude and more. Brazil's average investment figures were third largest, followed by South Korea, which had experienced a significant increase during the analysis period. While all countries experienced growth on average in the analysis period, Mexico, Argentina, and Brazil experienced significant fluctuations and also had the lowest average growth rates.

Domestic credit: Net domestic credit is defined as the sum of net credit to the non-financial public sector, credit to the private sector, and other accounts (World Bank, 2000). It is used as an indicator that measures the importance of domestic financing in manufacturing value added. The data were converted to 1995 US dollars and % GDP.

In actual dollar terms, Japan and the United States had the largest amounts of domestic credit available, with over US$ 5 trillion of domestic credit on average. Both countries experienced growth, with different patterns. The Japanese domestic credit increased steadily during the 1980s with 5 to 10% annual growth rates, and then stagnated after 1990. In contrast, the American domestic credit grew gradually in the mid-1980s then hit a plateau until the early 1990s, then began growing again. All developing countries experienced some growth, although the available credit amounts were more than one order of magnitude less than Japan and the US. Brazil and Mexico did experience some periods of negative growth in domestic credit availability. In particular, the Brazilian data showed two peaks, one in 1989 and another in 1993 followed by a crash, from which the country still appears to be recovering.

The 19-year trend in % GDP showed gradual increase in domestic credit availability in most countries. While the general trend is true, the actual values may not be very accurate, as data from Japan, Brazil, and Thailand reached beyond 100% GDP. In addition, the Brazilian performance included a 60% drop over one year, and a sharp increase, and another 90% drop.

FDI net inflow: Foreign direct investments have been recognized in the industrial development literature as an important source of manufacturing capabilities in rapidly industrializing countries. It is defined as the net inflow of investments to acquire a lasting management interest (10% or more of voting stock) in an enterprise operating in an economy other than that of the investor. It is the sum of the capital, reinvestment of earnings, other long-term capital and short-term capital as shown in the balance of payments (World Bank, 2000). This indicator was compared in % GDP and in 1995 US$.

The % GDP data showed that most countries had the net inflow of below 5% of GDP, except for Singapore, which averaged at approximately 10%. The data showed significant fluctuations. In actual monetary terms, the United States continued to have the largest net inflow throughout the analysis period, with wide fluctuations in the 1980s and a steady increase in the 1990s. Brazil ranked second on average, with significant growth since the early 1990s. Singapore and Mexico averaged third and fourth, increasing with some fluctuations. Japan maintained a relatively low level of net inflow, sometimes negative, only averaging at US$1.3 billion, eighth overall. India ranked ninth, with a strong growing trend in the 1990s.

Telephone availability: The availability of telephone is measured by the number of telephone mainlines, which are telephone lines connecting a customer's equipment to the public switched telephone network (World Bank, 2000). The availability of telephone has been used as a proxy for infrastructure readiness. The data are available in per 1,000 persons. The telephone availability increased in all nine countries between 1980 and 1998, with different growth rates and patterns. The top performer, the US, maintained a steady 3% annual growth and had 661 telephones per 1,000 persons by 1998. While Japan had the second highest availability in 1980, Singapore ranked second by 1995. South Korea also experienced high growth to reach over 400 telephones per 1,000 persons by 1995. In Mexico, the number of telephones grew from 40 per 1,000 persons in 1981 to 104 per 1,000 persons by 1998. The Mexican telephone availability is relatively similar to Brazil, and approximately half of Argentina. India remained the distant last, with only 3 per 1,000 persons in 1980 and 22 per 1,000 persons by 1998.[59]

4.1.4 Summary

The two leading industrialized economies, Japan and the United States, sustained strong performance and dominance in various technological capability indicators during the analysis period, especially in innovation-related indicators in science and technology.

[59] The analysis did not take into consideration wireless and cellular telephones, as such data were not available from the database. The exclusion of wireless and cellular phones is considered to have relatively minor effect on the analysis, as their availability was very limited in the majority of the analysis period.

The two countries also had the highest levels of available domestic credit and investments as well. In developing countries, the availability of domestic credit and investments was at least one order of magnitude smaller. Overall, indicators in the human capital category were found to have the least disparities between the developed and developing countries.

Some developing countries, such as South Korea and Singapore, experienced significant growth in many indicators, thus closing the gap between the developed and at least some developing countries. For example, South Korea ranked highest in manufacturing value added (in % GDP), and showed significant growth in R&D expenditures, patent applications. Singapore, on the other hand, achieved the highest ranking in high technology exports (% of manufacturing exports), as well as gross domestic and foreign direct investments (in % of GDP).

The analysis also revealed that some developing countries experienced declining or stagnant performance in a number of indicators, especially those related to innovation and invention. The export performance, both general and high technology, was also found to be not correlated closely with other indicators on innovation and invention. The following table summarizes the ranking of average indicator ranks in the three categories.

Table 18: Ranking of average indicator ranks in three categories

	MEX	ARG	BRA	IND	KOR	SGP	THL	JPN	USA
Science & tech.	7	8	5	6	3	4	9	1	2
Human capital	4	7	5	9	3	6	8	1	2
Economic structure	7	8	4	9	3	4	6	1	2

MEX=Mexico; ARG=Argentina; BRA=Brazil; KOR=Korea; SGP=Singapore; THL=Thailand; JPN=Japan; USA=United States.

Mexican Performance

Mexico had relatively low or negative growth rates in the innovation-related indicators, in particular R&D expenditures, which showed the greatest decline among the nine countries. At the same time, it showed significant growth in high technology exports. Mexico's tendency to rely more on non-domestic sources of technological capability was seen in its high non-resident to resident patent application percentage (highest among the nine countries), and high FDI net inflow.[60] The analysis also showed that other peer nations have caught up and outperformed Mexico during the analysis period in some parameters, such as R&D expenditures, manufacturing value added, and labor force with tertiary education. In summary, Mexico ranked middle or low in most indicators

[60] This observation is consistent with the inversely proportional relationship between FDI and R&D observed by other scholars.

compared with its peer economies, and was surpassed by other economies during the analysis period.

Section 4.2: Econometric Analysis of Manufacturing Value Added

4.2.1 Introduction

Manufacturing value added, which is the net output of a number of key industries, is a variable that embodies industrial development.[61] As a country gains more technological capability, it moves up the development "ladder" from natural resource-based industries to more complex manufacturing industries (Enos, 1991). This shift in the industrial base should result in improved manufacturing value added performance. This econometric analysis estimated manufacturing value added in nine countries from 1980 to 1998 as a function of variables that are widely believed to influence its performance, such as infrastructure development, economic structure and performance, and human capital development. The nine countries analyzed are Argentina, Brazil, India, Japan, South Korea, Mexico, Singapore, Thailand, and the United States, similar to the statistical analysis presented in the previous section. The objectives of this analysis were as follows:

- To evaluate the factors that influence technological capability, and to identify some key factors to be explored further in qualitative analysis
- To examine variations, if any, in influencing factors in developed versus developing countries
- To analyze Mexico's performance in manufacturing value added, and how Mexico compares with other countries

Since the focus of my overall research is in on the automobile sector, the analysis would ideally focus on specific data from the automobile sector. However, the lack of available sector-specific data led me to seek alternative, more consistently available data. Manufacturing value added was selected as an alternative variable, as it included output from the automobile and intermediate sectors, and was consistently available over the analysis period.

It is worth noting that this analysis does not explicitly confirm a causal relationship between the independent variables and manufacturing value added. Rather, the analysis, like other time-series econometric analyses, looks at the past behavior of manufacturing value added and the change in other parameters to infer something about its likely behavior in the future (Pindyck and Rubinfeld, 1998).

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[61] The formal definition of manufacturing value added is presented in the next section.

4.2.2 Principle Variables and Observations

The first task was to identify and analyze data on manufacturing value added, and to select a number of explanatory variables for further analysis. The analysis was based on data obtained from the World Bank Development Indicators database (World Bank, 2000). While the annual time series data contained in this database covers 1960 to 1998, a preliminary analysis found that a substantial amount of data prior to 1980 was missing for some of the explanatory variables under consideration. Based on this observation, the time period of analysis was set to 1980 to 1998, equal to the analysis period of the statistical analysis.

Dependent Variable

The dependent variable for this analysis is manufacturing value added, which is defined as the net output of industries belonging to ISIC divisions 15 to 37, after adding up all outputs and subtracting purchased intermediate inputs (World Bank, 2000).[62] The initial assessment confirmed the availability of the data in all nine countries, in 1995 US$.

Explanatory Variables

A preliminary list of explanatory variables was selected from the categories of indicators on technological capability, analyzed in the previous section (see Table 17). Definitions of these indicators are provided in the previous section. From the economic structure category, domestic credit (1995 US$) and foreign direct investment (1995 US$) were selected to evaluate the importance of domestic as well as foreign sources of financing and investment. The telephone availability (per 1,000 persons) was also considered as a proxy for infrastructure readiness.

From the human development category, the size of literate workforce was selected. This indicator, available as the number of persons, was selected as an appropriate estimate of the availability of workforce with basic skills, which is often sited as a necessity for technological capability acquisition. Other variables, such as % labor force with various levels of education, were rejected due to insufficient data availability. School enrollment figures were not used, due to difficulties associated with translating into meaningful variables, i.e., how to take differences in national education systems into account for lagging the school enrollment variables. Education expenditures were not used for the main analysis, as the figures showed little variability over the analyzed time period.

Most indicators from the science and technology category had a significant percentage of missing data, especially in developing countries, alluding to limited science and

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[62] ISIC divisions 15 to 37 include: manufacture of food products and beverages, tobacco products, textiles, wearing apparel, tanning and dressing of leather, wood and wood and cork products, paper and paper products, publishing, printing, and reproduction of recorded media, coke, refined petroleum products and nuclear fuel, chemicals and chemical products, other non-metallic mineral products, basic metals, fabricated metal products, machinery and equipment, office, accounting and computing machinery, electrical machinery and apparatus, radio, television, and communication equipment and apparatus, medical, precision, and optical instruments, watches and clocks, motor vehicles, trailers, and semi-trailers, other transport equipment, furniture, and recycling.

technology capabilities in such countries. As such, variables from this category were not selected for the econometric analysis.

In addition, two indicators on duties were considered. Import duties comprise of all levies collected on goods at the point of entry into the country. They include levies for revenue purposes or import protection, whether on a specific or ad valorem basis, as long as they are restricted to imported products (World Bank, 2000). Import duties have been used as a policy tool, especially for implementing the import substitution strategy, to strengthen and protect domestic manufacturing, by raising prices of imported goods that compete in the domestic market. On the other hand, duties on intermediate goods and raw materials may have a negative affect on manufacturing value added by constraining the flow of goods necessary for manufacturing. The data are available in % of imports.

Export duties are defined as all levies collected on goods at the point of export, in % of exports (World Bank, 2000). Decreasing or eliminating export duties is a relevant policy strategy for countries, especially for implementing the export promotion strategy, with relatively small domestic markets that need export potential to realize economies of scale. The data are available in % of exports.

4.2.3 Regression Model Formulation and Estimation

The analysis considered six independent variables, namely foreign direct investment, domestic credit, literate workforce, telephone availability, import duty, and export duty, and one dependent variable of manufacturing value added. A significant portion of my effort was spent on trying out numerous variations of regression models with different parameters. This section presents the development of the best-performing model for cross-country data.[63] The analysis used a software package called EViews (version 3.1), which is a widely used program for data analysis, regression, and forecasting. The summary statistics and correlation matrix of the normal and log-transformed data are shown in Appendix B.

The model formulation and estimation followed the four steps below:

- Develop the initial model for cross-country data
- Test and adjust for heteroskedasticity and autocorrelation
- Test and adjust for a lagged dependent variable
- Repeat test and adjustment for individual countries

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63 In addition to the model presented here, I have attempted regressions using per-capita averages of all parameters, use of total import and export duties in 1995 US dollars, as opposed to percentage, with non-logarithmic data, and so on. For the sake of brevity, I will not discuss them in detail, but they were found to be less statistically robust. In other cases, they were rejected as parameters embodied multiple influences (such as the dollar figure of export duties indicating both duty rate and volume of export), which limited their ability to explain the relationship.

The first three steps were first carried out for the overall data. The steps were then repeated using individual country data to estimate a specific relationship in each country. The following sections describe the steps in detail.

Initial Regression for Overall Data

The following regression was estimated using ordinary least squares (OLS)[64] to delineate the impact of changes in foreign direct investment, literate workforce, domestic credit, import duty, and export duty on manufacturing value added, using log-transformed data:

$$LNVAM = c + \beta_1{*}LNFDI(-3) + \beta_2{*}LNLITWORK + \beta_3{*}LNDOMCRE + \beta_4{*}LNTEL + \beta_5{*}LNIMDUTY + \beta_6{*}LNEXDUTY + \varepsilon$$

Where:

VAM:	Manufacturing value added in 1995 US dollars
FDI:	Net foreign direct investment in 1995 US dollars
LITWORKER:	Literate workforce in number of persons
DOMCREDIT	Net domestic credit in1995 dollars
TEL:	Number of telephone service per 1,000 persons
IMDUTY:	import duties in % of imports
EXDUTY	Export duties in % of exports
ε	Unexplained residual

The net FDI was lagged by three years to account for construction and preparatory phases.[65] The regression results are summarized in the table below, with t-statistics values in the parenthesis:

Table 19: Regression results of initial model

Constant C	Lnfdi(-3) β_1	Lnlitwork β_2	Lndomcre β_3	Lntel β_4	Lnimduty β_5	Lnexduty β_6	R^2	F stat
5.82	0.0157	0.483	0.311	0.613	0.0130	0.0874	0.884	74.95
(4.965)	(0.396)	(6.465)	(5.333)	(8.119)	(0.171)	(4.723)		

The t-statistic values indicated literate workforce, domestic credit, telephone availability, and export duties to be statistically significant at the 95% confidence level, allowing me to reject the null hypothesis that the parameters are jointly equal to zero. The F statistic

64 Ordinary least squares is a widely used method of estimation. The estimates using OLS have the minimum variance of all linear and unbiased estimates (Pindyck and Rubinfeld, 1998).

65 Time lags to account for the onset of plant operations have been used by other scholars. For example, Riedel used a lag of two years in his study (Riedel, 1975).

of 74.95 was compared with the critical value of $F_{5,59}$ (n = 66, k =7, q= 5), which is equal to 2.37 at the 95% confidence level. Since the 74.95 is greater than 2.37, the joint null hypothesis is rejected.

This equation, however, raised one concern, due to the large number of excluded observations (66 included, 64 excluded) attributed to missing EXDUTY data. As many countries have not levied export duties, the original data series contained many zeros, which became unusable after the log transformation. A dummy variable, WITHEXDUTY, was then used to evaluate the *effect* of the presence of export duties, rather than the *level* of export duties as embodied by EXDUTY. WITHEXDUTY was set equal to 0 if no export duties are levied, and 1 if export duties are levied. Equation 1 was then modified to include WITHEXDUTY, instead of EXDUTY. The low T statistic of 0.20 from the modified regression indicated that the null hypothesis could not be rejected. In sum, the significance of the effect of export duties could not be validated statistically, and was thus dropped from further analysis.

Regression Adjustments

The initial regression model was then adjusted as follows:

$$LNVAM = c + \beta_1 *LNFDI(-3) + \beta_2 *LNLITWORK + \beta_3 *LNDOMCRE + \beta_4 *LNTEL + \beta_5 *LNIMDUTY + \varepsilon$$

The following table summarizes the OLS regression results, with t-statistics in parentheses.

Table 20: Regression results of adjusted model (OLS)

Constant C	Lnfdi(-3) β_1	lnlitwork β_2	Lndomcre β_3	Lntel B_4	Lnimduty B_5	R^2	F stat
3.54 (7.38)	0.062 (3.13)	0.30 (4.79)	0.51 (11.07)	0.36 (7.89)	0.12 (2.56)	0.966	631

117 observations were included in this regression. Each of the estimated coefficients is significant at the 5 percent level, as indicated by the t-statistic values. The large F-statistic value allows me to reject the null hypothesis that there is no relationship between manufacturing value added and FDI, literate workforce, domestic credit, telephone availability, and import duties.

The regression results appeared to be plausible: we would expect the manufacturing value added to increase with more economic resources nationally and from abroad (domestic credit and net foreign direct investment), larger literate workforce, and better infrastructure (telephone). Also, higher import duties are interpreted to facilitate domestic production by import substitution, which means increased value-added manufacturing. The equation further indicates that the domestic credit availability is more important than the foreign direct investment.

Heteroskedasticity testing for overall data:

The next step in the model development was heteroskedasticity testing with the White test and adjustments for the overall equation.[66] The null hypothesis of homoskedasticity is rejected, as the White test statistic (18.31) is approximately equal to the critical value of the chi square (18.31) with 10 degrees of freedom at the 95% confidence level. The heteroskedasticity-consistent standard errors are tabulated below:

Table 21: Basic equation with heteroskedasticity

Constant C	Lnfdi(-3) β_1	Lnlitwork β_2	Lndomcre β_3	Lntel β_4	Lnimduty β_5	R^2	F stat
3.54 (8.73)	0.062 (3.22)	0.30 (4.56)	0.51 (10.55)	0.36 (9.79)	0.12 (2.26)	0.966	631.5

Autocorrelation Testing and Adjustment

The data were then tested for serial correlation using the Durbin-Watson test, which showed that a positive serial correlation exists, with an implied ρ estimate of 0.9 (see Appendix B for further detail). The Cochrane-Orcutt procedure was then used to correct for autocorrelation. A new estimate of ρ was calculated to be 0.85, relatively close to the one computed from the Durbin-Watson statistic. With the new ρ estimate, the following regression was performed:

$$LNVAM^* = \beta_0 (1-\rho) + \beta_1 {*}LNFDILAG^* + \beta_2 {*}LNLITWORK^* + \beta_3 {*}LNDOMCRE^* + \beta_4 {*}LNTEL^* + \beta_5 {*}LNIMDUTY^* + \varepsilon$$

Where:

$$LNVAM_t^* = LNVAM_t - \rho^* \, LNVAM_{t-1}$$
$$LNFDILAG_t^* = LNFDILAG_t - \rho^* \, LNFDI_{t-1}$$
$$LNLITWORK_t^* = LNLITWORK_t - \rho^* \, LNLITWORK_{t-1}$$
$$LNDOMCRE_t^* = LNDOMCRE_t - \rho^* \, LNDOMCRE_{t-1}$$
$$LNTEL_t^* = LNTEL_t - \rho^* \, LNTEL_{t-1}$$
$$LNIMDUTY_t^* = LNIMDUTY_t - \rho^* \, LNIMDUTY_{t-1}$$

66 Heteroskedasticity, or unequal variances, is observed when the variance of each error term is not constant over all observations. With heteroskedasticity, OLS estimators are not efficient, i.e., the variances of the estimated parameters are not the minimum variances. The White test is widely used to test for heteroskedasticity (Pindyck and Rubinfeld, 1998).

Table 22: Parameter estimates with serial correlation

Constant β_0	Lnfdi(-3) β_1	Lnlitwork β_2	Lndomcre β_3	Lntel β_4	Lnimduty B_5	R^2	F stat
5.6 (6.53)	0.001 (0.10)	0.67 (11.3)	0.19 (3.49)	0.67 (10.71)	-0.017 (-0.43)	0.86	122

The new estimates of coefficients and their statistical significant, summarized in the above table, differ from the original estimates. The results indicate that with autocorrelation, two of the estimated coefficients (FDI and IMDUTY) are not statistically significant. The coefficients for LITWORK and TEL increased, while the coefficient for DOMCRE decreased. The results can be interpreted as follows: with autocorrelation, value added manufacturing is a function of the domestic credit availability, infrastructure readiness (telephone availability proxy), and workforce readiness (literate workforce proxy). Value added manufacturing increases as values for these variables increase.

Lagged Dependent Variable Adjustment

The overall model was further assessed with a lagged dependent variable, using the following equation:

$$LNVAM = c + \beta_1 *LNFDI(-3) + \beta_2 *LNLITWORK + \beta_3 *LNDOMCRE + \beta_4 *LNTEL + \beta_5 *LNIMDUTY + \beta_6 *LNVAM(-1) + \varepsilon$$

Table 23: Parameter estimates with lagged dependent variable

Constant β_0	Lnfdi(-3) β_1	lnlitwork β_2	Lndomcre β_3	Lntel β_4	Lnimduty β_5	Lnvamlag β_6	R^2	F stat
0.61 (4.87)	-0.012 (-3.38)	-0.005 (2.52)	0.036 (-0.31)	0.039 (3.58)	-0.0048 (-0.47)	0.96 (44.39)	0.998	10995

The results indicate that value added manufacturing of the current time period is a function of value added manufacturing from the last time period. Also, higher infrastructure readiness (telephone proxy) leads to higher manufacturing value added, which is offset by the very small negative coefficients on FDI and worker literacy. The coefficient for LNTEL is an order of magnitude lower than its value computed from equation 4 (autocorrelation without lagged dependent variable). The regression yielded a very small partial adjustment coefficient of 0.04.

Autocorrelation Testing with Lagged Dependent Variable

To check for autocorrelation with the lagged dependent term, Durbin's M-statistic test was implemented:

$$\varepsilon = a + b_1 * LNFDI(-3) + b_2 * LNDOMCRE + b_3 * LNLITWORKER + b_4 * LNTEL + b_5 * LNIMDUTY + b_6 * LNVAM(-1) + \rho * \varepsilon_{t-1} + error$$

ε_{t-1} data was adjusted manually to eliminate any possible cross-country error attribution. With the t-statistic value of 4.18 for the coefficient on e_{t-1}, we reject the null hypothesis of ρ equal to zero. Based on this test, the first order auto-correlation appears to be present, with $\rho = 0.381$. To obtain consistent GSL estimates that account for autocorrelation, the Cochrane-Orcutt procedure was used. The new estimate of ρ was calculated to be 0.375.

Most Robust Estimation of Cross-Country Data

Incorporating the appropriate refinements described above, the most robust estimation of the cross-country data was developed as follows:

$$LNVAM^* = \beta_0 (1-\rho) + \beta_1 * LNFDILAG^* + \beta_2 * LNLITWORK^* + \beta_3 * LNDOMCRE^* + \beta_4 * LNTEL^* + \beta_5 * LNIMDUTY^* + \beta_6 * LNVAMLAG^* + \varepsilon$$

Where:

$LNVAM_t^* = LNVAM_t - \rho * LNVAM_{t-1}$

$LNFDILAG_t^* = LNFDILAG_t - \rho * LNFDI_{t-1}$

$LNLITWORK_t^* = LNLITWORK_t - \rho * LNLITWORK_{t-1}$

$LNDOMCRE_t^* = LNDOMCRE_t - \rho * LNDOMCRE_{t-1}$

$LNTEL_t^* = LNTEL_t - \rho * LNTEL_{t-1}$

$LNIMDUTY_t^* = LNIMDUTY_t - \rho * LNIMDUTY_{t-1}$

$LNVAMLAG_t^* = LNVALAG_t - \rho * LNVAMLAG_{t-1}$

(equivalent to $LNVAM_{t-1}^* = LNVAM_{t-1} - \rho * LNVAM_{t-2}$)

Table 24: Most robust estimates with autocorrelation and lagged dependent variable

Constant β_0	Lnfdi(-3) B_1	Lnlitwork β_2	Lndomcre β_3	Lntel β_4	Lnimduty β_5	Lnvamlag β_6	R^2	F stat
0.61 (2.75)	-0.0066 (-1.28)	-0.037 (1.51)	0.01 (0.39)	0.041 (2.18)	-0.0005 (-0.03)	0.94 (25.66)	0.996	4025

The results of cross-country analysis, shown in Table 24, suggest that manufacturing value added is a function of its performance from the last time period, and of infrastructure readiness (LNTEL). The new estimate of partial adjustment coefficient is 0.06, compared with 0.04 estimated without autocorrelation. This result is plausible, however somewhat uninformative for someone interested in learning how the other parameters influence manufacturing value added.

4.2.4 Individual Country Model Extension and Refinement

Now we return to the individual country data. Similar to the overall (cross-country) model, individual country data were analyzed and adjusted (if found appropriate) for heteroskedasticity, autocorrelation, and lagged dependent variable. The following table summarizes the most statistically robust model type and the parameter estimates for each country. Individual estimation results are attached in Appendix B.

Table 25: Parameter estimates for individual countries – most robust estimates

	Constant β_0	Lnfdi (-3)	Lnlitwork β_2	Lndomcre β_3	Lntel β_4	Lnimduty B_5	Lnvamlag β_6	AR(1)	R^2	F stat
Argentina (OLS, heteroskedastic)	-29.44 (-1.37)	-0.034 (-0.60)	**3.12 (2.53)**	**0.23 (2.13)**	-0.45 (-1.45)	**0.22 (1.97)**	N/a	N/a	0.94	9.54
Brazil (n/a)	28.6 (0.6)	**-0.056 (-2.39)**	-0.75 (-0.32)	-0.022 (-0.12)	0.18 (0.07)	0.055 (0.27)	0.44 (0.19)	0.46 (0.18)	0.79	1.6
India (nonlinear, auto-regressive)	**50.2 (3.24)**	0.006 (0.79)	-1.60 (-1.79)	0.15 (0.59)	**0.61 (2.1)**	-0.06 (-0.61)	N/a	**0.87 (8.57)**	0.99	139
Japan (lagged dependent var.)	**117 (4.23)**	**-0.048 (-2.66)**	**-9.06 (-3.97)**	**0.72 (17.94)**	**0.4 (2.21)**	0.073 (1.40)	**1.83 (3.94)**	N/a	0.99	390.1
Korea (OLS, heteroskedastic)	-17.66 (-2.78)	-0.0037 (-0.37)	**2.26 (4.08)**	0.063 (0.43)	**0.52 (5.45)**	**0.22 (2.39)**	N/a	N/a	0.996	493.5
Mexico (OLS, heteroskedastic)	1.68 (0.38)	**0.053 (4.53)**	**1.23 (5.02)**	0.07 (1.47)	-0.28 (-1.73)	0.00 (0.02)	N/a	N/a	0.98	112.9
Singapore (lagged dependent var.)	-17.7 (-0.99)	0.005 (0.174)	2.00 (1.45)	0.57 (1.32)	-1.80 (-1.33)	**-0.32 (-3.24)**	**0.41 (2.08)**	N/a	0.99	131.3
Thailand (lagged dependent var.)	-16.9 (-1.27)	-0.005 (-0.21)	**1.22 (1.36)**	-0.11 (-0.51)	-0.004 (0.03)	**0.25 (2.12)**	**0.94 (3.45)**	N/a	0.99	208.9
US (OLS, hetero-skedastic)	**-13.6 (-2.97)**	**-0.018 (-2.93)**	0.17 (0.66)	**1.19 (12.45)**	**0.61 (2.20)**	-0.11 (-1.21)	N/a	N/a	0.99	878.7

Argentina: Manufacturing value added for Argentina was estimated as a function of literate workforce, domestic credit, and import duties. Models with autocorrelation and lagged dependent variables showed insignificant statistical evidence for autocorrelation and the presence of a lagged dependent variable. The coefficients were therefore estimated again with OLS, accounting for heteroskedasticity, as shown above.

Brazil: Regression estimates were made with models that account for autocorrelation, a lagged dependent variable, and both autocorrelation and a lagged dependent variable. None yielded results with statistical significance, in terms of F and t statistics, similar to the initial model estimation. This indicates that the change in manufacturing value added in Brazil cannot be explained by any of the models. The estimation difficulties may stem from the large fluctuations in the data on manufacturing value added and foreign direct investment, as mentioned in the previous section.

India: The best estimate was found to be the nonlinear regression model with autocorrelation. This model indicates that only the infrastructure readiness has a statistically significant positive effect on manufacturing value added. The regression estimates of models with a lagged dependent variable found that the variable was statistically insignificant, with or without autocorrelation.

Japan: Missing Data hampered model refinement. Nevertheless, the Japanese case is best described as follows: manufacturing value added is a function of domestic credit and infrastructure readiness (telephone proxy), and slightly offset by negative FDI and reduction in the literate workforce. Although its magnitude is questionable, the performance of manufacturing value added was also positively influenced by the performance of the last time period. As the literacy rate has not changed in Japan the past 20 years, the negative literate workforce coefficient represents the reduction in the number of workers, rather than the decrease in the literacy rate. The negative coefficient could perhaps be explained as the results of labor saving automation and transition from labor-intensive to more high-technology sectors. Models with autocorrelation could not be run, due to insufficient number of data points.

Korea: Literate workforce, import duties, and infrastructure readiness were statistically significant, with a positive effect on manufacturing value added. The estimates of ρ with nonlinear autoregressive models, with or without a lagged dependent variable, were statistically insignificant. This indicates that the best estimate for Korea is the heteroskedasticity-consistent OLS equation.

Mexico: Mexican manufacturing value added was found to be a function of FDI and literate workforce. Mexico was the only country among its developing country peers with statistically significant FDI relationship to manufacturing value added. The estimates of ρ with nonlinear autoregressive models, with or without a dependent variable, were found to be statistically insignificant. This means the best estimate for Mexico is the heteroskedasticity-consistent OLS equation.

Singapore: For Singapore, its manufacturing value added was estimated to be a function of manufacturing value added from the last time period, and a decrease in import duties. The OLS equation with a lagged dependent variable showed the best statistical fit for the Singapore data. The partial adjustment coefficient was calculated to be 0.59.

Thailand: Import duties and manufacturing value added were positively correlated. The OLS equation with a lagged dependent variable showed the best statistical fit, similar to Singapore. The partial adjust coefficient was calculated as 0.04.

US: The results of model applications with the US data are not entirely robust, possibly due to the small number of usable observations (11 for heteroskedasticity-consistent OLS). Domestic credit has a strong and significant positive effect on manufacturing value added, as expected. The US case had the highest coefficient for domestic credit of all countries, indicating the strength of the US domestic financing capability. The infrastructure readiness also has the expected positive sign, and is statistically significant. While the FDI coefficient was negative, like Japan, its coefficient is quite small, approximately 1% of the domestic credit. The non-linear estimation showed suspect results, including a negative lagged dependent variable coefficient and ρ greater than 1.

4.2.5 Summary and Implications of work

The objective of this analysis was to determine the relationship between the manufacturing value added performance and parameters that describe developments in human capital (i.e., literate workforce) and economic structure (i.e., foreign direct investment, domestic credit, telephone availability, and import duties). The cross-country model suggested that the manufacturing performance of the last time period and infrastructure readiness were statistically significant as explanatory variables. The analysis also showed some country variations in explanatory variables and their magnitude. In particular, differences in developed and developing economies in explanatory variables were observed.

Cross-country Data Modeling

The cross-country modeling analyzed data from both developed and developing countries together. The initial model included five indicators, which were all found to be statistically significant with positive effects on manufacturing value added. Further model refinement found the presence of heteroskedasticity, autocorrelation, and a statistically significant lagged dependent variable. The modified model is a nonlinear regression with autocorrelation. This modified model suggests that manufacturing value added can be described as a function of its performance in the last time period and telephone availability, which is a proxy for infrastructure availability.[67] The model is intuitively plausible, that the future performance of manufacturing value added can be

[67] This result is consistent with an existing theory of industrial development, which states that the past performance of manufacturing experience is a good indicator of industrial development potential (Amsden, 1989).

forecasted as a function of its past performance and by the level of infrastructure readiness. The accuracy of the model, as measured by R^2, is 0.996. The model did not illustrate, in a statistically significant manner, what other indicators influenced manufacturing value added.

Individual Country Modeling

Analyses with the individual country data found country variations in statistically significant parameters and model refinements. In many cases, they were found to be plausible, given what is known about their state of development. In other cases, however, the lack of data points may have hampered their assessment.

Developed countries: For the United States and Japan, manufacturing value added could be described as a function of domestic credit and telephone availability. Both countries also showed a negative relationship between manufacturing value added and foreign direct investment. As the coefficients for FDI are 1/50 to 1/100 of the coefficients for domestic credit, the results can be interpreted as follows: the strong availability of domestic capital for investments positively influenced the growth in manufacturing value added, despite the negative influence of the declining foreign capital inflow.

Developing countries: Among the seven industrializing nations, statistically significant and robust models could be developed in six countries. These countries are Argentina, India, South Korea, Mexico, Singapore, and Thailand. For these countries, import duties and literate workforce were found to be the most consistently significant variables to describe the manufacturing value added performance. Import duties were found to be statistically significant positively in Argentina, Korea, and Thailand, and negative in Singapore. The literate workforce was positively significant in Argentina, South Korea, and Mexico. The R^2 values ranged from 0.94 to 0.99, and F statistic values of 9.53 to 493.5, all rejecting the joint null hypothesis.

Unlike the developed countries, none of the developing countries, except for Argentina, showed domestic credit as a statistically significant variable to describe manufacturing value added. The contribution of domestic credit in Argentina was much weaker than the US and Japan, approximately 1/3 of Japan or 1/5 of the United States, as shown in Table 25.

There are possible explanations for this difference. First, different industrial sectors that may have prospered in developed vs. developing countries during the time period. Perhaps such differentiation required different variables for further development. Second, it is conceivable that the needs of countries change during the various phases of industrial development.

In case of Brazil, none of the explanatory variables and model variations was found to be statistically significant in terms of F and t statistics. This indicated that the change in manufacturing value added in Brazil could not be explained by parameters that were found to be significant in other countries. The statistical analysis in the previous section found significant fluctuations in some indicators, perhaps due to severe economic downturns that the country experienced.

Mexican Modeling

The Mexican case showed that manufacturing value added can be described as a function of literate workforce and foreign direct investment. The model includes the literate workforce variable that is common for developing countries. At the same time, the Mexican model was the only one that showed a positive relationship between FDI and manufacturing value added of the eight countries with statistically significant model.

This result is somewhat expected and fits with the industrial development path of the country in the analysis period. Since the 1980s, Mexico replaced its import substitution development strategy with more open, export promotion strategy. A significant part of this development was financed with foreign direct investment, as domestic financial sources were limited. Indeed, domestic credit is not a statistically significant parameter in the model.

Models from other developing countries that followed the same industrial development path did not include FDI as a statistically significant variable. In addition, Mexico's factor for literate workforce variable was the lower than Argentina and South Korea, the two other countries where literate workforce was statistically significant. These observations may indicate the possible over-reliance on FDI in Mexico, at the cost of human capacity development that other developing countries may be emphasizing more.

Further Observations

This analysis faced some major challenges associated with finding quantitative evidence of factors for technological change. One such challenge is determining the existence and magnitude of any causal links between manufacturing value added and the explanatory variables. While the results showed that manufacturing value added could be explained by a number of indicators of technological change, it did not address whether (and how) such indicators caused manufacturing value added to increase. We should be cautious not to draw any conclusions on the causal relationship between manufacturing value added and these indicators, even if the function generated high values of R^2. In time-series studies, high values of R^2 can often be obtained as any variable that grows over time is likely to adequately explain the variation of any other variable that grows over time (Pindyck and Rubinfeld, 1998).

However, the analysis did yield significant insight to be analyzed further in the complementary qualitative analysis. For example, the Mexican model included foreign direct investments as a statistically significant factor, as well as literate workforce. This means that the Mexican manufacturing output can be described as a function of exogenous (FDI) as well as endogenous factors. Because exogenous and endogenous factors have different policy relevance and opportunities for interventions, this needs to be explored further in the next phase of the research.

The analysis was also hampered by limited data, especially in individual countries. Regressions with lagged variables decreased the number of usable observations, influencing the results' reliability. Possible improvements for future analysis include longer time span (more observations) at the individual country level, analysis of additional variables, and also the use of moving averages to smooth out annual data fluctuations

Chapter 5. Case Studies of Environmental Technological Change

The previous chapters have analyzed the institutional, legal, and industrial structures of the Mexican auto sector and its technological capability. The analysis so far revealed the strong influence of external factors in the process of general technological change and capability development in Mexico. The research now focuses on technological change for environmental improvement, or environmental technological change. Three case studies of environmental technology introduction in Mexican automobile sector are conducted to identify factors and processes that describe how their introduction was realized.

This chapter consists of five sections. The first section describes the rationale for the selected technology cases, and methods used to collect the necessary information. The second section describes the first technology case, catalytic converters. The third section is about the introduction of the Tier 1 vehicles. The fourth section presents the introduction of the on-board diagnostic system. The findings are summarized in section five. The case study results are further synthesized into a conceptual model, which is described in Chapter 6.

Section 5.1: Three cases of environmental technology introduction

Three technological case studies were selected for in-depth analysis as follows:

1. Catalytic converters (introduction from 1991)
2. Tier 1 vehicles (introduction from 1999)
3. On-board diagnostic (OBD) system (introduction from 2002)

These are some key technologies that have been introduced by environmental regulation for emission control, first in the US, followed by Mexico. The functions of each technology are analyzed in more detail in the following sections.

5.1.1 Rationale for Technology Selection

These cases were selected for three reasons. The first reason is the significant emission reduction capability of each technology case. The second reason is that the timing of their introduction corresponds to major changes in the legal, institutional, and industrial structures in Mexico, as described in Chapter 3. Analyzing cases within this time frame allows me to track changes in the relative importance of the factors of technological change.

The third reason is that the three cases represent different technology attributes of pollution mitigation in automobiles. One of the technology attributes is the level of complexity of manufacturing and integration into the vehicles. The catalyst control and Tier 1 technologies involve relatively simple installation in the automobile sector. They also require relatively few proactive measures by drivers to ensure proper functions, primarily in the use of unleaded and low sulfur fuel. They are considered to be relatively stand-alone technologies, provided the basic requirements, primarily appropriate fuel quality, are met. The OBD system, on the other hand, requires more complex technical capability for installation, as well as hardware and training for the automobile service and repair industry. Because the OBD system is a monitoring system and does not minimize emissions on its own, drivers need to take proactive measures to get the cars repaired to ensure emission reduction. Another technology attribute of interest is the nature of pollution mitigation - technologies can either treat pollution, or prevent the generation of pollution. The first two cases are examples of pollution treatment. The OBD system is concerned with emission reduction, as it is a monitoring system to prevent emission increase. It is worthwhile to analyze whether these differences in technology attributes influence the process of technological change.

5.1.2 Case Study Data Collection Methodologies

Understanding the process of technological change requires an in-depth analysis of specific contexts. As succinctly summarized by one scholar, "...factors can be dealt with only by historical analysis and case studies that expose the social, economic, and political conditions that influence individual events" (Girifalco, 1991). The technology cases were analyzed with information collected from multiple sources and methods, including interviews, a survey of Mexican automakers, as well as a review of literature. Each source and methodology is described below.

Interviews

Interviews were conducted with representatives from three major categories of stakeholders. These categories are industry, environmental and transportation agencies, and government agencies for economic and industrial development. There is a substantial turnover of mid- to high-level government officials associated with changes of administrations. Such turnovers can take personnel from a federal agency to a local agency, from industry and academia to the government, and vise versa. Due to this fact, many persons interviewed could provide multiple perspectives from various positions in different institutions throughout the case study period. In order to get a historical perspective, care was taken to reach persons who have been involved in the pertinent issues in the government and industry from the 1980s to the present.

Approximately 35 interviews with approximately 50 individuals, encompassing over 100 person hours, have been conducted. To protect the confidentiality of the interviewees and survey respondents, the analysis does not contain information that can reveal their identify, in agreement with the standards set forth by the MIT Committee on the Use of Humans as Experimental Subjects (COUHES). In addition, former representatives of various Mexican government agencies and academic institutions who had/have been MIT visiting scholars and students have provided valuable information.[68]

- **Industry**
  The industry-wide perspective was discussed with the Association of Mexican Automobile Industry (AMIA). From individual companies, technical and government affairs directors as well as engineers were interviewed. The following companies were interviewed: Ford, Volkswagen, BMW, Renault, General Motors, and Nissan. Daimler-Chrysler, Honda, and Peugeot could not be reached for individual interviews. The Manufacturers of Emission Controls Association (MECA) in the United States was also interviewed to get the perspective of technology suppliers.[69] In addition, PEMEX has been an active participant in the Mexico City Project, and has provided information on the fuel characteristics and performance.

- **Environmental and Transportation Agencies**
  Interviews were held with representatives of environmental authorities at the federal and state/district level. Director generals, directors, and sub-directors of various departments at the federal and local agencies, a former vice minister of environment, as well as an advisor to the current environment minister were interviewed. National agencies interviewed included the National Institute of Ecology (INE) and the Secretariat of Environment and Natural Resources (SEMARNAT). At the local level, senior and mid-level personnel from the Secretariat of Environment of the Federal District and the Secretariat of Ecology of the State of Mexico were interviewed. In addition, representatives from the Secretariat of Transportation of the Federal District were interviewed.

- **Economic and Industrial Development Agencies**
  Interviews were held with director level personnel from the Standards Section and the Automobile Development Section of the Secretariat of Economy (formerly SECOFI). Several meetings were also held with project coordinators and environmental managers of the National Petroleum Institute. An in-depth interview was held with a senior level director of environmental and legal affairs of the Secretariat of Finance (SHCP).

Survey of Mexican Automakers

A survey of Mexican automakers in Spanish was distributed in the summer of 2001. With the cooperation of the Association of Mexican Automobile Industry (AMIA), the survey was forwarded to technical and government affairs managers of the nine AMIA member companies. Written or oral responses were obtained from five firms. Their

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[68] Further information on the interviews may be obtained from the author in person.

[69] MECA is an industry association for the catalytic converter sector, whose mission is to work with government agencies to provide technical information on emission control technologies. MECA currently has approximately 45 member companies, representing approximately 90 to 95% of the North American market (MECA, 2000).

responses were incorporated into the case analysis. Due to the small sample size as well as the prevalence of partial responses, a formal statistical analysis of responses was deemed unsuitable and therefore not conducted. A copy of the survey is included as Appendix C.

Literature Review of Factors of Technological Change

To complement the primary data collected from interviews and the survey, the literature on emission control technology development and automobile sector development in Mexico was reviewed. Industry statistics were obtained from AMIA and used in analysis. The legal and institutional descriptions presented in Chapter 3 provided the key basis to understand the industry and government actions in the case study analysis. In addition, the literature of technological change for general and environmental purposes was analyzed. This analysis and comparison with the Mexican case are presented in detail in Section 3 of Chapter 6.

My case study analysis focused on environmental, political, and institutional aspects of technological change for environmental improvement. While analyzing technological change from the economic perspective or within mathematical approaches is equally important, such analysis was deemed to be outside the scope of my research.

Section 5.2: Case I—Catalytic converters (1991, 1993)

5.2.1 Background

Technology Description

Catalytic converters, currently considered to be one of the most effective control devices for automobiles, treat exhaust gases by oxidation and or reduction of pollutants. They are box-shaped, and contain ceramic cells, whose hyperactive surface area (substrate) contains platinum, palladium, and/or rhodium (catalyst) that perform the catalyst function. The exhaust gases pass through the surface area and get treated by the precious metals. Catalytic converters are normally located between the gas collector of the motor and the muffler of the exhaust tube.

Catalytic converters treat hydrocarbons, CO, and NO_x. An oxidation reaction converts hydrocarbons and CO into CO_2 and water. A reduction reaction converts NO_x to N_2. Three-way converters, developed in the early 1980s and used widely today in the US and Mexico, are equipped for both oxidation and reduction capabilities to treat hydrocarbon, CO, and NO_x emissions. Two-way converters are equipped for oxidation only, and treat hydrocarbon and CO emissions. While catalytic converters are primarily an end-of-pipe technology, improved control of the air-fuel ratio with the use of oxygen sensors can improve fuel efficiency (MECA, 1999a, MECA, 1999b, Slott, 2000). In addition to gasoline-powered automobiles, catalytic converters are used in alternative fuel vehicles powered by natural gas, propane, methanol, and ethanol, some trucks, buses, motorcycles, and off-road equipment.

Catalytic converters are supplied to the automobile sector by the catalytic converter sector. Supply contracts between catalytic converter manufacturers and automakers tend to be long-term, with established relationships. Technology development in this sector has been shaped by emissions standards in the US, which have compelled the firms to make investments by clearly defining the technology requirements (MECA, 2000). A large percentage of innovations in this sector have occurred in the US due to technology forcing standards.

Initial Conditions

Discussions between the industry and government for the introduction for catalyst control began around 1986, when the Mexican economy was still stagnating in recession. The negotiations were preceded by a general rise in environmental awareness in the early 1980s. Environmental awareness and policy momentum began to build when De la Madrid assumed presidency in 1982, and took several initiatives to establish legal and institutional frameworks for environmental management, including the establishment of the Secretariat of Urban Development and Ecology, or SEDUE (see Chapter 3). However, the economic crisis and lack of resources limited the actual implementations of initiatives. Some former environmental officials recalled that air pollution management from mobile sources was still not a policy priority at the early stage of the negotiations.

When the discussions began, Mexican emission standards were equivalent to US standards from the early 1970s. Vehicles were not equipped with catalytic converters, and the availability of fuel injection vehicles, needed for efficient catalyst functions, was limited due to a wider availability of carbureted vehicles. This state of technology was in contrast to the United States, where oxidation catalyst control started in 1975, and three-way catalytic converters were put in place by 1980. Thus, when the discussions started in Mexico, the control technology was already widely available in the international market. The environmental authorities were aware of the availability of catalyst technologies in the international market. The also knew, from the industry's growing export performance, that some firms had the capacity to build cars that met the US standards. Some of these firms were removing parts to sell the export models in the domestic market, as catalysts could easily be removed to save on technology costs, according to the environmental authorities.

5.2.2 Influencing Factors and Negotiation Process

The initial stage of discussions did not go smoothly. Former environmental officials recalled that the industry was not very receptive or cooperative. The environmental authorities felt that discussions for standards revision were necessary, as the relative *laissez-faire* approach on the environment had not resulted in voluntary improvements of passenger vehicles.

The Mexican Automobile Industry Association (AMIA) played an influential role as a key institution in consolidating the industry position and representing the sector during negotiations.[70] The fundamental position of AMIA was to accommodate and advocate the member firms that lagged behind in the technological capability.[71] AMIA continues to be act as a major institution that facilitates dialogue among the auto sector, and between the sector and the government.

Technology Attributes and Conditions

Three technology attributes and conditions were pertinent for the catalyst case. They are cost considerations associated with the technology and manufacturing process change, fuel availability, and installation requirements of the technology.

Cost Considerations

One major concern for the industry in the introduction of catalyst control was the cost increase associated with the technology introduction, both for production line changes and unit technology costs. The industry stated early in the discussions that there were not enough consumers in Mexico that would want and could pay for the technology. The attitude of the sector, according to former government officials, was that the Mexican market was neither big nor important enough to necessitate cooperating with the environmental authorities. The sector would provide the best technology for which the consumers could pay.

The environmental authorities argued that the production line improvements were necessary anyway to better integrate local production and supply with a regional network for strategic reasons, and they were not being undertaken exclusively for local environmental reasons.[72] Indeed, some firms began to develop the capacity to manufacture and export fuel injection vehicles as the integration of the Mexican auto sector into the North American network began, before the debate on the catalyst introduction got started in Mexico. The subject of regional integration is described in more detail in the section on auto sector characteristics in Chapter 3. The cost increase associated with the catalyst technology addition was a more valid point. The authorities argued that the auto sector was wealthy and stable enough to pay to reduce the environmental impacts of vehicles. Vehicles sold in Mexico with less technologies were priced the same or slightly higher (before taxes) than similar models sold in the US, according some government officials from that time. Based on this observation, the authorities argued that Mexican automakers enjoyed a higher profit margin in Mexico

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70 AMIA's official mission is "...to promote the growth of the Mexican automobile industry, maintaining its sense of responsibility for the community and the environment, through proactive representation of the common interests of the affiliates. To act as a spokesman, consultant, and forum for consensus, from which sectoral information and industry leadership emanate, in a context of strict observance of applicable regulations and promotion of policies to the mutual benefit of associates (AMIA, 2002a)."

71 The environmental authorities sometimes criticized AMIA as "going only for the common denominator."

72 At least one automaker representative stated that his firm was in agreement with the position of the authorities at the time.

than in the US, and could therefore withstand the additional cost associated with the catalyst introduction.[73]

Fuel Quality and Availability

Another major point of concern for the automakers, as well as the environmental authorities, was the adequate provision of unleaded gasoline. One of the key technology attributes necessary for proper functioning of catalytic converters is the adequate fuel quality. Some pollutants in fuel, such as lead and sulfur, reduce the catalyst efficiency by forming deposits on the catalyst surface and reducing its efficiency. The availability of unleaded gasoline is necessary to ensure the catalyst function, as the surface area of the catalyst can be poisoned permanently by a single tank of leaded gasoline.[74] More detailed descriptions on sulfur effect are found in Chapter 7. Fuel injection engines are usually used for cars with catalyst control for better control of combustion properties.

As the planning for future production involves long-range thinking and considerable investments, the auto sector did not agree on the technology introduction unless the uncertainties associated with the unleaded gasoline provision were minimized. The need for unleaded gasoline necessitated the involvement and agreement of the national petroleum monopoly, PEMEX, in the negotiations.

A significant pressure to phase out lead from gasoline came from the public. The public easily understood the linkage between leaded fuel and negative health impact, and politicized the phase-out of leaded gasoline as a government responsibility, as PEMEX was seen as part of the government. As a firs step, PEMEX reduced the lead content of Magna from 2.5 to 1.0 cc/gal in 1986 (Molina and Molina, 2002c).

The provision of unleaded gasoline posed two interlinked challenges to PEMEX; addressing the additional refining and distribution costs, and providing enough volume to meet the demand. PEMEX needed to invest in refining upgrades and distribution networks to provide unleaded gasoline. The additional cost of providing unleaded gasoline with adequate octane quality ranged from 5 to 30 cents per liter, based on experiences in the US, Australia, Europe, and other countries. The figure was somewhat higher for developing countries due to a need for larger capital investments (Faiz, Weaver et al., 1996), although exact cost estimates from PEMEX could not be obtained. Investment proposals needed to be authorized by the Secretariat of Finance, which is commonly referred to as *Hacienda*. The environmental authorities discussed the proposal to phase out lead with *Hacienda* officials, presenting the positive health benefits of lead removal, mounting public pressure for cleaner environment, and the possibility to introduce cleaner and more efficient vehicles. The proposal was eventually approved by *Hacienda*. PEMEX investment proposals still require approval of the government,

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73 This position is in line with the polluter pays principle.

74 Catalyst poisoning can also occur from sulfur and phosphorous in the fuel or engine oil (National Research Council, 1999). Sulfur poisoning is more prevalent for close-coupled catalytic converters for low emission vehicles (LEVs) and ultra low emission vehicles (ULEVs) (MECA, 1999a, MECA, 1999b).

perhaps as a mechanism to protect and manage this significant contributor to the national fiscal revenue.[75]

The second challenge of meeting the gasoline demand was compounded by the closure of a major refinery in the MCMA with 100,000 barrels per day capacity, *18 de Marzo*, in 1990 in a drive to reduce industrial emissions. This refinery was one of seven refineries, and accounted for 7 to 9% of national production capacity in the late 1980s (PEMEX, 1998). In essence, PEMEX was faced with a challenge to provide a more expensive new product when the overall gasoline demand was increasing yet the refining capacity was decreasing. A lead-in time was also necessary to reconfigure the refineries, and set up the distribution and sales infrastructure.

Faced with these two challenges, PEMEX began to import unleaded gasoline from the US. PEMEX introduced unleaded gasoline, Magna Sin, in September 1990. The volume of unleaded gasoline sales increased significantly from 1992, as shown in Table 26. The leaded gasoline sales surpassed leaded gasoline sales by 1995. Meeting this increased demand required increased volume of imported unleaded gasoline. As shown in Table 26, the share of imported unleaded gasoline increased steadily after its introduction in 1990, in terms of % share and actual volume. The commitment to environmental policy, as judged by economic impact, is significant. In 1997, approximately US$1.2 billion was spent for gasoline importation In terms of the percentage of total export revenue, over 10% has been allocated in 1997 to import gasoline, increasing significantly from 0.5 % in1987 (PEMEX, 1998).

Table 26: Share of domestic and imported unleaded gasoline

	1990	1991	1992	1993	1994	1995	1996	1997
Domestic production of unleaded gasoline produced (%)	89%	86%	64%	56%	72%	75%	74%	68%
Imported unleaded gasoline (%)	11%	14%	36%	44%	28%	25%	26%	32%

(PEMEX, 1998)

[75] The contribution to PEMEX to the national fiscal revenue has averaged at 31% between 1987 and 1997. The annual percentage has ranged from 24% in 1991 and 1992, to 43% in 1987 (PEMEX, 1998).

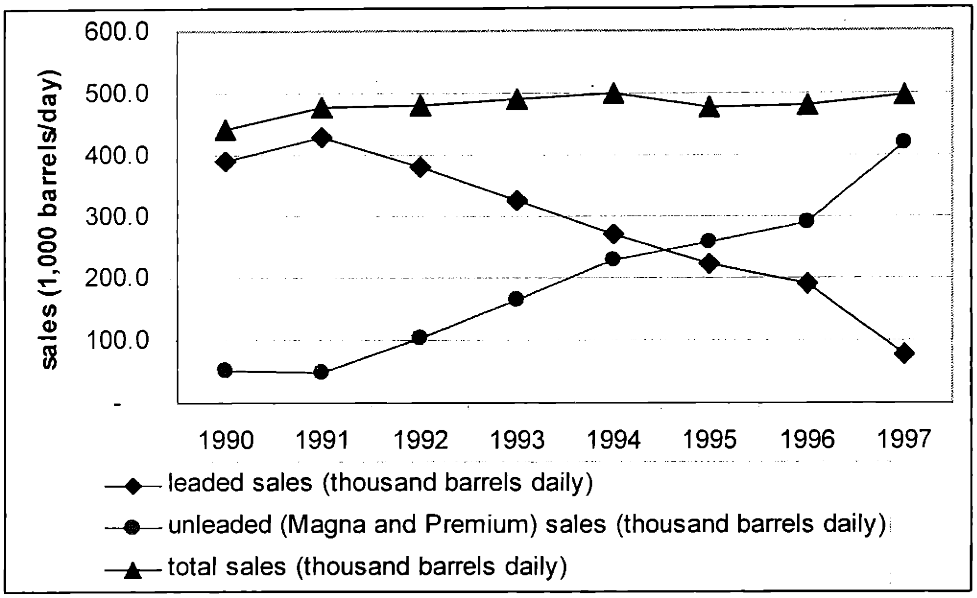

Figure 11: Domestic demand for leaded and unleaded gasoline

(PEMEX, 1998)

Installation Requirements

In terms of the manufacturing and installation sophistication, the catalyst technology is considered as a "stand alone" technology, and relatively easy to incorporate into the vehicle design and to install as well as remove. This ease of installment and removal has likely compelled the industry to remove them from imported vehicles prior to the introduction of more stringent emission standards.

Environmental Institutions

Institutional Strength and Capacity

The relative weakness of environmental institutions, both perceived and real, played a role in the resistance of the auto sector and the difficulty of reaching consensus. Compared to the economic and industrial authorities, the environmental authorities were much weaker in institutional capacity as well as in influence. Since 1982, the government agency in charge of environmental issues was the Secretariat of Urban Development and Ecology (SEDUE), which was the first institution to deal with environmental issues as one of its major mandates. SEDUE suffered from fragmentation of institutional setting as well as limited mandates. True to its name, SEDUE's policies tended to be based on ecology and urban development. Different aspects of environmental management were still administered by various other secretariats, in addition to SEDUE. Such fragmentation resulted in relatively ineffective administration and ad-hoc policy making, and corresponding lack of consistent policy implementation and enforcement (OECD, 1998).[76]

Within SEDUE, there was a lack of human resources with technical and managerial expertise. In terms of domestic higher education opportunities, the Environmental Engineering program at the National Autonomous University of Mexico (UNAM) did not begin until the late 1970s, and 1982 was the first year that the program produced graduates. To provide educational opportunities, authorities sent their personnel abroad for technical and managerial training, with significant resource commitments. The analytical and technical capability was also limited. As discussed in Chapter 3, limited data and research on air pollution had been conducted up to the 1980s. One former official recalled that there were almost no personal computers in federal environmental authorities as of 1985, severely curtailing the analytical capacity of available data.

International assistance was necessary during this period to build technical and human capacity, and to establish stronger environmental institutions. The U.S Environmental Protection Agency provided technical assistance to install an air quality monitoring network, called RAMA in 1985 (Molina, Molina et al., 2002). Technical personnel from US EPA were also assigned to the Environmental Authorities to provide assistance. In addition, the Japanese Government granted an $850 million ecology loan to combat air pollution.[77][78]

Procedure for Standard Formulation

The discussions for catalyst introduction happened before the Methodology Law went into effect in 1992. One former official commented that the weak standard formulation procedure requirements ironically enabled the environmental authorities to pass the standards relatively quickly, once the agreement with the auto sector was reached. A real and credible threat of unilateral policy intervention existed, compelling the industry to negotiate and come to an agreement with the authorities.[79]

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76 In addition to difficulties associated with administrative integration, SEDUE suffered from a succession of scandals that undermined its authority and effectiveness (Borchardt, 1994).

77 A portion of the Japanese funding was allocated to establish the National Center for Environmental Research and Capacity in 1997. The center is referred to as *Centro Nacional de Investigación y Capacitación Ambiental*, or CENICA.

78 While the technical and human capacity of the Mexican environmental authorities have improved significantly since this period, international technical assistance has continued to today, from France, Germany, Japan, the United States, as well as the World Bank.

79 This "flexibility" and speediness of standard formulation was also regarded as an obstacle to transparency, and led to the passing of the Methodology Law. A representative from the Economic Secretariat stated that prior to the Methodology Law, the process of introducing regulation was not transparent. Various agencies established mandatory obligations, sometimes haphazardly without publishing them in the official gazette. Auto sector representatives had various examples of arbitrary policy making without stakeholder consultation in the 1980s at the federal and local levels.

Economic Institutions

The economic and industrial institution in charge of the auto sector development was the Secretariat of Economy and Industrial Development, SECOFI, as described in Chapter 3.

Institutional Strength and Capacity

The weak environmental institutions were in contrast to economic and industrial development authorities, which had well-established interactions with the auto sector and extensive experiences of policy applications to realize development goals. Interactions between the auto industry and the government to achieve economic and development goals, which began in the pre-war period, have been quite significant since the 1960s, as discussed in Chapter 3. By 1990, five Automobile Decrees had been issued, with directives on production and export goals, local integration requirements, as well as incentives to facilitate the industry to meet the requirements.

The Mexican economic and industrial development authorities regarded the auto sector as "one of the country's best hopes for advancing its industrial infrastructure while managing its foreign debt" (Womack, 1986). As such, the authorities were reluctant to introduce measures that could negatively affect the sector performance. SEDUE received directives from SECOFI not to introduce environmental measures that could put any restrictions on foreign direct investment (FDI).

The industrial and economic policy formulation began to change in the 1980s, due to two interlinked reasons. The first reason is that the government officials began to recognize that deregulation was the best approach to improve the balance of payments, which was one of the primary policy objectives. The second reasons is that the policymakers became aware of limitations of policy interventions in shaping the sector, given Mexico's position in the sector's economic structure as well as increasingly dynamic globalization and regionalization (Morris, 1998). Unlike the previous phases where policy shaped the industry, the industry began to influence policy. As a consequence, this sector policy change resulted in an increasing convergence of interests towards facilitating regional integration of production between the auto sector and the Mexican government (Studer-Noguez, 1999).

The dialogue between the industry and government, and policies for industrial development, was evolving towards liberalization and more hands-off approach, as the environmental authorities were negotiating for tighter environmental and institutional control over the auto sector. In effect, the two government institutions were moving towards different and sometimes conflicting directions of policy interventions.

Technological Capability in Industry

The level of technological capability varied within the automobile sector. While some have had several years of manufacturing experience in vehicles with catalytic control that could meet the US emission standards, others did not. Such differences in technological capability were a function of the local sector characteristics, influenced by the global automobile sector characteristics and industrial and economic policy. In addition, several inconsistencies that emerged, perhaps unintentionally, between the environmental and economic policies influenced the introduction of catalyst technologies. These factors are described below.

Global Auto Sector Characteristics

The period from 1970s to1980s was a period of evolutionary changes in the global auto sector, such as changing demand for cars, incorporation of new technologies for production and products, as well as increasing competition from the Japanese manufacturers. Within the regional context, the sector began to integrate operations in Mexico, US, and Canada into a North American production framework (Studer-Noguez, 1999). One firm went through re-organization during the 1980s to be part of the North American operations, while previously the Mexican operations were a separate entity or part of Latin American operations.

Some industry representatives recalled the extensive involvement of corporate headquarters abroad, as well as Mexican senior management, in the dialogue leading up the agreement to introduce catalytic converters. Their involvement was crucial, as decisions for new plant establishments and upgrades were made increasingly for global and regional integration of production and markets, and less for domestic reasons. One firm representative said that most changes in Mexico that his firm experienced during the 1990s could be attributed to the (international) corporate policy, irrespective to a large part of specific Mexican conditions. Such changes were often brought into the company with the senior management, who had experienced new ideas and concepts in various regional operations in the US, Asia, and Europe. This particular firm began to incorporate global vehicle design, manufacturing, and sales of some models, necessitating decision making that encompassed different regions.

Technical and management training opportunities were provided at corporate headquarters, or conducted locally with experts sent to Mexico from abroad. This point is discussed in more detail in later sections.

In addition to the gradual internationalization of general decision-making, the acceptance of corporate environmental citizenship began to take hold in Europe, Japan, and the United States. Automobile companies were not immune to this movement. By the early 1990s, a number of international industry codes of conduct had been developed, such as the CERES principles by the Coalition for Environmentally Responsible Economies (1990), International Chamber of Commerce (ICC) Business Charter for Sustainable Development (1991), and Keidanren Global Environmental Charter (1991). Ford, GM, and Volkswagen had adopted the ICC Business Charter by 1992 (UNEP/SustainAbility, 1994). Directives from headquarters in US, Germany, and Japan tended to be more positive and supportive of environmental improvements and investments, sometimes providing the outside support and credibility necessary to reach consensus within the local operations.

Local Auto Sector Characteristics

The global and regional sector evolution had profound influence on the domestic auto sector during the 1980s. New production facilities in the northern and border areas and upgrades of existing plants in the central region enabled the sector to increase the export performance from virtually zero in 1980 to close to 50% by 1987 (AMIA, 2002b, Studer-

Noguez, 1999). As a large percentage of these vehicles were exported to the US, the export-oriented firms had established production and managerial capability to manufacture cars that could meet the US emission standards within several years. However, the domestically oriented firms tended not to have the same technology access and manufacturing experience. This point is described in more detail in the following section. While the geographic proximity to the US emerged as a substantial comparative advantage for Mexico, its other comparative advantage of low cost labor appeared to be of less significance during this time period. Labor-intensive production processes began to diminish, due to robotic assembly technologies, new production management, and simplified product designs (Womack, 1986).

This change in manufacturing production in a relatively short time period resulted in a significant need for managerial and technical capacity building in Mexico. One company representative said that the largest and most significant efforts to catch up and to incorporate new industry ideas happened in the early 1990s, at the time of the catalyst control introduction. It was necessary for firms to adjust technologies to meet local conditions, such as altitude adjustments to compensate for less oxygen content, and adjustments to transmission, as well as differences in emission certification requirements. Most firms interviewed said that the local adjustments, small or big, were important, particularly to adjust to local fuel, such as lower octane and variability in fuel quality, as well as for local driving conditions.

It was difficult to obtain the actual financial commitment of the auto sector to comply with the catalyst requirements. One firm provided approximate figures, but because of its general nature, the data verification could not be conducted.[80] Nevertheless, this firm responded that it improved the existing production lines between 1991 and 1993 to comply with the new standards. The firm did not install any new production lines during this period. The introduction of new exhaust and fuel injection systems cost approximately US$3 million. US$1 million was also allocated for training at the corporate headquarters, as well as with suppliers. Motor adjustments to meet local conditions were also made, costing approximately US$2 million.

One export-oriented firm knew that improvements to production lines were necessary to phase out the carburetor assembly system in the next 2 to 4 years. To introduce catalyst control, electronic fuel injection, exhaust gas recirculation (EGR) system, and air pumps were either improved or newly added to vehicles. For this firm, technology availability was not a serious issue, as it had access to domestic and imported parts. Investments were made as a lump sum, and not separated into general versus environmental investments. The local office had the responsibility of locating and coordinating with suppliers, as well as locating competitively priced parts in Mexico. While technology adaptations to meet local conditions were necessary, they could be resolved. The firm representative commented that local development had been an important part of the

[80] Furthermore, the lack of detail and verification made it impossible to determine whether the industry concern for the cost increase was indeed a valid issue.

Mexican operations, but was eventually phased out in the early 1990s, only to reveal some problems that needed local attention.

Some have argued that the Mexican industry, including the auto sector, used improved environmental performance as a bargaining chip to carve out favorable conditions for NAFTA. While the exact extent to which the bargaining consideration affected the discussion on catalyst introduction is debatable, the fact that the move towards liberalization had a profound effect, both positive and conflicting, on the environmental technological change appears to hold true.

Conflicting Policies and Barriers

The environmental authorities sought to improve the air quality by introducing new emission standards that would require catalyst control. During the same time period, the industrial policy regime was in a transitional stage. New policy measures for sector liberalization and conventional measures for domestic sector promotion created a gap in access to technologies and technological capability among the automobile firms. Many interviewees from the government and industry recalled that conflicting policies created unfavorable conditions for the introduction of environmental technologies in some firms. A survey of the literature on industrial policy applications in Mexico from that era yields a picture that is consistent with the recollections of the interviewees.

Vehicle Production and Market Structure

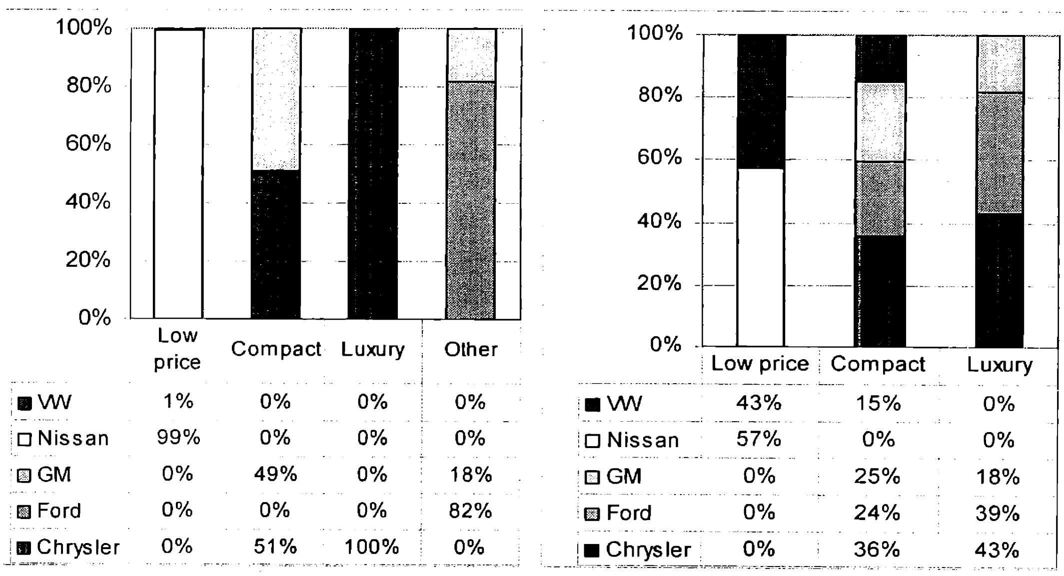
As of 1987, only five firms, Chrysler, Ford, General Motors, Nissan, and Volkswagen, were active in the domestic market. Because of import restrictions, automakers could not enter the market without establishing domestic production facilities. There were three domestic market segments: low price, compact, and luxury/sports. For the export market, there were four segments: low price, compact, luxury/sports, and other, which included a number of models produced only for exports.

The production and sales shares of vehicle categories differed significantly for the domestic and export markets. The domestic demand was largely for low price and compact vehicles, whereas the export demand was for export only models and compact vehicles. As summarized in Table 7, approximately 60% of the domestic sales for 1987 was for low price vehicles, followed by 31% of compact cars. The luxury and sports market was relatively small, with only 11% of sales share. For the export market, approximately half (47%) came from the other category. 31% were compact vehicles, followed by 14% of luxury and sports vehicles.

A review of firm shares in model segments for the domestic market reveal that two non-US firms dominated the low price market segment, while the Big 3 shared luxury and compact segments, as shown in Figure 12. For the export market, the Big 3 dominated the two strongest categories (other and compact), also shown in Figure 12. The Mexican automobile market in the 1980s can thus be characterized as an isolated oligopoly, where the US firms were dominant in high end and export markets, and the non-US firms were strong in lower priced and domestic markets.

Table 27: 1987 Shares of vehicle categories for domestic and export production

Vehicle Category	Domestic production	Domestic share	Export production	Export share
Low price	85,461	59%	10,397	8%
Compact	44,920	31%	42,441	31%
Luxury and sports	15,338	11%	19,308	14%
Other	0	0%	63,335	47%
Total	145,719	100%	135,481	100%



(Domestic) **(Export)**

Figure 12: Firm share of market segments in 1987

Barriers to Catalyst Introduction

The export orientation and market segmentations had significant implications on technology access and capabilities. Specifically, the following barriers to the introduction of catalytic converters existed in the Mexican auto sector:

1. Disparity in access to technologies and parts from abroad according to export performance

2. Firm difference in the number of imported cleaner vehicles according to export performance

3. Variation in experience and technological capability to produce export quality vehicles that met more stringent emission standards

4. Different consumer response to price in market segments

5. Protection for key domestic models

In addition, the whole sector was subject to price control, which affected the ability to change prices to reflect cost increase. These barriers are described in more detail below.

- **Limited Technology Access**
  The market orientation and export performance strongly influenced the access to technologies and parts from abroad, including emission control technologies. At the time of negotiations, the auto sector was under the 1983 or 1989 Automobile Decrees, as described in Section 5 of Chapter 3. Both Decrees required automakers to use a minimum percentage of locally manufactured parts and components. The percentage of local content requirement was lower for export models. The requirement was only 30% for new export models from 1983 through 1993. On the other hand, existing domestic models were subject to a significantly higher local content requirement, at 50% until 1985, and 60% from 1987, and reduced to 36% in 1989. The requirement could be reduced for domestic models depending on export performance. As a result, export-oriented firms were able to import parts and components necessary to comply with tighter emission standards, as they already had access to such technologies for exported vehicles, and their export credit allowed them to import. On the other hand, domestic market-oriented firms needed to use more local parts, and had limited access to the key technologies from abroad. Initially, catalytic converters had to be imported, as the domestic supply was limited or nonexistent in the early years. The necessity to import meant that domestically-oriented automakers under more stringent import control had less access to imported technologies, or would have had to replace some of the imported parts and components with domestic ones to equip vehicles with imported catalytic converters.

  Indeed, firm differences in the procurement of catalytic converters were documented from the survey and interviews. One domestically oriented firm used 100% domestic catalysts for domestic vehicles, and 100% imported parts for exported vehicles as of 1993.[81] One export-oriented firm established a subsidiary catalyst manufacturing facility in the border region during the negotiation phase. This facility and another subsidiary in the US have since produced virtually all catalysts needed for the North American market for this firm. In addition, the cost competitiveness of parts and components were varied among imported and local

81 Since then, this firm has gradually switched to importation, and now relies 100% on imported catalysts.

parts, which could have hurt the domestically-oriented firms, which were more restricted in the choice of parts. Domestic parts and components were sometimes cheaper, yet others were more expensive than the imports, as discussed in Chapter 3.

- **Fewer Imported Vehicles**
  Through the 1980s, imported vehicles tended to be cleaner than new vehicles produced in Mexico, because the emission standards in Mexico were far more lax than most vehicle producing countries.[82] The domestic-oriented producers could import fewer cleaner vehicles compared with export-oriented producers, as the vehicle importation was contingent on the export performance. As of 1983, makers of export models could sell 20% of their export models in the domestic market. Starting 1989, exporting firms could start importing vehicles up to 15% of their domestic sales, provided they generated $2.50 in export performance for each $1.00 worth of imported vehicles (OECD, 1990). As a result, the fleet average emission performance was better for exporting firms compared with domestically-oriented firms.

- **Less Experience and Technological Capability**
  As shown in Figure 12, the domestically oriented manufacturers produced smaller volumes of export quality vehicles that could meet the emission standards of destination countries, primarily the United States. In 1987, the Big 3 firms exported slightly over 125,000 vehicles, corresponding to 70% of total production. Volkswagen exported 74 vehicles, corresponding to 0.2% of its total output. Nissan exported slightly over 10,000 vehicles, corresponding to 17% of its total production. Nissan vehicles were exported to Central America and the Caribbean region, where the emissions standards were more lax than the United States (OECD, 1990). These numbers indicate that Big 3 firms had much more experience and technological capability of producing vehicles that could meet US emission standards. On the other hand, VW and Nissan managers and engineers had less experience of producing cars with US level emission control. Their manufacturing facilities and personnel did not have the technological capability necessary to make such vehicles.

- **Anticipated Consumer Response to Price Increase**
  The two domestically oriented firms were concentrated in the lower cost vehicle market. Nissan and VW split the domestic low cost vehicle market, with 57% and 43% market shares each. VW also had a 15% market share in the compact vehicle market. Nissan produced only one low cost model called *Tsuru*. Volkswagen produced 3 models in the low cost segment, and 1 model in the compact market segment. Because the market for cheaper vehicles is more sensitive to cost increase compared to luxury models, these manufacturers argued

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[82] The emission performance was based on the availability of appropriate gasoline, provided that the catalytic converters were not removed.

that firms that served the lower-cost market segment disproportionately felt the negative cost impact. They were consequently more opposed to the proposed standard. The imported parts and components had import duties, further increasing the vehicle cost. These firms argued that they were providing many jobs because of the high local content, and deserved special consideration to protect the workforce.

- **Protection for Key Domestic Models**
  The government excluded firms other than VW and Nissan from producing sub-compact vehicles, which minimized competition in this market segment, and effectively delayed product improvement, including environmental performances.

  In addition, the *Auto Popular* program was established in 1989 to promote the production and sales of vehicles that were accessible to the public (described in Chapter 3). The program provided tax and duty advantage for producers, lower price and tax exemption for consumers. It proved to be enormously popular, resulting in a 68% sales increase of VW sedan from 1988 to 1989. Approximately 30% of vehicles purchased in the early 1990s fell under this program. The share of *autos populares* is currently approximately 10% (SE, 1999). The program did not contain measures to address the emission performance of the vehicle, other than compliance with emission standards. Compared to other vehicles of the same size, the emission performance of the current two *auto popular* models is not good. By not incorporating other measures, the government missed an opportunity to improve environmental performance of vehicles with a one-third market share in Mexico.

- **Price Control Program**
  The price control program, or *Pacto Economico*, regulated pricing of certain goods and commodities, administered by SECOFI. Vehicle prices were controlled under this program, and price changes necessitated justification and approval of SECOFI. As the introduction of catalyst control required additional expenditures, it was necessary to request a price change. Even though such price increase was justified on environmental grounds, the environmental authorities did not have the mandate to require technologies that resulted in price increases without the approval of SECOFI. One former official who dealt with SECOFI commented that negotiations were quite difficult. In the end SECOFI allowed the automakers to raise their prices.

In summary, various policy inconsistencies that existed during this time period had significantly negative effects on the process of technological change. There were firm differences in technological capability, local contents and employment, and corresponding difference in technology access for environmental requirements as well as capabilities. Due to these differences, export-intensive firms tended to be more open towards tighter environmental requirements, while domestic-oriented firms were less open towards tighter environmental controls.[83]

The environmental authorities were aware of general differences in capacity and ensuing positions among firms. The authorities felt that such differences and the eventual acceptance of some firms were crucial in compromising and eventually leading to an agreement. The agreement accepted a proposal by some firms and AMIA to include an interim standard for 1991 and 1992 that could be met with oxidation catalysts.

Other Factors

Two other specific factors emerged from interviews and the literature as specific elements that help to understand the introduction of catalyst control. They are public awareness of the environmental issues, and political leadership that lent credibility and impetus for action.

Public Awareness

The level of public awareness and mobilization on environmental issues was particularly high during the late 1980s. The phenomenon of public mobilization emerged from the aftermath of the 1985 earthquake, which destroyed a significant part of Mexico City, with a loss of 10,000 lives. Frustrated with government inaction, citizens took upon themselves to organize rescue, recovery, and rebuilding operations. This citizen movement was a defining moment for the Mexican civil society, according to many observers.[84]

In response, the government became more politically alert towards public outcries as well as politicizing of certain events (Borchardt, 1994). Environmental issues, including air pollution, came to the forefront of public debate and resulted in subsequent government response. For example, an environmental group named *Mejora Tu Ciudad*, concerned with traffic volume and pollution, asked the citizens in 1987 to participate in a voluntary program to stop driving one day a week. This was the start of the *Hoy No Circula* program. While the program enjoyed widespread support, it declined from lack of resources and support. The DF and EdM governments took notice, and introduced it as a mandatory program for short-term, emergency program in 1989. It was eventually included in PICCA, and remains in effect until today (Molina and Molina, 2002b). Another example is the public support for lead phase-out from gasoline. The public recognized the clear health risks of lead in gasoline, successfully pressuring government (PEMEX) to phase it out.

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83 During the interviews, a representative from a domestic-oriented firm stated that the uncertainty associated with fuel provision as the most significant factor associated with his firm's reluctance to the proposed standard. On one hand, he downplayed the importance of these conflicts, yet agreed that the reluctance was linked to the necessity of planning for future production, which involves long-term thinking.

84 See Foweraker and Craig, 1990 for detailed analysis.

The high level of public awareness, however, did not translate into consumer demand for cleaner vehicles, or willingness to pay extra for protection, according to the auto industry. Various industry representatives stated that environmental performance improvement, such as emission reduction, did not, and do not, provide any market advantage. The only possible exception was the fuel economy for consumers in the medium price range.[85] The lack of willingness to pay a premium is not surprising, as the same observations have been made in developed countries. Consumers tend to buy an environmentally friendly product only if the product has same attributes as a conventional product, such as price, performance and appeal.

Political Leadership

Political leadership had a role to play in the negotiation process leading to the adoption of the catalyst control technology. One key individual with such political leadership was Manuel Camacho Solís, according to several interviewees. Camacho was the Secretary of Environment (SEDUE) from 1986 and a potential presidential candidate, and had the political weight and clout to force changes. During his tenure at SEDUE, some of the fundamental legal and institutional frameworks were established, such as what ultimately became the General Environmental Law of 1988 (LGEEPA), discussed in Chapter 3. Camacho was subsequently appointed as the Mayor of the Federal District.[86] With his move from the federal to the local government, the institutional framework for air quality control at the local level was started. One of his initiatives was the establishment of the Metropolitan Commission for Pollution Prevention and Control (CMPCCA) in 1992, which was modeled after the South Coast Air Quality Management District (SCAQMD). The Metropolitan Commission was instrumental in implementing the PICCA air quality program, discussed in Chapter 3, under the leadership of Fernando Menendez, who also had significant leadership and coalition building skills (Borchardt, 1994).

5.2.3 Outcomes

Both the government representatives and auto sector representatives commented that their working relationship improved after the initial resistance, although the negotiations required quite some time to reach an agreement. The environmental authorities and the auto sector came to an agreement to introduce more stringent emission standards, after PEMEX agreed to introduce unleaded gasoline from 1990.

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85 Unlike the United States, the availability of comparable fuel economy has been limited, perhaps due to the lack of fuel economy standards. As such, it would have been difficult for consumers to have objective fuel economy information to compare one model over another. This limitation further undermines the possibility of turning environmental attributes into market advantages.

86 Until recently, the mayor of the Federal District was appointed by the President of Mexico, and not selected by popular vote. Camacho was appointed to the post by President Salinas. Camacho was ultimately not selected as the PRI's presidential candidate in 1994. Camacho later became the Peace Commissioner in the Chiapas guerrilla conflict but resigned.

Emission Standard Introduction

The new vehicular standard went into effect with the 1991 model year vehicles. The auto sector successfully negotiated a two-tier emission standard to allow for a gradual phase-in of catalyst technologies. The maximum emission limits for HC, CO, and NO_x for 1991 and 1992 model years and 1993 and beyond are summarized in Table 28. The interim emission standards from 1991 to 1992 could be met with oxidation catalysts, approximately 16 years after the equivalent US standards were introduced. The final emission standards that required the introduction of three-way catalytic converters were introduced from 1993, 13 years after the equivalent US standards came into effect. The phase-in period and delayed introduction of the three way catalysts was negotiated primarily for the domestic market-oriented firms. Some export-oriented firms bypassed the interim period, and began to sell vehicles with three-way catalysts by 1991. All industry representatives contacted felt that the emission standards had an extremely strong and positive effect on the introduction of the catalyst technology. The effect of the emission standards was to set an explicit timing and pacing of the technology introduction that all firms had to follow.

Table 28: Maximum emission limits for passenger vehicles with catalytic converter

	Total hydrocarbons (g/km)	CO (g/km)	NO_x (g/km)
1991 model year	0.70	7.0	1.40
1993 model year	0.25	2.11	0.62

(COMETRAVI, 1999a)

Provision of Unleaded Gasoline

The provision of cleaner gasoline started from 1990. Unleaded gasoline, *Magna Sin*, was introduced by PEMEX in 1990, replacing a leaded premium gasoline, *Extra*. As of 1993, the lead content of leaded gasoline was further reduced. The phase-out of leaded gasoline was completed in the MCMA in September 1997, and nationally by 1998.

Meeting the unleaded gasoline demand posed a challenge for PEMEX, due to limited domestic supply and cost increase. PEMEX relied on the importation of unleaded gasoline, up to 45% of domestic consumption, to meet the growing demand, as shown in Table 26 earlier in the section. In 1993, US$760 million was allocated for gasoline importation, which corresponds to approximately 10% of the total export performance of the same year. To maintain supply, PEMEX established a joint venture with Shell in 1993, where the firm purchased 50% of the fuel refining facility in Deer Park, Texas. PEMEX agreed to receive part of the payout in the form of unleaded gasoline, totaling 45,000 barrels per day. It agreed to provide a long-term supply of heavy Mayan crude, which represents 70% of Mexican oil export (Oil & Gas Journal, 1994). By 1997, PEMEX Refining recorded an operating loss of US$860 million, "...largely due to higher expenses associated with the importation of unleaded gasoline..." and labor costs (PEMEX, 1997).

The new standards also generated additional impetus for catalyst manufacturers to establish operations in Mexico. As of 2000, at least eight companies have established operations in Mexico, as described in Chapter 3.[87] A majority of them are multinational firms establishing operations to service the Mexican manufacturers. Such operations conduct very little, if any, research and development in Mexico, as most technology development has already been undertaken in the US (MECA, 2000).

Factors with Positive Effects

Three factors were considered by the industry representatives to have had a strongly positive effect. They are emission standards in Mexico, enforcement of emission standards, and the ensured availability of unleaded gasoline. At this time period, the emissions standards in export market appeared to have effects only to exporting firms.

The globalization and regionalization of the auto sector had a strongly positive effect. While directives from headquarters were not relevant to some, corporate image and goodwill were important to all firms. The availability of imported technology or locally produced technology by multinational firms was pertinent, but its degree of importance varied, primarily depending on the firm's market orientation. Finally, a sector-wide consensus on the proposed regulation mattered significantly.

The domestic legal and institutional framework for industrial and economic activity was also relevant to the industry. The availability of foreign direct investments for expansion and modernization of plants had a positive effect in creating appropriate conditions for technology introduction. Conditions of trade set forth by NAFTA began to be pertinent to many firms by the early 1990s. One firm commented that the change in industrial policy related to liberalization was very important, while another said it had no effect.

In addition, the local capacity for technology adaptation was important, including local research and development. The managerial capacity within the auto sector as well as the availability of locally trained workforce had positive effects in creating appropriate conditions for technology introduction. Many firms allocated significant resources and effort to develop such capacity, as discussed earlier in this section.

The rest of the factors defied generalization. The ease of technology incorporation to the assembly process was important to one firm, but not to another. The perceived importance of ambient air quality standards differed, also. One firm said that the standards were extremely important while another commented that the influence of ambient air quality standards was indirect, as ambient standards include other sources of

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[87] The following firms are operating in Mexico: Arvin Exhaust (packager), Bosal International (packager), CarSound (packager), Cartec (packager), Equipo Industrial Automoriz (packager), PEASA (packager), Tenneco Automotive (packager), Allied Signal Environmental Catalyst (catalyst manufacturer). CarSound and Engelhard also export their products to Mexico (MECA, 2000).

emissions. The link of ambient standards and *Hoy No Circula*, on the other hand, was recognized, but was considered limited to compel firms to introduce catalyst control.

Factors with No Effects

Demand for cleaner vehicles in Mexico and exporting countries had no effect on the technology introduction, as firms did not think that environmental attributes influenced consumer demand. While the cost increase associated with catalysts was a concern for all firms, they recognized that the requirement affected all firms, and did not give any market advantage to a particular firm. The concern for discrepancy in technology access and capability was addressed by the two-year interim period. Technology availability from Mexican firms did not matter to firms, as long as they were available imported or from multinational suppliers. Bilateral and multilateral assistance had no influence on the automobile sector. Finally, firms did not think that strategic change at the firm level for specialization, or industry's response related to administrative changes had any effect.

Factors with Negative Effects

Several respondents were critical of the institutional capacity of government agencies, which may have prolonged or hindered the negotiation process. Some firms stated that the lack of availability of technology in Mexico had a profoundly negative effect on the technology introduction. Many interviewees indicated, explicitly or implicitly, that the conflicting influence between industrial and environmental policies had a negative effect on the technology adoption, resulting in a compromise to accommodate firms that were more profoundly affected than others.

All firms responded that the new vehicle tax, ISAN, and the value added tax, IVA, had a strongly negative effect on the technology introduction. The automakers felt that both taxes increased the out of pocket consumer cost, which made it more difficult to incorporate technologies that required price increase. They also felt that both schemes slowed down the vehicle turnover, while the Secretariat of Finance felt that the tax impact on the turnover was not as significant as the industry has stated. The automobile sector has continued to raise the taxation scheme as one of the key culprits for delaying vehicle turnover and slowing consumer demand.

Technology Implementation

When vehicles with catalytic converters became available, the concern for catalyst poisoning by lead emerged. While the adoption of different nozzle shapes had virtually eliminated the possibility of inadvertent miss-fueling at gas stations, leaded fuel remained less expensive than the unleaded fuel, creating a perverse price incentive for consumers to use leaded gasoline, as shown in Figure 13. The price difference between leaded and unleaded gasoline was 14% in 1991, and 9% in 1992. To minimize the negative incentive for leaded gasoline, PEMEX lowered the price difference between the two fuels. By 1996, the price difference was almost nonexistent at 3%.

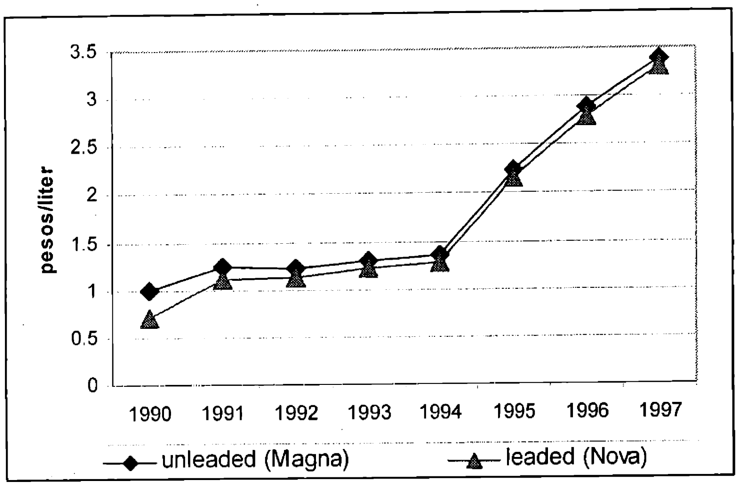

Figure 13: Mexican gasoline price trend (1997 pesos/liter)
(PEMEX, 1998)

Section 5.3: Case II—Tier 1 vehicles (1999)

5.3.1 Background

Technology Description

Tier 1 vehicles refer to vehicles that meet the emission standards that originally became effective in the United States from the 1994 model year, as stipulated in the 1990 Clean Air Act Amendment. The Tier 1 standards were implemented to achieve a 40% reduction in NO_x, and 24% reduction in hydrocarbons from the previous standards. Evaporative emission standards were also tightened, requiring automobile manufacturers to reduce vehicle emissions resulting from fuel evaporation (Faiz, Weaver et al., 1996).

The Tier 1 standards also were intended to close loopholes that existed in emission control in the Tier 0 standards. The loopholes included the extremely high emissions for short periods caused by high loads on engine, such as acceleration and air conditioner operations, as well as high in-use emissions associated with malfunction and failure of emission controls. While the Tier 1 standard levels were based on the performance of electrically heated catalysts, different manufacturers met standards with various technologies. Examples of technology improvements include more precise fuel control, using port fuel injection rather than carburetors, and catalysts with incremental improvements that can be placed closer to the engine to faster warm-up (Wenzel and Ross, 1999).[88]

Initial Conditions

The Mexican federal environmental authorities began to debate the introduction of more stringent new vehicle emission standards with the automobile sector around 1997. The efforts to tighten the standards came from the recognition of still lax emission standards and stagnating air quality trends. The standards implemented in 1993 were essentially equivalent to US standards as of 1980, with some key differences. While the gap between the US and Mexico, measured in terms of years between the equivalent standard introduction in the two nations, decreased from 23 years with the catalyst case to 13 years, the Mexican standards were still lagging behind the US standards. The air quality indicators, as described in Chapter 3, showed that while the concentrations of some pollutants stabilized during the 1990s, standard violations were still rampant. This meant that while the introduction of the catalytic converters did minimize pollution from new vehicles, additional measures were still necessary.

5.3.2 Influencing Factors and Negotiation Process

Technology Attributes and Conditions

The technology attributes and conditions for the Tier 1 case were not as critical as the catalyst case, primarily because the fuel quality had improved since the early 1990s. The cost, also, was less of an issue than the Tier 1 case.

<u>Fuel quality and availability</u>

Similar to the catalytic converter case, Tier 1 vehicles are sensitive to fuel quality, and require unleaded gasoline, preferably with low sulfur. The level of sulfur sensitivity of Tier 1 vehicles, however, is far less than the sensitivity of more advanced technologies. The phase-out of leaded gasoline was completed in the MCMA by 1997, and nation-wide in 1998, thereby eliminating the concern for catalyst lead poisoning.

<u>Cost Implications</u>

The introduction of Tier 1 technologies was estimated to increase the vehicle price by US$100, according to the regulatory impact assessment conducted by INE. INE also determined that only 42% of production would incur the cost increase, as the rest already met the established limits. The technology cost was estimated to be approximately 0.5% to 1.5% of the vehicle price, depending on the model. Domestic low-cost models had higher percentages, as the prices were lower than other models (INE, 1999).

Environmental Institutions

Throughout the 1990s, the environmental institutions at the federal, state, and local levels continued to gain strength in human and technical capability. The automobile sector was

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[88] The reduction of in-use emissions was partially addressed by OBD, which is described in more detail in the next section.

more willing to cooperate with the authorities, compared to the negotiations for the catalyst implementation.

Institutional Strength and Capacity

At the federal level, the Secretariat of Environment, Natural Resources, and Fisheries (SEMARNAP) was established in 1994, as described in Chapter 3. With the establishment of the National Ecological Institute (INE) and Federal Attorney for Environmental Protection (PROFEPA), the environmental authorities were further strengthened for standard formulation as well as enforcement.

The financial commitment to the environmental authorities was relatively high, as shown in Table 29. The allocation of financial resources to SEMARNAP as the share of GDP indicates that Mexico has allocated two to three times the amount allocated in the US and Canada in the mid to late 1990s, as shown in Table 29. Measured in per capita expenditure, the Mexican allocation is one-half to one-third of the US allocations, and two-thirds of the Canadian per capita expenditures.

At the local level, the authorities began to build their quantitative and analytical capacity, which enabled them to collect and analyze air pollution data. Such analysis increasingly allowed them to evaluate the issues, and to make policy decisions based on such evaluation. The 1994-95 emissions inventory yielded evidence that transportation sources accounted for a large share of NO_x, CO, and hydrocarbon emissions.

Table 29: Resource allocation to environmental agencies from 1995 to 1999

	Mexico			US			Canada		
	Amount (US$mil)	Per capita (US$/pp)	GDP Share (%)	Amount (US$mil)	Per capita ($/pp)	GDP Share (%)	Amount (US$mil)	Per capita ($/pp)	GDP Share (%)
1995	n.a.	n.a.	n.a.	7,558	29	0.08	474	16	0.08
1996	949	10	0.3	6,281	24	0.1	426	14	0.07
1997	1,162	12	0.29	6,779	25	0.08	386	13	0.06
1998	1,371	13	0.33	7,361	27	0.08	425	14	0.07
1999	880	9	0.18	7,771	28	0.08	414	14	0.07

(Hufbauer, Esty et al., 2000, World Bank, 2000)

At the metropolitan level, the Metropolitan Environmental Commission (CAM) was established in 1996. The CAM adopted the Comprehensive Air Quality Improvement Program, referred to as the 1995 – 2000 PROAIRE, in 1996. The 1995 – 2000 PROAIRE contained various measures for vehicular air pollution mitigation. One of such measures had the objective of obligatory introduction of cars that use reformulated gasoline, alternative fuels, as well as zero-emission vehicles in the national market. INE was designated to coordinate with SECOFI to discuss with the auto sector to set emission standards to reflect advanced in technologies in the global level and the availability of new fuel in Mexico (CAM, 1996)

The discussions for the Tier 1 technology introduction took place within the framework of the Metropolitan Commission (CAM), with the involvement of federal, state, and local environmental authorities and the industry. The involvement of the federal authorities was necessary, as new vehicle standards fall under their jurisdiction. The federal authorities were willing to provide an incentive of exemptions of new vehicles from inspection requirements to the auto sector to facilitate the earlier phase in of the Tier 1 technology. As the inspection programs for in-use vehicles fall under the jurisdiction of state and local governments, their involvement and support was critical. The CAM was involved as a coordinating body of metropolitan-wide programs, including *Hoy No Circula* and inspection and maintenance programs. Its mandate also included providing support to measures that mitigate air pollution in the metropolitan area.

External Environmental Policy

The external environmental policy, particularly in the US, profoundly influenced the Mexican environmental policy making for the introduction of the Tier 1 technology. The Tier 1 standards spurred technology adaptation and innovation in emission control equipment and engines in the US, as discussed earlier. Because the Tier 1 standard implementation in the US began in 1994, the technology availability and stability was well established by the late 1990s. The Mexican standards were a delayed implementation of US standard with some key differences, benefiting from the availability of technology development and demonstrated effectiveness in the US.

Economic Institutions

Economic and industrial institutions moved towards regional integration of industry and trade liberalization during the mid to late 1990s. The most prominent institutional framework that changed the course of policy formulation was the North American Free Trade Agreement (NAFTA), which went into effect in 1994. With NAFTA, many of the trade and industrial policies that had been used in Mexico, such as the local content requirement and import restrictions of new cars, were given explicit schedules to be phased out. The formulation and application of independent policy options to influence the automobile industry that are specific to Mexico began to be phased out in earnest with the NAFTA, as described in Appendix A (Studer-Noguez, 1999). The Secretariat of Economy (SE) revised the latest Automobile Decree in 1995, to be phased out by 2004.

During this period, SE was increasingly moving away from independent policy formulation, and placed more emphasis on ensuring that new regulations and policies were in line with NAFTA. SE's main concern was to avoid creating technical barriers to trade. Many interviewees stated that NAFTA has become the de-facto economic and trade policy of Mexico, and the role of SE is as an enforcer of rules. SE's retreat from direct policy interventions and increased involvement as an observer/examiner of standard compliance has also led to the standardization of procedures for standard setting.

The standard-setting and rule-making procedure was formalized as a new law on methodology and standardization, or *Ley Federal Metodología y Normalización* in 1992. With this law, the process of public consultation and consensus-based regulation became officially accepted. SE has been assigned responsibility to review all regulations and standards proposed by various government agencies.

The exact degree and nature of SE's involvement in the Tier 1 standard formulation remain somewhat unclear. On the one hand, some interviewees commented that the involvement of SE decreased during the 1990s, others stated that SE had substantial influence and voice in minimizing potential negative economic effect on the auto industry. One interviewee commented that it would have been impossible politically to require Tier 1 implementation as of 1999. In any case, it is true that SE had more formal oversight over the standard setting procedure than when the catalyst implementation was being discussed.

Technological Capability in Industry

The variation in technological capability among the automobile sector decreased throughout the 1990s, due to the increased regionalization of the auto sector that resulted in the creation of new manufacturing facilities as well as upgrading of older facilities at the local level, profoundly influencing the characteristics of the local sector.

Global Auto Sector Characteristics

The global auto sector exerted greater influence on the development of the Mexican auto sector. Firms were able to establish manufacturing capacity in Mexico for regional production, rather than for the domestic market. This is described in more detail in section on the local auto sector characteristics below.

Directives for proactive environmental improvement were becoming more evident, and global headquarters increasingly supported investment decisions and business practices that were less environmentally damaging or pro-environmental, according to some firm representatives.

Local Auto Sector Characteristics

The Mexican automobile sector experienced significant growth in the 1990s to the early 2000s, facing a phase-out of new vehicle importation ban from 2004 and full market liberalization. The sector experienced domestic market growth, increased production, different product destinations, as well as a substantial increase in vehicle imports.[89]

The integration of the Mexican sector into the North American market continued, as evidenced by the volume of total production, as well as in export and import records. The sector production volume almost doubled between 1994 and 2001, from 1.1 million vehicles in 1994 to 1.8 million vehicles by 2001. The sector average figure for export increased significantly from 52% in 1994 to 76% in 2000 and 2001. Approximately 1.4

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[89] The import ban on used vehicles will be phased out from 2009 over 10 years as stipulated by NAFTA.

million vehicles were exported in 2001, predominantly to the US. Company differences in export destinations remained in place (AMIA, 2002b, AMIA, 2001).

The domestic vehicle demand increased steadily after the currency crisis of 1994 and 1995. The 2001 sales reached approximately 917,000 vehicles, compared to slightly less than 600,000 vehicles sold in 1994, and only 185,000 vehicles in 1995. The average annual growth rate of vehicle sales between 1997 and 2001 was 23%, based on sales data reported by AMIA (AMIA, 2002b). In fact, the growth in the domestic market was not a significant factor in the increase in the sector production, as the number of domestically produced vehicles sold in Mexico has stagnated at around 425,000 vehicles per year since 1998, and has not exceeded the 1993 performance of 522,000 vehicles. Thus, the expansion of domestic production capability can be attributed largely to the export market, as a result of the regionalization of the sector.

With the phase-out of import restrictions stipulated by NAFTA, the percentage of imported vehicles in the domestic sales increased drastically. The share of imported vehicles for the domestic market increased from 13% in 1994 to approximately 50% by 2001. They were imported from the US, Japan, Europe, and Latin America. The number of models available also increased, with an influx of US and international models. In addition to the five original firms, three additional companies established manufacturing operations in Mexico. Vehicles from seven other brands became available in Mexico as imports. Table 30 summarizes the entry of these firms and models into the Mexican market. While the market shares of these new models are still quite small, they have grown from 2% in 1997 to 7% by 2001 (AMIA, 2002b, AMIA, 2002c).

Table 30: Entry of firms and vehicle makes into the Mexican market

	Manufacturing in Mexico	Model Availability
1995	BMW, Honda	
1996		Peugeot, Porsche
1997		Audi
1998		Jaguar (Ford)
1999		Volvo (Ford), Seat
2000		
2001	Renault	Land Rover (Ford)

(AMIA, 2002c, AMIA, 2002b)

The NAFTA rules of origin provide de-facto privileged access to North American market for American producers and special protection against non-North American producers. Additional firms began establishing manufacturing operations in Mexico primarily to meet the rules of origin regulation to avoid tariffs.

With the drastic increase in the volume of exports, the capacity to build cars that met the emission standards in the export markets was definitely established. However, there still existed emission discrepancies in similar models offered in the US and Mexico. In one case during the mid-1990s, the authorities became aware that one luxury model manufactured in Mexico had higher emissions in Mexico than in the export markets. This model was being sold at approximately the same price before tax in both countries despite the emission differences, according to the environmental authorities. The high emission level of the domestic model compelled the authorities to deny the granting of the 0 sticker in the inspection, which meant that the vehicles were subject to driving restrictions under *Hoy No Circula.*[90] The authorities believed that customers for such high-end models could very well afford to pay for better technologies. After much negative publicity, this particular model was equipped with more sophisticated technologies, and passed the inspection to get the 0 sticker. From the perspective of the manufacturer, the firm was facing capacity constraints in an older Mexican plant that assembled this particular model, and was in the process of establishing a new manufacturing plant to replace the older plant. The establishment of the newer manufacturing facility, which was established to concentrate the North American production, facilitated the introduction of cleaner vehicles in Mexico (Paxman, 1993).

Conflicting Policies and Barriers

Compared to the catalytic converter case, the degree of policy conflicts and inconsistencies was much less. The vehicle price control system was abolished by the mid 1990s. The gap in technology access as well technological capability was much minimized, simply by the phase out of import-export control measures, as well as through the regionalization of the Mexican auto production discussed above. The *Auto Popular* program, however, remained very popular. The number of vehicle models offered under this program increased to two, accounting for approximately 30% of total new vehicle sales in the mid 1990s. Because the program did not include environmental goals, the Mexican government missed a large opportunity to introduce cleaner vehicles to a substantial share of the market.

Public Awareness

The public awareness on the environmental issues was still present, but lacked the enthusiasm that it had once generated in the 1980s. So there was no real politicizing of the technology introduction or air pollution mitigation at the time of discussions. One reason is that there was no clearly discernable linkage between the proposed technology and human health, unlike the lead gasoline case. In addition, the public attention on environmental issues has somewhat shifted towards other problems, such as water quality and food safety (Lezama, 2001). This may be due to the fact that the MCMA air quality had improved for some pollutants, and that the number of contingency days has decreased. Again, no consumer demand or market advantage was derived from the provision of cleaner vehicles.

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[90] The inspection and maintenance program, as well as the sticker system for the driving restrictions, is explained in Chapter 3.

5.3.3 Outcomes

Emission Standard Introduction

The new vehicular emission standard (NOM-042-ECOL-1999) went into effect in late 1999. The standard included two maximum emission limits, one for the 1999 and 2000 model years, and another for the model year 2001 and beyond, as summarized in Table 31. The standards for the 1999 and 2000 model years were identical to the previous standard, whereas the standards for 2001 and beyond were equivalent to the US Tier 1 standards. The standard further stated that 1999 and 2000 model year vehicles that meet the standards set for the 2001 and beyond model year vehicles were exempt from inspection and maintenance requirements for 2 years (SEMARNAP, 1999). In essence, SEMARNAT agreed to delay the official Tier 1 standard requirement to 2001, and provided an incentive for the automakers to voluntarily comply with Tier 1 standards earlier.

Table 31: Maximum emission limits for Tier 1 vehicles

	Total HC (g/km)	Non-methane HC (g/km)	CO (g/km)	NO_x (g/km)	Evaporative HC emissions (g/test)
1999 model year	0.25		2.11	0.62	2.0
2001 model year		0.156	2.11	0.25	2.0

(SEMARNAP, 1999)

The incentive of the exemption from the inspection requirement took form of the introduction of the new "double zero" stickers. The 00 stickers entitled the vehicles to be driven seven days of the week, free of *Hoy No Circula* restrictions. The incentive did not incur any financial burden on the inspection and maintenance programs in EdM and DF.[91] The vehicle owners were required to pay the full price for the 00 sticker, equaling four inspection fees. The incentive was the convenience of not having to get the vehicles inspected for 2 years, as well as the exemption from driving restrictions.

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[91] The inspection and maintenance program, which began in 1988, was introduced to reduce emissions generated by in-use vehicles by ensuring maintenance, and to promote vehicle turnover. Each vehicle in the MCMA is subject to biannual inspection. Based on the inspection results, model year, and fuel type, vehicles can obtain exemptions from the *Hoy No Circula* program. The test procedures and emission limit have been set forth at the federal level by SEMARNAP. The program administration is at the local level, ad both EdM and DF support centers in their jurisdictions. The CAM is responsible for coordination. The program has had a number of issues associated with coordination, disparity in administration and monitoring, operational deficiencies, lack of follow-up, as well as theft of certificates and stickers (Gakenheimer, Molina et al., 2002). Efforts are underway to improve the program.

The auto sector responded in large part by voluntarily providing Tier 1 vehicles to the domestic market. The success of the voluntary phase-in of the Tier 1 technology could be attributed to two reasons. The first is that SEMARNAP was able to provide an incentive that was attractive enough to the auto sector and eventually to consumers, in cooperation with local entities.[92] The second reason is that the automobile sector had the manufacturing capacity as well as adequate access to technologies to market vehicles ahead of the legal requirement.

Remaining Issues

While the US standards stipulated the durability requirement (emission warranty) of 80,000 miles, the Mexican standard did not include any in the standard. The auto sector argued that the poor conditions of the road infrastructure, variable gasoline quality, as well as aggressive Mexican driving patterns presented too large a challenge and burden for the sector to be held responsible by itself. The exclusion of the warranty also precluded the implementation of the OBD system, which had also become mandatory in the US as of 1996.

Section 5.4: Case III—On Board Diagnostic System (2002)

5.4.1 Background

Technology Description

The on-board diagnostic system, referred to as OBD, monitors various emission-related vehicle components and systems, and alerts the driver of malfunction or deterioration. The system was initially developed by the US automakers, such as Ford and GM, in the early 1980s as a tool to diagnose emission-related malfunctions from electronic engine control systems. The increasing complexity of electronic engine control systems, which replaced mechanical systems, necessitated the emission malfunction detection system to be more sophisticated (US EPA, 1997).

The first generation of OBD system was available in the US from 1988 to 1995. The second generation of OBD, known as OBD II, has been introduced in the US since 1994 with an expanded monitoring scope and specific performance criteria. OBD II has been required in all light duty vehicles as of 1996 in the US. The OBD III system, which is under development, can report emission status with remote monitoring and reporting (National Research Council, 2001). Unlike other emission standards that are performance based, the OBS standard is prescriptive, as the regulation specifies the technology in detail.

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92 This means that the current inspection scheme in the MCMA, which requires biannual inspections, are perceived by consumers to be enough of inconvenience to attach value to having them exempt.

The on-board computer, or electronic emission control unit, monitors certain powertrain functions and controls various operating parameters to help the vehicle run efficiently with lowest emission levels. The control unit also detects malfunction or deterioration that can affect the vehicle emission levels. The unit controls ignition, engine operating temperature, engine misfire, air injection, exhaust gas recirculation (EGR), catalysts, evaporative systems, fuel system parameters, and other functions (US EPA, 1997). The OBD system is made up of the diagnostic software in the on-board computer, plus various sensors and actuators.

Unlike treatment technologies, the OBD system does not reduce emissions on its own. Instead, the system contributes to emission reduction through monitoring, detection, and alerting the driver more accurately and quickly. When the system detects a problem that could cause emissions to go above 1.5 times the emission standards, a dashboard light that shows "Service Engine Soon" or an engine symbol appears, to inform the driver. It can notify the driver of a problem before he/she notices driving irregularities, preventing elevated levels of exhaust and evaporative emissions. The system can also detect problems that may not be noticeable upon visual inspection, facilitating more prompt and cost-effective repair. Early diagnosis followed by timely repair can often prevent further degradation and malfunction.[93] In addition, car manufacturers have an increased incentive to improve vehicle performance and reliability in order to prevent problems that can lead to OBD detection (US EPA, 1997).[94]

Another advantage is that the system stores information about the problem the vehicle is having, which can be retrieved by the service technician for quick and accurate repair. To utilize the system, service technicians need to be qualified and trained properly, and facilities need to be equipped with diagnostic and repair equipment. The OBD system may be combined with inspection and maintenance programs to provide information for effective maintenance of vehicles (National Research Council, 2001).

Initial Conditions

The Mexican Tier 1 standards that took effect in 1999 left out two key components, compared to the US emission control requirements. They were the OBD requirement and warranty provision.[95] Successful OBD utilization is contingent on the warranty provision to a large part, as the likelihood of consumers seeking repair is much lower if they are financially responsible for the repair. As the auto sector was against the warranty provision for Tier 1 standards, the OBD requirement was also not put in place. So while

[93] For example, a spark plug malfunction, which can cause the engine to misfire, sometimes goes undetected by the driver. With OBD detection of the misfire, the driver can get the spark plug repaired inexpensively. Without OBD detection, the engine misfire can result in catalytic converter degradation, which is more costly to repair (US EPA, 1997).

[94] The NRC has cited work by Grimm, Bremer et al., 1980 and Gumbleton and Bowler, 1982 on the analysis of vehicle reliability improvement by OBD (National Research Council, 2001).

[95] In this section, the phrase OBD generally refers to the OBD II system, unless otherwise specified.

the OBDII system has been required and installed in virtually all vehicles as of 1996 in the US, Mexican vehicles were not required to be equipped with one as of 1999.

Similar to the other two cases, the technology availability in the international market was already demonstrated and therefore was not an issue. Again, extensive vehicle exports to the United States confirmed the availability of technological capability and experience of building cars with the OBD system in some, if not all, of the auto companies in Mexico.

5.4.2 Influencing Factors and Negotiation Process

Technology Attributes and Conditions

The OBD case presented specific requirements to ensure its utilization. In addition, the questions about the fuel quality emerged, similar to the catalyst case. The cost implications are discussed separately later in this section, as the industry response moved the issue beyond technology attributes into the realm of strategic decisions.

Requirements for OBD Utilization

Compared to the other technology cases, the OBD system has additional, more complex technical and human requirements. This is primarily because the OBD system does not reduce emissions on its own and requires follow-up action, unlike the catalytic converters. The first requirement is that the driver must take the vehicle in for a checkup and repair when the indicator light goes on. Drivers are more likely to take the car in for repair if the vehicle is still under warranty, and if the driver is aware of the warranty provisions. As such, a significant effort is necessary to inform the consumers about the OBD system, its merits, and vehicle warranty provisions. Second, the repair service sector needs adequate technical and human capacity to take advantage of the system's monitoring information, including computers to read the information off the on-board system. Also, the installation of the OBD system is rather complex, requiring more sophisticated labor and skills in the automobile assembly compared to the other two cases of technologies.

A technical issue that has generated considerable debate in the US is the appropriateness of the OBD use in a testing program for inspection and maintenance, which has been required to be phased in as of 2002 in the US. Recent analyses have indicated that the use of OBD may result in the rejection of a larger percentage of vehicles that meet the emission standards set forth in the inspection and maintenance programs. The OBD indicator light currently goes on when the system detects a problem that could result in emissions to go above 1.5 times the vehicle certification standard. Studies have shown that most OBDII failing vehicles had actual emissions less than 1.5 times the certification standard, as the problem that trigged the light may have been intermittent, or did not generate emissions above 1.5 times the standard. In addition, many current inspection programs in the US have emission threshold levels that are much than 1.5 times the certification standard. Based on these observations, the US National Research Council recommended an independent evaluation on the effectiveness in terms of emissions and cost of OBD II testing for inspection and maintenance programs (National Research Council, 2000).

Fuel Quality and Availability

Similar to the catalytic converter case, the provision of adequate fuel was a critical issue for the technology introduction, although the OBD system introduction does not explicitly require fuel quality improvement per se. That being said, the automakers were very much concerned with the availability of low sulfur fuel in the future, as the OBD agreement included other commitments for advanced technology introduction by the auto sector. However, the agreement did not include PEMEX. Two reasons for the auto sector concern may be speculated. The first reason is that the indecision on gasoline availability increases the uncertainty associated with the technology introduction for the auto sector. The advanced technology introduction is contingent upon the phase-in of low sulfur gasoline, as the sophisticated emission systems can be damaged by sulfur in the fuel. If the major objective of the agreement were to minimize policy uncertainty, the auto sector would have a strong incentive to pressure and convince PEMEX to commit to the provision of low sulfur gasoline. The second is that the auto companies have committed to the emission warranty provision, which could potentially make them liable for repairs for damage to emission systems caused by high sulfur gasoline.

PEMEX did not sign the voluntary agreement, based on their environmental, financial, and technical analyses. While they have agreed to provide some low sulfur gasoline, the actual concentration as well as the scope of availability had not been decided as of early 2002. PEMEX has argued that an aggressive phase-in of very low sulfur gasoline is not cost effective in reducing emissions. Also, the lead-time needed for plant modernization to provide low sulfur fuel can be long, 3 years or more, according to IMP officials. As a consequence, the low sulfur gasoline provision at an early date may force PEMEX to rely more on low sulfur gasoline importation, similar to the unleaded fuel provision.

Technological Capability

By the late 1990s, there remained very little variation in the level of technological capability among the auto sector in Mexico.

Global and Local Auto Sector Characteristics

One notable difference between the catalyst case and OBD was the level of voluntary technology implementation in cars sold in Mexico. Many vehicles sold in Mexico had already been equipped with OBD when the discussions for the phase-in began.[96] Some firm differences did exist in the rate of OBD installation. The reasons for some firms to sell vehicles equipped with OBD II in Mexico are described in the section on Cost Implications. One firm began to install OBD in 100% of vehicles sold in Mexico, both imported and domestically produced, as of 1995. This firm began to export vehicles with OBD as of 1998, 100% with OBD. The OBD system has been 100% imported. Another (export oriented) firm began selling OBD-equipped vehicles as soon as they became available in the US, from 1994 or 1995. Another firm, which is more domestically oriented, indicated that approximately 40% of their OBD parts is imported, and the rest is

[96] The sale of OBD-equipped vehicles without requirement is consistent and somewhat expected, similar to the need for computer control in vehicles that led to voluntary installation of OBD in GM and Ford cars in the 1980s in the US.

obtained from Mexican or multinational firms with manufacturing facilities in Mexico. Not all vehicles from two other (domestically-oriented) firms were equipped with OBD as of 2001, although the approximate percentage was not provided. For one of the domestically oriented firms, imported models have had more or less the same specifications as the US models and equipped with OBD II. The domestic models were undergoing upgrades to be equipped with OBD as of 2001.

While there were firm differences in the percentage of vehicles equipped with OBD and the technology source, the gap in technology access and capacity, so pervasive in the 1980s, was no longer a significant issue that warranted sector-wide opposition.

Similar to the Tier 1 case, the involvement of global headquarters was strong and positive, following an increasing integration of Mexican operations into the global and regional sector structures. One firm indicated that the three areas where the global headquarters had significant participation in the OBD implementation were the evaluation of the firm position, the decision to agree to install OBD, and determination of the supplier sources. The global headquarters were also involved, albeit slightly, with interacting with other firms to determine the sector position in Mexico. They were not involved in financing decisions, nor were they involved in determining the vehicle destinations. This may be because this firm had already equipped 100% of their cars with OBD by 1995.

Cost Implications

The introduction of OBD did require some production line improvements as well as technology costs. For example, one domestically oriented firm installed diagnostic equipment in production lines between 1994 and 1995, with US$6 million investments. Sensors and equipment were approximately US$100 additional per vehicle. This firm also stated that it conducted in-house training sessions of engineers and workers related to OBD.

<u>Leveling the Playing Field</u>

Costs associated with the OBD introduction were an important factor, but its importance differed from the catalyst case. First, the increase in the imported vehicles from the US meant that many vehicles came to Mexico already equipped with the technology. An increasing number of cars produced in Mexico for export to the US also came equipped with OBD. Unlike the catalytic converters, the OBD system is very much integrated into the engine and exhaust system with various sensors. It cannot be easily removed once installed to save on the technology cost. Due to these factors, the auto firms that sold cars with OBD did not choose to remove them or sell cars without OBD. Instead, these firms sought to "level the playing field" by requiring all firms to install OBD.

<u>Competitive Advantage of Regulation</u>

One firm recognized the advantage of regulation as not only to level the playing field, but also to provide advantages to firms that have superior environmental performance (Porter and van der Linde, 1995). This firm, which began importing OBD-equipped vehicles in 1994, convened a meeting with officials from the federal environmental authorities to demonstrate that the company was voluntarily incorporating state of the art technologies despite cost increases and possible resulting loss of market share. In return for superior environmental performance, this company requested the authorities to introduce incentives for cleaner vehicles, such as granting an exemption for *Hoy No Circula*, or providing tax credits. The proposal had been presented to the local government, but was rejected as it was seen as an elitist measure, according to the firm representative.

The federal environmental authorities studied the proposal, and then discussed with other automakers, which opposed it. The industry association felt that it was not in the interest of the industry as a whole to introduce incentives that reward some models and firms, and not others. Such action could undermine the lobbying effort done on behalf of the industry, and fragment the industry position. In the end, the federal authorities decided not to introduce incentives as proposed. Instead, the auto sector and authorities reached a voluntary agreement with incentives at a later date, as described in the following section. The firm representative still believes that the original proposal would have generated more environmental benefit than the agreement that the sector reached later in 2000. He explained that the incentives included in the agreement (i.e., exemption from inspection for 2 years with 00 stickers) could be granted without having all the advanced technologies, as the inspection emission standards much less stringent than the OBD potential.

Vehicle Financing Opportunities

Access to credit is thought by many to be a key factor in increasing vehicle demand and turnover. The concern for price increase and its effect on reduced demand has been somewhat alleviated by an increasing availability of vehicle financing opportunities. While still limited, financing schemes for new vehicle purchasing are now offered by dealerships, sponsored by auto firms. Financial institutions have also begun to provide auto loans. Leasing, which appears to have influenced the vehicle turnover in the US, has not been made available in Mexico.

Environmental Authorities

As mentioned in the Tier 1 technology case, the institutional capacity of environmental authorities at federal and local levels has developed considerably in the past 10 years. The relationship between the auto sector and the authorities was cooperative, albeit cautious.[97]

To reach consensus on the OBD introduction, the auto sector and the authorities sought mutual benefits. The authorities wanted all vehicles sold in Mexico to be equipped not only with OBD, but with other advanced technologies. Fully cognizant of the increasing regional integration of production and vehicle supply, the authorities pursued an agreement on the full introduction of US or European standards in Mexico in a near

97 While many interviewees agreed that the relationship between the auto sector and the environmental authorities has improved, short-term strategizing sometimes threatened to undermine the cooperation. For instance, during the discussions on the agreement, responses from the auto sector sometimes took longer than anticipated. Some in the government attributed this delay to a strategic move by the auto sector to withhold commitment on the technology introduction, in anticipation of an upcoming administration change and possible shift in policy direction.

future. The agreement would require the Mexican auto sector to introduce US or European standards two-years after the original phase-in dates stipulated in the country where the standards are being implemented. In other words, the environmental authorities were moving toward less independent policy formulation, to move towards direct introduction of standards from an export market and/or dominant countries with strong auto sector performance.

The environmental authorities were willing to provide an incentive to the industry to realize this objective. The government offered to extend to the new vehicles an exemption from in-use vehicle inspections for 2 years, which total four inspections. The new vehicles are offered the 00 stickers which make them eligible for *Hoy No Circula* exemptions.[98] In addition to convincing the industry to introduce new technologies, the measure was expected to boost the consumer demand for newer vehicles and replacement of older, more polluting vehicles.

The auto sector, on the other hand, wanted the continuation of the vehicle exemption of inspections as an incentive for consumers to purchase new vehicles. Also, the sector likely deemed that the certainty and consistency of adopting established standards from dominant and/or export countries were preferable over policy uncertainties that have been experienced in Mexico. Indeed, one auto sector representative stated that if the industry is told to adopt new regulations in a planned manner, it could meet them by establishing plans for technological change, production improvements, and other necessary measures. He and others argued that the authorities tend to underestimate the lead-time required by the industry to make changes necessary to adopt standards. They cited several examples of seemingly ad-hoc and hasty policy introduction or changes.

Similar to the Tier 1 case, discussions and eventual agreement took place within the framework of the Metropolitan Commission (CAM), with the involvement of SEMARNAT from the federal level, Secretariat of Ecology from the State of Mexico, and the Secretariat of Environment from the Federal District. The industry was represented by AMIA.

Economic and Industrial Authorities

The involvement of the Secretariat of Economy, or SE, was minimal in the OBD case, as explained in the Tier 1 case.

Contrary to the decreased involvement of SE, *Hacienda* has begun to be more involved in the use of economic instruments for environmental improvements. *Hacienda* has proposed to incorporate environmental criteria into the existing vehicle tax program, called *ISAN Ecologíco*.[99] The original *ISAN* is based on the sales value of vehicles,

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98 The sticker system and *Hoy No Circula* are explained in more detail in Chapter 3.

99 *Hacienda* has also been in charge of the administration of the environmental trust fund, or *Fideicomiso Ambiental del Valle de México*, which was based on a gasoline surcharge as described in Chapter 3. *Fideicomiso Ambiental* stopped the surcharge collection in 1998. The Mexico City Project has made recommendations to restart this trust fund.

ranging from 2 to 10%, with an exemption for *autos populares*. The new proposal intended to promote the introduction of cleaner vehicles with less NO_x emissions by reducing the ad valorem tax and incorporating an environmental tax based on the NO_x emission performance of each vehicle model. The portion of the tax based on NO_x emissions is to increase annually to 90% at the maximum. An official indicated that the rationale from the *Hacienda*'s perspective is based not only for the revenue but also for taxing a luxury good. New cars are bought by citizens in the top 30% income bracket, according to government studies. *Hacienda* has also concluded that *ISAN* plays a very minor role in the new car demand, contrary to the auto sector view, except potentially in the border region. As such, it is a suitable instrument to incorporate environmental criteria to move towards the polluter pays principle, according to the *Hacienda* representative.

The institutional mechanism to deal with environmental issues has been reinforced with the establishment of the Environmental and Legal Affairs Direction in 2001. The environmental expertise has also been strengthened by appointing a former Director General for Environmental Regulations of INE in this division (SHCP, 2001). Through this division, *Hacienda* is moving towards introducing environmental criteria into the tax reform, according to the official.

Policy Inconsistencies

Inconsistencies between industrial and environmental policy had largely diminished by the late 1990s. The only exception was the *Auto Popular* program, which still remained in place as of 2001 but may be phased out in a near future. The program accounted for over 91,000 vehicles sold as of 1998, and 66,000 vehicles in 1999 (SE, 1999). The program accounted for approximately 10% of the total vehicle sales. While the % share has dropped from 30% of during the early 1990s, the number of units sold is not far off from the 1990s. This program continues to present a missed opportunity to promote cleaner vehicles, by not including more stringent environmental criteria in the model certification.

Public Awareness

The level of public awareness and mobilization on environmental issues was similar to the Tier 1 case. Like the other technology cases, the introduction of the OBD system did not result in any market advantages nor did it come out of consumer demand.

5.4.3 Outcomes

Voluntary Agreement on Introduction of OBD and Advanced Technologies

The phase-in of the OBD system and warranty provision took a form of a voluntary agreement, which also included the commitment to introduce advanced emission standards and technologies introduced in the US and Europe. The voluntary agreement, which was signed in November 2000, was reached within the framework of the Metropolitan Environmental Commission (CAM), and signed by AMIA, INE, and State of Mexico government, as well as the DF government. The stated objective of the agreement is to improve new gasoline vehicle emissions from model year 2001, by gradually incorporating technologies that exceed the requirements set forth by emission standards. This agreement is effective for 10 years, can be modified by mutual agreement among the parties. In this agreement, AMIA committed to incorporate OBD system (OBD II, European OBD, or similar systems) as well as durability standard of 80,000 km (50,000 miles) by each firm, following the schedule below:

Table 32: Phase in schedule for OBD and warranties in Mexican automobiles

Model year	2001	2002	2003	2004	2005
Phase-in schedule	Start	20%	40%	60%	100%

AMIA also committed to introduce Tier 2 and Euro IV vehicles, 2 years after the start of their phase-in in the US or the European Union, and to reach full phase-in 2 years after the European or American phase-in has been completed. If the Tier 2 standard was modified and implemented earlier, the Mexican implementation will be adjusted.

In return, the environmental authorities committed to grant the 00 verification certificate to new vehicles. Specifically, the authorities agreed to grant an exemption of vehicle inspection for 2 years (4 inspections) for private passenger vehicles, and for 1 year (2 inspections) for medium and heavy-duty vehicles. The exemption is applicable to all new vehicles that meet the emission limits set forth in the 1999 standards, i.e., Tier 1 standards (CAM-AMIA, 2000).

Why Voluntary Agreement?

Some possible explanations have emerged to explain why the agreement was voluntary, rather than a regulation. According to one industry representative, the timing of the discussion in relation to the administrative calendar influenced the decision to make it voluntary. The agreement was signed in November 2000, one month before the Fox administration came into effect. The environmental agencies were facing a turnover of senior management, and did not have enough time to go through the standard formulation process. The new administration may have had different policy priorities, and could have delayed any action on this matter. The voluntary agreement was therefore a political compromise. Another firm representative thought of the agreement as a preliminary step, which could eventually evolve into a regulation. He felt that the fact that the industry and the government could make a voluntary agreement was positive evidence of progress in the business-government relations. Also, the industry was concerned about the lack of commitment from PEMEX, and would not have agreed to a regulation without the confirmed availability of low sulfur gasoline.

Factors with Positive Effects

Several factors were considered to have had positive effects on the introduction of the OBD systems in the Mexican vehicles. First, external environmental policies, particularly emission and air quality standards set in the dominant countries and export destinations had a profound effect in shaping the technology introduction, as they were harmonized as Mexican environmental policy. The domestic environmental policy also had a strongly positive influence on the technology introduction. In particular, the voluntary agreement established a clear timing and pacing of the technology introduction to which all firms committed. The provision of policy incentives, such as exemptions from the driving restrictions and inspection requirements, helped the industry to commit to the technology introduction. The use of such incentives points to the strengthened domestic policy and institutional frameworks, as well as the capacity of personnel.

The increasing integration of the Mexican operations into the regional and global manufacturing and supply mechanisms has contributed to the availability of technologies as well as manufacturing capability of vehicles with advanced technologies. Trade liberalization has also increased competition and vehicle imports, which in turn increased the willingness of the Mexican sector to introduce technologies.

Factors with No Effects

Current domestic industrial policy besides NAFTA had very little effect on the introduction of OBD and other technologies. In addition, demand for cleaner vehicles in Mexico as well as exporting countries continued to have no effect on the technology introduction. The access to technology and technological capability were not major issues, as most firms had developed technological capability to manufacture vehicles that meet the US requirements. The policy conflict between environmental and domestic policy was minimized, as they both began to phase out independent policy formulations.

Factors with Negative Effects

The lack of clear commitment from PEMEX to provide low sulfur gasoline remains as the major negative factor that could delay or prohibit the introduction of new technologies, which undermine the viability of the voluntary agreement. Two other concerns raised during the negotiation process were the financial load of the auto sector and incremental vehicle price increase. Because the technology introduction is a sector-wide commitment, the financial burden is universal and without any particular market advantage to one firm. As for the financial load of the auto sector, it can be argued that industry had already committed to introduce technologies in the Mexican production facilities prior to the agreement, as a majority of vehicles produced in Mexico already gets exported to the US and Europe, with appropriate technologies. The agreement extends the commitment of the industry to less than half of current Mexican production volume, which is destined for domestic sales and export to Latin American and other countries.

Observations

The case of OBD introduction highlighted changes in the policy formulation strategy of the Mexican government, and the industry response. From the government's perspective, the agreement enforced the tendency towards the harmonization of Mexican standards with standards from dominant countries and export destinations. This tendency also underlies the gradual phasing out of independent polices and regulations on globalized or regionalized sectors, such as the auto sector. Such changes are consistent with the current philosophy of Mexican policymaking, which has evolved from specific interventionist to dissuasion of independent policy formulation, as embodied by NAFTA.

From the industry's perspective, the agreement underlined the industry preference for policy consistency and predictability at the national and regional/global levels. By agreeing to provide advanced technologies that follow the US and European standards for the next 10 years, the industry minimized the possibility of being subject to regulatory requirements specific to Mexico. With the regionalization of production and trade liberalization, the barriers that the industry once faced in technology access and capacity building have been minimized. The firms recognized that the compliance with US standards should not be an issue, as an increasing share of domestic production has been exported to the US, and a large share of imported vehicles has come from the US. The 2-year delay in standard implementation in Mexico is therefore almost like a bonus to allow some firms to incorporate changes to the domestic models, and to benefit from the cost reduction that inherently happens after the initial technology adoption through learning and scale economies.

In addition, firms began to seek competitive advantage of environmental regulation by gaining some incentives for the provision of superior environmental service. The industry also faced an increasing competition in the domestic market with new entrants and more vehicle importation, due to less protection and restrictions. It is possible that the industry sought to minimize product differentiation in environmental performance, which could lead to consumer and regulatory pressure in the future.

Remaining Issues

The voluntary agreement did not address two key aspects of the introduction of advanced technologies. First, while the auto sector committed to the introduction of OBD and warranty, the agreement did not mention how it will be implemented or utilized.[100] There was no mention of whether or how the system will be used in the inspection and maintenance program. It did not mention the training and capacity building of garages, repair and service industries, or the inspection centers. Training activities have been recognized as one of the key components in ensuring the use of the OBD information in vehicle inspections and repair. There was also no mention of public awareness activities on the merit and use of the OBD information. These measures are necessary to realize the advantages of the OBD system, and should be considered further. A government representative explained that one of the primary objectives of the OBD introduction was to get the industry to agree on introducing the state-of-the art technologies in Mexico. He also stated that the federal environmental agencies are in the process of setting up a mechanism to monitor the warranty provision, and determining how to utilize the information generated by the OBD system. He argued that the US experiences of OBD

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[100] The issue of policy implementation has received attention and has generated an extensive body of literature. Wildavsky's seminal work highlighted the necessity of considering actual policy implementation during the policy formulation phase to achieve the policy objectives (Pressman and Wildavsky, 1984).

testing in the inspection programs should be analyzed before Mexico can determine its course. Awareness raising activities will also be organized at a later date.[101]

Second, the agreement failed to include a commitment from PEMEX to provide low sulfur gasoline, which is necessary to introduced Tier 2 and other technologies. The agreement included a phrase in which the authorities and AMIA expressed the need for low sulfur gasoline of 30 ppm for Tier 2 vehicles to reach its optimal emission control (CAM-AMIA, 2000). A government representative commented that the agreement was signed without PEMEX for two reasons. The first reason is that it would not have been possible to convince PEMEX within a reasonable time frame before the administration change that took place. Another reason was that a signed agreement could be a powerful tool to pressure PEMEX into providing low sulfur gasoline. The official also acknowledged that the warranty provision of 80,000 km, or 50,000 miles, is lower than the requirement set forth by the US EPA. This, again, was a compromise, and in his view a reasonable one considering some of the concerns that the auto sector had raised in the past, such as driving patterns and poor infrastructure, have not been resolved fully.

Section 5.5: Summary

5.5.1 Case Study Observations

The case study analysis generated the following observations on the introduction of environmental technologies. In the catalytic converter case, differences in technological capability and technology access at the firm level, as well as fuel quality were important factors that constrained industry's willingness to introduce the technology. These barriers to the implementation largely stemmed from inconsistencies in the objectives of the Mexican environmental and industrial policy instruments, as well as the relative institutional weakness of the environmental authorities.

In the Tier 1 case, increasing regionalization of production and supply minimized the firm level differences in technological capacity, which in turn decreased the barriers as well as the sector resistance to the technology implementation. The strengthened capacity and credibility of the environmental authorities enabled them to offer incentives to the auto sector, which resulted in the voluntary introduction of the technology two years before the more stringent legal requirement went into effect.

In the on-board diagnostic (OBD) system case, the industry accepted a voluntary agreement to introduce the OBD technology and to adopt emission standards two years after their introduction in the US and Europe. This agreement was a strategic move to reduce uncertainty in the regulatory environment, and to maximize the consistency over the ten-year period that the agreement covered. For some firms that sold OBD-equipped vehicles in Mexico since the mid 1990s, the voluntary agreement was a way to level the

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[101] In addition, the environmental authorities are now formulating a proposal to modify the terms of the voluntary agreement to shorten the phase in schedule, and to review the warranty.

playing field by making other firms to supply vehicles with OBD. The regionalization of production and supply, similar to the Tier 1 case, enabled the firms to supply the technology. From the legal and institutional standpoint, trends towards the harmonization of emission standards at the global level with dominant countries as well as export markets contributed to the environmental authorities' decision to move away from independent policy formulation. While the introduction of the OBD technology has not begun yet, it is likely that the industry will start implementation, given the current availability of OBD-equipped vehicles in Mexico.

The analysis also generated several common factors that influence the process of environmental technological change. These factors and process steps are described in more detail in the next chapter, and conceptualized into a model.

5.5.2 Effects of Technology Attribute Differences

One of the reasons for selecting these cases was to evaluate whether differences in technology attributes influenced the process of technological change. The first attribute was the level of complexity of manufacturing and integration into the vehicles. For the catalyst case, the relative ease of technology add-on and removal compelled the industry to remove them from vehicles before the emission standards were established. The OBD system, on the other hand, had multiple sensors and other parts, and was more integrated into the vehicles, which made it more difficult to remove. Imported vehicles and export models were consequently made available in Mexico with the OBD system intact after it became mandatory in the US. Firms that offered vehicles with OBD approached the authorities to gain competitive advantages from superior environmental performance through incentives, and then to level the playing field by having all producers to equip their vehicles with OBD. While other factors clearly impacted the automakers' response, it is likely that the level of technology integration into the vehicle did influence whether the industry would choose to remove the parts to recoup cost, or to seek compensation through other means.

As for the difference in the nature of pollution mitigation, i.e., treatment versus prevention, it was not possible to compare the cases, due to the lack of experience with the actual OBD utilization for pollution prevention. However, it is highly likely that developing countries will require more intensive capacity building of repair and service personnel as well as awareness-raising to utilize the information that the OBD system provides, compared to the US and Europe.

5.5.3 Role of Environmental Policy

The three case studies have shown that environmental policy has been a necessary but not sufficient factor to induce environmental technological change in the Mexican auto sector. Environmental policy determines **pace and timing** of environmental technology introduction. However, environmental policy did not and does not impact the acquisition of technological capability in the sector. Instruments to facilitate technological capability acquisition have been in the realm of industrial policy formulation.

The case studies have illustrated that some environmental technologies had indeed been introduced voluntarily without policy initiatives, due to the increasingly regional/global nature of the sector as well as the technological attributes described above. However, the technology introduction by all firms occurred at specific times, as prescribed by environmental policy. Applications of incentives by the environmental authorities also helped to convince or compel industry to agree on the implementation schedule. Based on these observations, the importance and role of environmental policy cannot be underestimated. This finding is theoretically analyzed further in the next chapter.

5.5.4 Consistency with Previous Research Steps

The case studies revealed the importance of external factors, including global sector characteristics and trade regimes in the introduction of environmental technological change. The relevance of external factors is consistent with the comparative analysis described in Chapter 4, which found foreign direct investments (FDI) was one of the statistically significant factors that positively influencing manufacturing value added in Mexico.

Chapter 6.
Conceptual Model Development

Chapter 5 provided in-depth descriptions of the introduction of specific technologies in the Mexican automobile sector. This chapter synthesizes the information on the three technology case studies presented in Chapter 5 to conceptualize a model that describes the introduction of air pollution mitigation technologies in the Mexican auto sector.

This chapter consists of three sections. Section 1 describes the main process steps of technological change, and factors and their points of influence within the process. The general model is then applied to the three cases in Section 2, and shows how the relative importance of different factors has changed in the three cases. Section 3 presents a review of existing concepts and models based on which my model was developed, and explains similarities and differences.

Section 6.1: Factors and Processes

Conceptualizing a model of technological change for environmental improvement is a challenging task, considering the multitude of factors that influence a complex process. Nevertheless, it is a useful exercise to articulate some of the common factors and process stages in a model. Such model can be applied to explain the technology cases and to show changes in the relative importance of factors and process stages. The model can also be compared with existing concepts of general technological change to identify similarities and differences.

6.1.1 Process Stages

The first stage of the model development was to identify the major process stages of environmental technological change. The theories and concepts of general technological change were reviewed and contrasted with the case study analysis, as discussed in Section 6.3. The following three process stages were identified:

- Legal and institutional framework development
- Technological capability acquisition
- Technology implementation

The process stages are three key building blocks necessary for technological change to occur. Each process contains specific activities, as tabulated below in Table 33. The establishment of legal and institutional framework includes the clarification of objectives and strategies for air pollution mitigation, institutional framework establishment, and policy framework establishment. The legal and institutional framework is divided into two, domestic and external. One key external framework is the North American Free Trade Agreement (NAFTA), which went into effect in 1994, during the case study analysis period. The domestic framework includes the changes in the institutional framework for industrial, economic, and environmental management and legal mandates at the federal, state, and local level, as well as coordination at the metropolitan level.

The second process stage is the acquisition of technological capability necessary to realize the prescribed change, including establishing the production capability, investment capability, as well as adaptation capability. The acquisition of technological capability includes financial, managerial, as well as technical skills. While the classifications of technological capability acquisition found in the literature include innovation capability, it is not explicitly included in this model, as the case studies and quantitative analyses found little evidence of major innovation in the Mexican auto sector. On the other hand, incremental innovations did occur, especially for the catalyst case, to take the altitude effect as well as driving cycles and their influence on vehicular emissions into account. The tangible indicator of technological capability is the installation of environmental technologies in Mexican vehicles, both for domestic and export markets.

Finally, technology implementation refers to the actual phase-in of air pollution mitigation technologies into the vehicle fleet, and focuses on the infrastructure needed to maintain the adequate technical performance of the technology, referred to as technology infrastructure. The technology infrastructure encompasses the provision of adequate fuel, inspection and maintenance services, and repair. The infrastructure development is especially pertinent for the OBD case, as emission reduction with OBD requires both hardware and software, i.e., equipment installation and human capacity development, within the service and repair sector and inspection facilities. The tangible indicator of technology implementation is the emission reduction.

The three process stages are iterative, with considerable feedback among them. For example, technology adaptations may be required during its phase-in schedule to adjust the technology to meet the local conditions. Also, the legal and institutional frameworks may be changed according to enforcement and inspection data generated during the technology implementation phase.

Table 33: Examples of activities in process stages

Legal and Institutional Framework	Technological Capability	Technology Implementation
Objective and strategy clarification Institutional framework establishment Policy framework establishment	Production capability Investment capability Adaptation capability	Technology infrastructure establishment

6.1.2 Factors

The quantitative analyses and the case studies have shown that external factors have played an increasingly significant role in technological capability acquisition in Mexico in the past 20 years. Taking this finding into account, factors that influence environmental technological change are classified into three different categories: domestic, external, and hybrid. Domestic factors refer to factors that are determined within the domestic policy and institutional boundaries. External factors, on the other hand, are largely determined outside domestic policy and institutional boundaries. Both external and domestic forces influence hybrid factors. Some of the factors are related to, and in return influenced by, the formulation and development of the process stages. None of the factors exerts influence on all process stages. Some of the factors are similar to the ones identified for the Mexican electric sector (Norberg-Bohm, 1996), which are described in more detail in Section 6.3.

Domestic Factors

Three domestic factors have been identified as: environmental policy, industrial and economic policy, and domestic sector characteristics.

Environmental Policy

Environmental policy is an important factor for technological change for environmental improvement, though it has not been considered explicitly in the literature on general technological change. Environmental policy sets performance standards, which require vehicle technology options or fuel options for compliance.[102] The introduction of technology may also be stipulated voluntarily, such as voluntary agreements and covenants between the authorities and the industry. In this research context, the catalytic converter case and the Tier 1 vehicle case have been prescribed by emission standards for new vehicles. The OBD case has been implemented through a voluntary agreement between the industry and the environmental authorities. In addition, vehicle inspection programs and driving restriction programs (*Hoy No Circula*) regulate the emission performance and influence the vehicle use and fleet turnover. Such programs have direct impacts on emissions, and act as incentives to the auto sector and consumers. In addition to the emission standards, other environmental policy, such as ambient air quality standards, has contributed to technological change, as described in Chapter 3.

Environmental policy impacts the technology implementation element by specifying the pace and timing of technology introduction. The use of incentives in conjunction with emission standards influences the domestic sector characteristics. Environmental policy, on the other hand, does not directly influence the acquisition of technological capability.[103] This is because environmental policy does not specify or facilitate *how* the industry should invest, develop, and/or adapt necessary technologies to comply with

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[102] In the case of OBD regulation in the US, the standard specifies the use of this particular technology, rather than specifying performance that needs to be achieved.

[103] The link between environmental policy and technological capability acquisition is that environmental policy formulation is informed by the technological capability of the industry.

established standards. Technological capability acquisition has instead been mediated by industrial and economic policies. The impact of environmental policy on innovation has also been minimum, as Mexico has consistently applied technology-following standards. Legal and institutional frameworks profoundly influence environmental policy and vice versa, as described in further detail in Section 6.3.

Industrial and Economic Policy

Technological change improves industrial production and economic growth, as described in Chapter 1. Industrial and economic policy is applied to guide the process of industrial and economic improvement. Specific Mexican industrial and economic policy applications include: foreign direct investment regulations, local content requirement, protection of domestic models and producers, import restrictions on vehicles, parts, and components, export promotion, price control, and people's car program.

These policy instruments guide how the industry acquires domestic technological capability, which is the second process stage. Industrial policy has also been applied to influence the domestic sector characteristics, by controlling and protecting the number of firms and vehicle models. In addition, access to domestic sources of investments and foreign exchange are other important domains of industrial and economic policy. Industrial policy is influenced by changes in both domestic and external legal and institutional frameworks.

Domestic Sector Characteristics

The literature on technology diffusion has identified several factors linked to the sector structure and firm characteristics, such as firm and market size, market share, production orientation (domestic versus export oriented), input and technology prices. In addition to these general factors, firm difference in environmental technology access and rate of technology adoption are considered for this research. The domestic sector characteristics may explain firm differences in technological capability, policy receptiveness, as well technology implementation.

External Factors

Two external factors have been identified as: external environmental policy and global sector characteristics.

External Environmental Policy

The external environmental policy encompasses emission standards in the export destination, as well as emission standards that are considered as dominant at the global level. Within the Mexican context, these standards primarily mean the US and European standards. This is an important factor to consider for two main reasons. The first is that Mexico is now moving towards emission standards that are similar to the US standards, to be implemented with a two-year delay as Mexican standards. The US standards implicitly dictate which types of technologies should be used for compliance in Mexico. These observations indicate that external environmental policy influences domestic environmental policy, as well as technology attributes and characteristics. Another reason is that a larger percentage of vehicles sold in Mexico have been equipped with key US technologies even before the local implementation of US standards. This is due to an increasing number of imported vehicles and regionalization of production, which have been influenced by changes in the external legal and institutional framework.

Global Sector Characteristics

The integration and relative positioning of the Mexican automobile sector within the global sector structure is a relevant factor to consider. The automobile companies currently operating in Mexico are all multinational firms, as there are no Mexican passenger vehicle manufacturers.[104] These firms have been operating in Mexico due to its geographical proximity to supply the North American market, and to manufacture vehicles for the domestic market. Decisions regarding manufacturing locations for various model types, key supplier relationships, investment decisions, production upgrades, as well as strategy formulation for globalization, regionalization, and/or specialization tend to be formulated at the global level, in consultation with the local branches. The corporate headquarters may provide directives that are more environmentally proactive and advanced, compared with decisions that would be made at the national level.[105] Each of these points may influence technological capability building, as well as the actual implementation of technologies. The global sector characteristics also influence the domestic sector characteristics as well as technology attributes and conditions.

Hybrid Factors

Technology Attributes and Conditions

Technology attributes and conditions have both domestic and external characteristics. Due to the technology-following emission standards as well as delayed application of US standards, both the availability and choice of technology have already been established, and thus externally determined. On the other hand, some of the conditions that must be met for technology introduction are domestically determined. One significant example is the quality of gasoline required for the technology introduction, such as unleaded and low sulfur gasoline, and their availability. The level of manufacturing complexity and integration of the environmental technology has influenced the industry response, as well as its negotiation strategy with the authorities. Other factors, such as driving patterns and altitude-related adjustments, influence the performance of environmental technologies and may necessitate technology adaptation, or incremental innovation. Technology attributes and conditions influence the technological capability acquisition and the actual implementation of technologies.

6.1.3 Conceptual Model for Case Analysis

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[104] The heavy truck and bus sector has Mexican manufacturers, such as DINA, Mexicana De Autobuses, and Trailers De Monterrey. This analysis is focused on the passenger vehicle manufacturers.

[105] Such decisions at the global level may be influenced by better access to scientific, technical, and political information, for corporate image, as well as for global compliance of standard environmental requirements.

Figure 14 depicts the general conceptual model of technological change for environmental improvement in the Mexican auto sector. The model incorporates the three process stages and six factors, and their causal linkages and lines of influence. The process stages are shown in hexagons. Domestic factors are shown in oval, and external factors are in rectangles. The hybrid factor is shown in a rectangle with rounded corners. Arrows depict causal linkages and lines of influence, which are accompanied with descriptions that are specific to each case, as explained in the following section. As the model shows, environmental technological change is a complex system, with multiple causalities and lines of influence. The in-depth case study methodology was more suited for articulating such mechanism, as quantitative analytical methods tend to be too aggregated to capture details of factor and process linkages.[106]

[106] Stewart argued that empirical research to explore the multiplicity of causal factors and interactions of technological`change was necessary and valuable contribution to the literature (Stewart, 1984). While such analysis was conducted for general technological change, it has not been done for environmental technological change in a systematic manner.

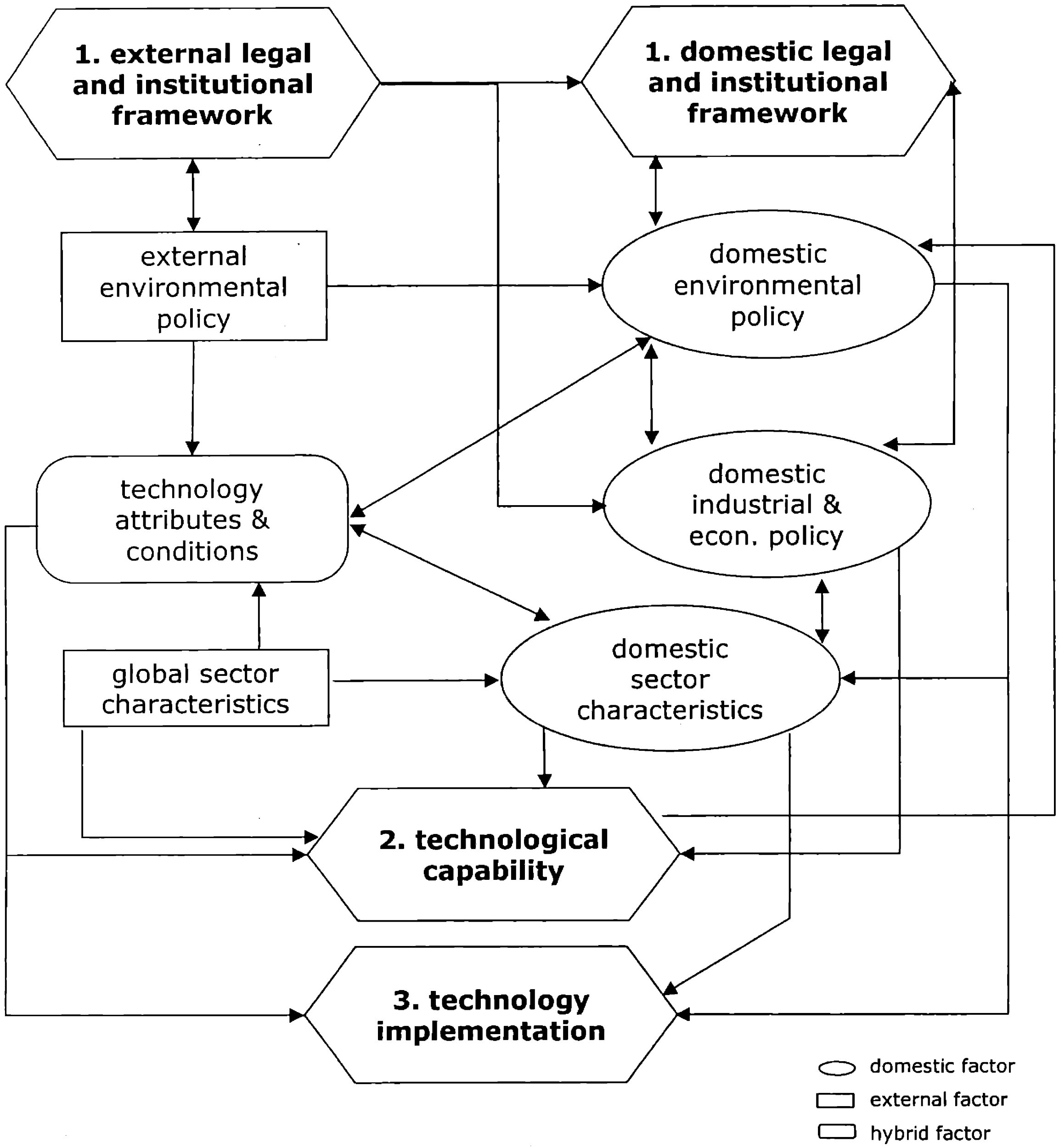

Figure 14: Conceptual model of environmental technological change

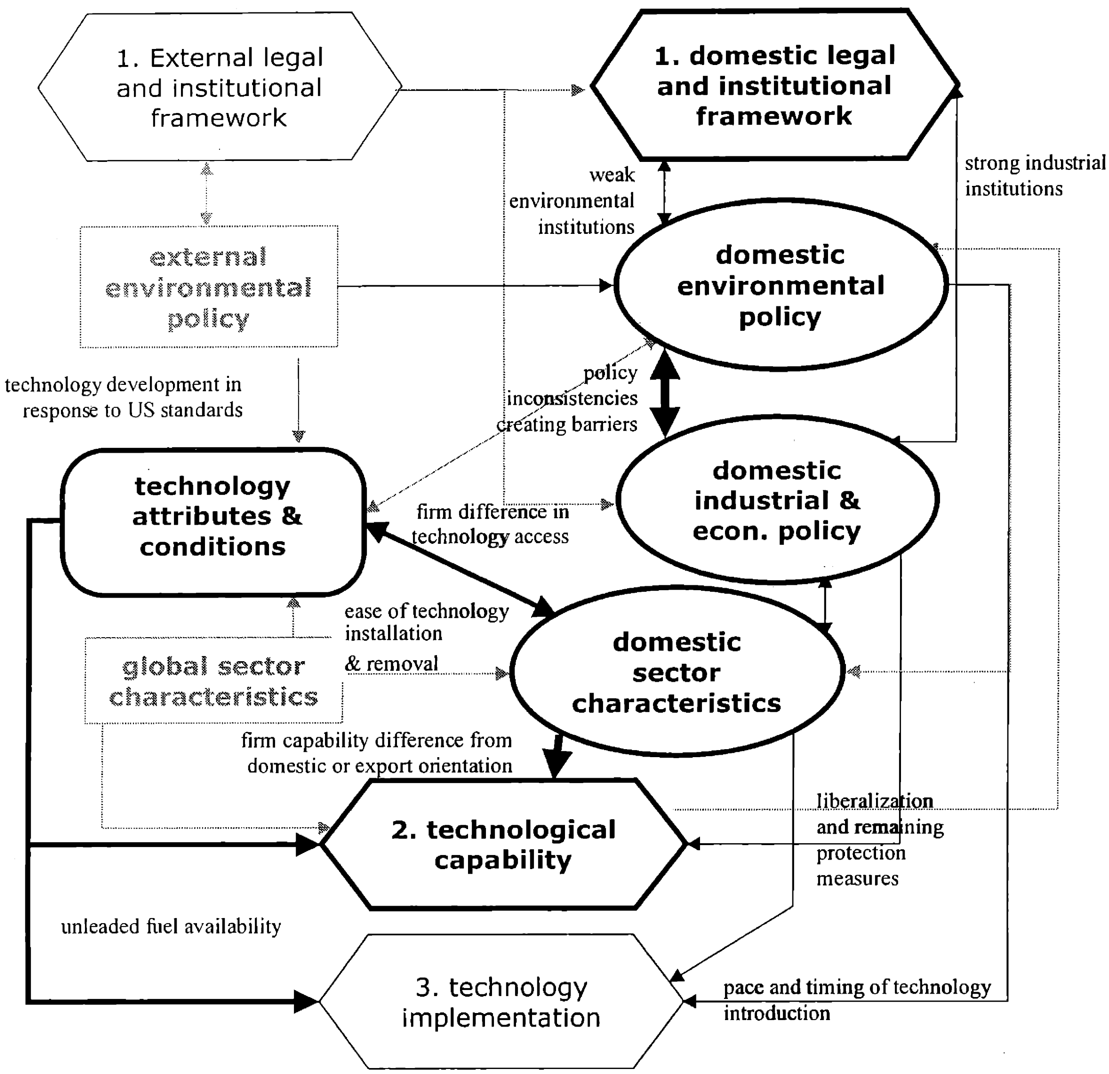

Figure 15: Catalytic converter technology case

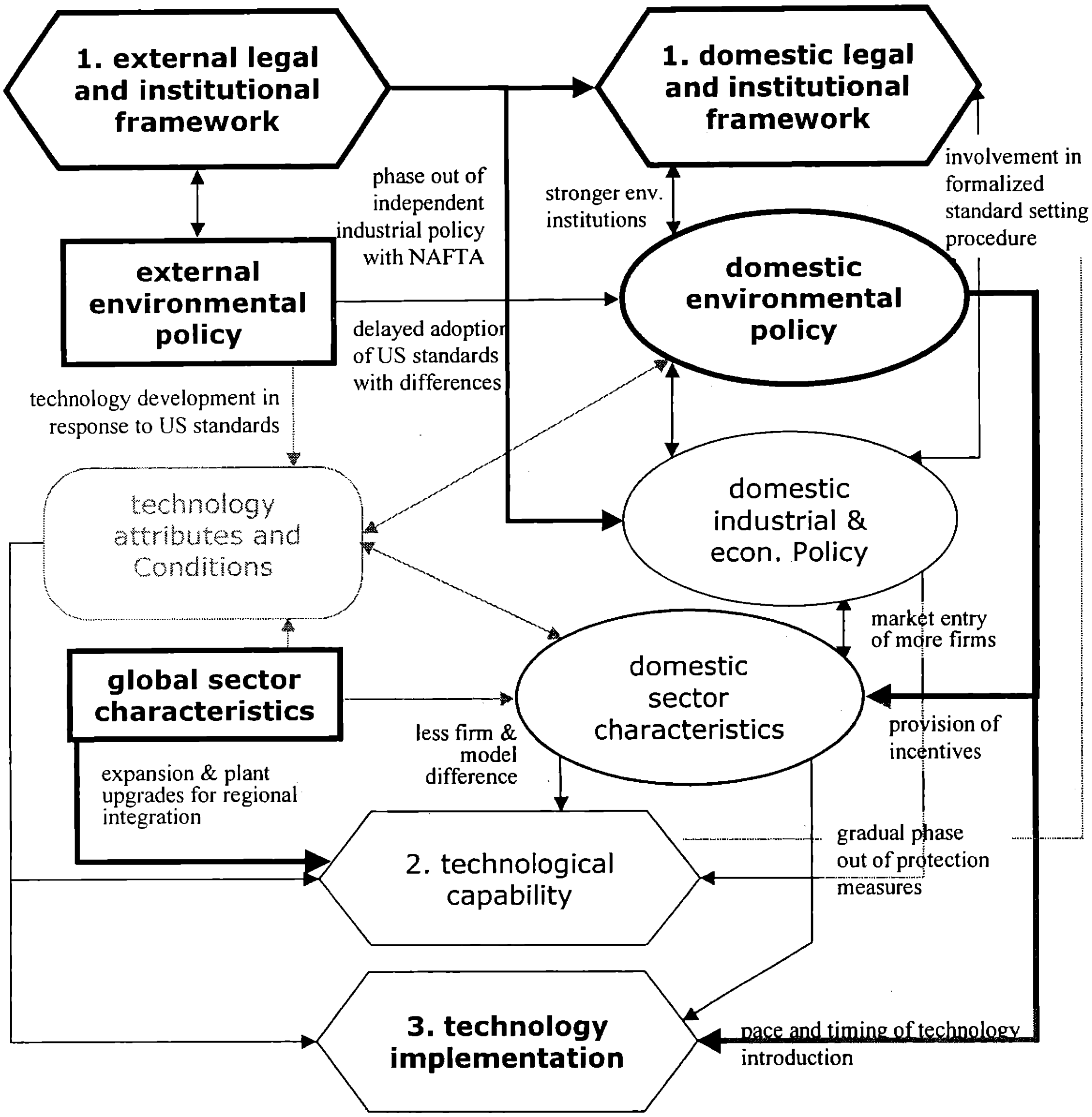

Figure 16: Tier 1 technology case

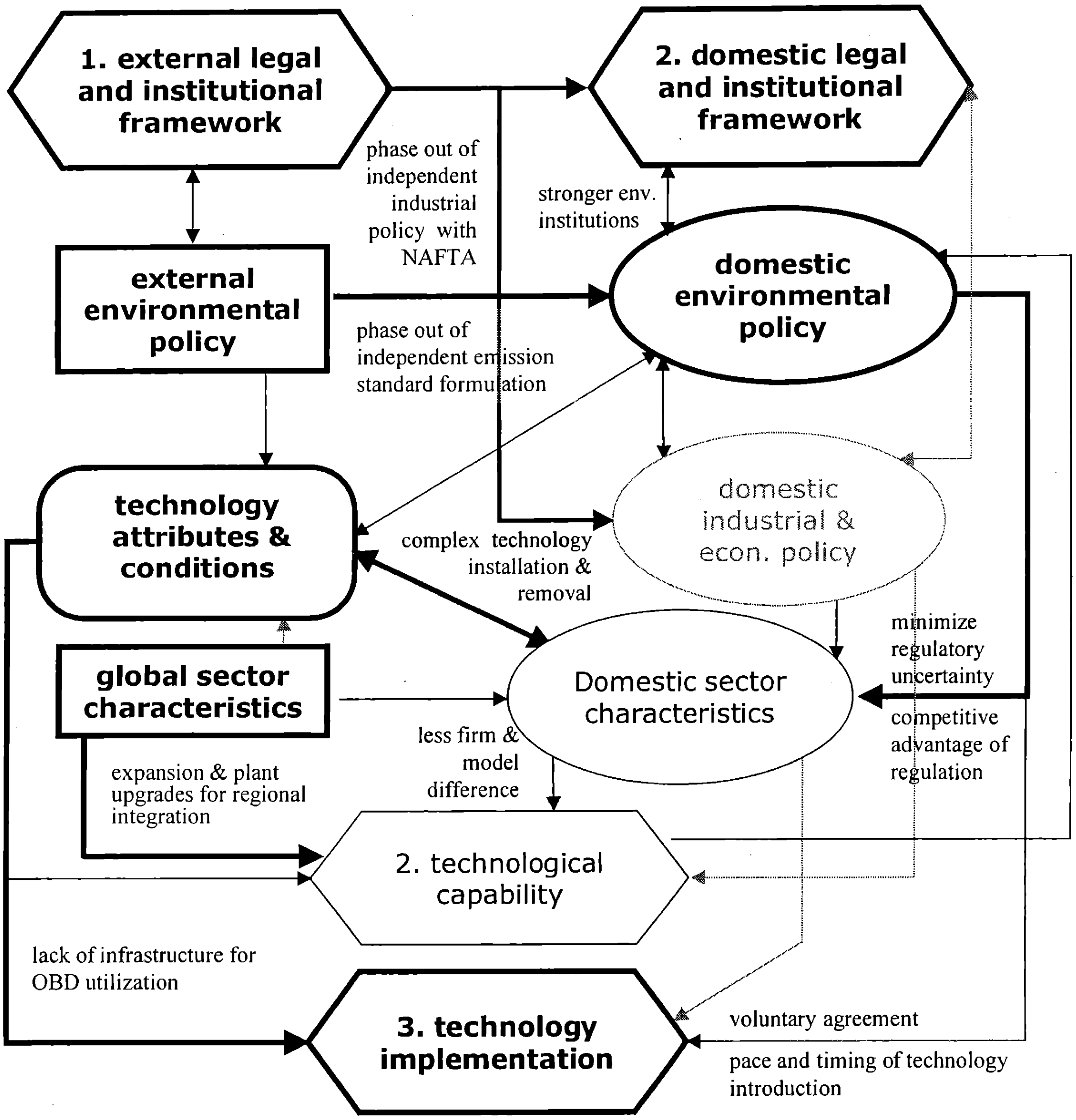

Figure 17: On-board diagnostic system case

Section 6.2: *Model Application to Technology Case Studies*

The next task was to analyze the case studies using the model framework, including specific explanations of how factors influenced the process stages and vice versa. The model provides a useful explanatory or conceptual lens through which to view each of the cases; and allows these cases to be differentiated on the relative strengths and significance of the factors and stages that influenced each technology outcome. The relative importance was shown by the thickness of the process stage and factor boxes, as well as the arrows that connect them. Descriptors with arrows provide specific information pertinent in describing each case.

6.2.1 Case 1—Catalytic Converter

Figure 15 depicts the model application of the catalytic converter case. In this case, two process stages that required most effort and change were establishing the domestic legal and institutional framework, and developing technological capability in the auto sector. The domestic environmental laws and institutions were weak, in contrast to the strong industrial economic policy and institutions with a long history of interactions with the industry. Relevant factors were domestic environmental policy and industrial policy, particularly inconsistencies between them that created barriers to the technology introduction. The domestic sector characteristics were influenced by industrial policy, which created a protected oligopolistic sector structure, and indirectly created a firm level difference in access to imported technology, which was needed to comply with the environmental standard.

The technological attributes, particularly the quality and availability of unleaded fuel, were also important, because they negatively impacted the willingness of the industry to invest in the technological capability. In addition, ensuring the fuel availability at a competitive price was necessary to maintain the integrity of technology implementation, as the emission reduction capacity of the technology was dependent on unleaded fuel utilization. Fuel price adjustments involved the coordination of environmental, economic, and energy institutions and policy.

Domestic factors acted more as constraints than facilitators of environmental technological change in this case. The progression to reach technology implementation took considerable time, as institutional development and technological capability acquisition required significant negotiations and lead-time.

6.2.2 Case 2—Tier 1 Technology

The model application on the Tier 1 technology case is shown as Figure 16. In this case, the external legal and institutional framework, NAFTA in particular, began to have a profound impact, shifting the domestic industrial and economic policy towards liberalization. The domestic legal and institutional framework was equally important, as the institutional strength and credibility enabled the environmental authorities to offer incentives to the auto sector to implement the Tier 1 technology ahead of the legal mandate. Three factors were important in explaining this case. The external environmental policy, particularly in the US, was relevant as the US Tier 1 emission standards were taken as a prototype for the domestic standards, with some differences. Domestic environmental policy was relevant, not only because it set the pace and timing of the technology introduction, but also because policy instruments could be used as incentives for the industry. Also, the global sector characteristics led to the increasing integration of the Mexican sector into the regional manufacturing and supply network, thereby improving the technological capability.

In the Tier 1 case, the factors and process stages of relevance began to shift from domestic to external factors. While the domestic factors were important and reflected domestic concerns, they, too, were increasingly influenced by external factors.

6.2.3 Case 3—On-Board Diagnostic System

The model application for the OBD case is shown in Figure 17. In this case, the external institutional framework was again an important process stage, due to the gradual move away from independent formulation of emission standards towards harmonization with the standards in the dominant export markets. Harmonized emission standards offered policy consistency and minimized uncertainty, which the industry found attractive. Also, the external framework established a regional trade and industrial policy regime, which continued to phase out industry protection measures. The domestic legal and institutional framework was also crucial, as the rapid technological improvements to harmonize with US and European standards require institutional strength for enforcement and management, similar to the American and European authorities. Global sector characteristics continued to influence the domestic sector, as explained in the Tier 1 case. The technological capability acquisition was relatively easily achieved, as the production, project execution, and investment capabilities have been acquired through the integration of the Mexican sector into the regional production network. The OBD system's complexity in installation and removal influenced the firms to seek competitive advantage, and to agree on the sector-wide system implementation. In addition, the link between domestic environmental policy and domestic sector characteristics was important, as the use of policy instruments as incentives to the automakers played an important role in the introduction of this technology.

The technology implementation stage was found particularly pertinent for the OBD case, as the technical infrastructure necessary to utilize the OBD information to achieve emission reduction, such as installation of computers and machinery for OBD information retrieval and use, training of repair and service personnel, and incorporation of OBD information into the inspection program, have not occurred. The emission reduction potential of the OBD system remains unclear, as the technology implementation stage still has not been completed.

6.2.4 Key Observations on Model Application

The model application generated several key observations. First, it showed that the relative importance of factors and process stages differ among the three cases. Specifically, the process has been increasingly influenced by external factors. The domestic factors remain relevant, particularly domestic environmental policy; however, they, too, are under profound influence of external factors.

The impact of environmental policy in the process of environmental technological change has evolved. During the catalyst case, the prevalence of conflicts and inconsistencies with other policy measures delayed the technology implementation. The environmental authorities also had to compromise on interim emission standards. In the Tier 1 case, environmental policy instruments could be used to provide incentives to the auto sector for an earlier introduction of the technology. The environmental authorities had enough credibility and institutional strength to overcome resistance over an earlier legal phase-in date, by providing attractive incentives. In the OBD case, the environmental authorities could convince the auto sector to commit to a 10-year agreement for technology phase-in, by agreeing on a long-term policy consistency with the US and European standards, and minimizing regulatory uncertainty which has concerned the industry in the past. This change in the role of environmental policy can be attributed to institutional development and strengthening of the legal framework for environmental protection. In addition, policy coordination at the federal, state, and local level has been crucial in devising incentives at the local level to implement emission standards and an voluntary agreement at the federal level.

Another important observation of the model application is the limited influence of each factor over the entire process stages as well as other factors. In particular, while environmental policy contributes to build the legal and institutional frameworks and impacts the technology implementation by setting the pace and timing of introduction, it did not, and does not, impact technological capability acquisition. As described in the previous section, this is because technological capability acquisition has remained in the realm of economic and industrial policy applications. Policymakers should be cognizant of the influence and limitations of each factor, and interactions among factors, to minimize policy fragmentation, and to improve policy efficacy in the future.

Section 6.3: Existing Concepts of Technological Change

My model of environmental technological change is based on the theories and concepts of technological change and technological capability acquisition in developing countries. Some key concepts on the three process stages and factors that make up my model are reviewed in this section.

6.3.1 Concepts on Institutional and Legal Framework

Institutions impact technological change by shaping interactions between firms and the government, and among firms, which in turn influence policies and strategies on technology in both public and private sectors. The role of institutions on economic development is a well-studied subject (see North, 1990, Powell and DiMaggio, 1991, Rosenberg and Birdzell, 1986). For developing countries, scholars have highlighted the need to identify market failures that can be ameliorated through non-market institutions, which may involve governments to establish such institutions, and those that could be ameliorated by making markets to work more efficiently (Stiglitz, 1989, Stiglitz, 1994). Within the context of technological change, the role of institutions for human capability development, and the significance of institutional change and planning, particularly in science and technology institutions, to realize technical change have been explored (see Stewart, 1984, Ranis, 1984, King, 1984, Veloso and Soto, 1998). Enos further argued that the creation of technological capability requires the fulfillment of human capacity development in technical matters, establishment of skill-generating institutions, and establishing a common goal towards which technical skills and institutions are geared (Enos, 1991).

The establishment of institutional and legal frameworks is important for environmental technological change, and perhaps more pertinent than general technological change. Because environmental technological change tends to be required by law, the establishment of the framework to develop, analyze, enforce standard as well to provide incentives is a key necessity. The inclusion of the external legal and institutional framework into the model, and separation from the domestic framework, was also considered pertinent, due to the increasingly global and regional nature of the production and sales, facilitated by trade and liberalization. The notion of government intervention in the case of market failure is a well-established one, especially within the context of environmental protection, as described further in later sections, while it remains controversial within the context of industrial development.

6.3.2 Concepts on Technological Capability

My conceptual model incorporated key observations from two subjects that have received much scholarly attention in the developing country context. The first is the acquisition of technological capability. The second is the means by which technologies become available to developing countries. The first subject, technological capability, refers to the capacity to adopt, adapt, and create new technologies. In other words, technological capability is concerned with how to utilize the technology that has been made available at the firm level, through innovation, diffusion, or transfer. The concept, therefore, is a part of the process of technological change, as well as an outcome (Norberg-Bohm, 1996). The theoretical understanding of technological capability acquisition has emerged from empirical research conducted at the firm level, which emerged from dissatisfaction with conventional theories of technology development (Fransman, 1984, Katz, 1984, Lall, 1984, Dahlman, Ross-Larsen et al., 1987; Amsden, 1989).[107] These studies focused on the adoption and adaptation of technology, and identified key types of capability, such as production, investment, and innovation capabilities (Dahlman, Ross-Larsen et al., 1987), or production, project execution, and innovation capabilities (Amsden, 1989). The roles of government and policy interventions that facilitate technological capability acquisition have also been debated in the scholarly arena, as stated in the previous section.

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[107] The emergence of the firm level analysis was due to the limitations in the explanatory power of two dominant theories of technology in development. These theories were dependency theory and neoclassical economics. Inadequacies of the dominant paradigm led to a shift in research focus. Schumpeter's thinking, where technological change plays a dominant role in economic development, had a significant impact on work in the area of technology in developing countries (Fransman, 1984).

In the second subject, the means by which technologies become available to developing countries, scholars have focused on the role of innovation and diffusion (see Sahal, 1981, Minami, Kim et al., 1995). Innovation, as defined by Schumpeter, entails commercial or practical application of a new product or process, while diffusion is the process where by a new technology or technique is adopted over time (Schumpeter, 1935). Technology transfer refers to the diffusion of technology, including the transfer of knowledge, and adaptation of an existing technology to a new use. Technology transfer has been the most important mechanism for technological change in developing countries. Innovation has also played an important role in technological change in developing countries, primarily through technology adaptations, or assimilations, to suit local conditions under which technologies must operate, referred to as incremental innovation (see Nelson and Winter, 1982, Fransman, 1984).[108]

My model formulation incorporated observations from these two areas of research on developing countries. First, the concept of technological capability acquisition was recognized as one of the process stages for environmental technological change. The inclusion of this topic within the process of technological change for environmental technologies was deemed appropriate, for two reasons. The first reason is that in all three cases of environmental technology introduction, firms had to acquire technological capability to introduce the technologies. The second reason is that because environmental policy interventions have not dealt with the actual acquisition of capability, the subject tends to get little, if any, attention in the environmental policy dialogue. As a result, an explicit inclusion of this process is warranted to both reflect the reality and to call attention to its importance in national economic development.

Mexico's technological change has been based on diffusion and incremental innovation, following technology-following standards and agreement. While most firms interviewed responded that local adaptations of technologies were an important factor to ensure successful technology introduction, these adaptations did not progress to full-fledged innovation in Mexico. This finding is consistent with the comparative analyses from Chapter 4, which showed that Mexico's innovation-related parameters were quite low, even compared to other developing countries. As such, the model did not specifically include innovation.

6.3.3 Concepts on Technology Implementation

The issue of implementation has received attention from analyses of efficacy of various government programs. Pressman and Wildavsky's seminal analysis highlighted the necessity of considering the actual implementation during the policy formulation phase to achieve expected policy outcome (Pressman and Wildavsky, 1984). Technology implementation, especially those mandated by policy, may be analyzed within this context.

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[108] In some cases, such technology adaptations led to the emergence of a different technological trajectory from developed countries, leading to the development of new products and processes (Katz, 1984, Lall, 1984).

Technology implementation was incorporated as the third process stage of environmental technological change, so that effects of various factors could be depicted explicitly. Implementation is concerned with achieving policy outcomes as envisioned in the planning process. Within the context of this research, implementation is realized as reduction of pollutant emissions. Functions of this process stage are different and more critical for technological change for products, such as the case of automobiles. This is because the actual implementation of product-based technological change takes place outside the firm, and involves actions of product users, such as vehicle owners. In particular, the OBD case highlighted the need for adequate technology infrastructure to influence the actions of consumers to realize the envisioned emission reduction.

6.3.4 Concepts on Influencing Factors

The factors for the conceptual model were based on various determinants of general technological change from the literature, particularly from the technological capability acquisition literature discussed above. Firm-level studies have articulated the importance of several key determinants, including government policies, technological efforts undertaken at the firm level, market conditions, as well as effects of technological trajectories (Katz, 1984, Dahlman, Ross-Larsen et al., 1987, Amsden, 1989).[109] [110] The literature also delineated a number of indicators of technological capability, many of which were analyzed in Chapter 4. More recent studies highlighted the importance of values and attitudes, physical resources, knowledge and skills, national objectives, political factors, governmental regulations, world competition, macro and microeconomics, institutional structures, markets, inherent possibilities in technology (Girifalco, 1991).

Research on environmental technology implementations has explicitly recognized the importance of policy, and argued for policy development, including direct regulation, economic instruments, procurement, that takes advantage of the "...cumulative and self-reinforcing characteristics of technical change" (Freeman and Soete, 1997). A study of Mexican electric sector identified five determinants of environmental technological change as: domestic policy environment, firm characteristics, international energy and environmental politics, industrial structure, and technology attributes. This model contained three process stages, which are sector policy formation, sectoral planning, and technology implementation (Norberg-Bohm, 1996). Another model was focused on the decision to adopt an environmentally beneficial technology, and incorporated three main

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109 Lall's analysis of technological capability in India focused on three policy fields, namely trade policies, industrial policies, and science and technology policies. His analysis has found that such policies have had both positive and negative effects in building technological capability. On the positive side, a base of industrial technologies has been established as a result of policies towards domestic production and technical efforts. On the negative side, such policies resulted in inefficiency and backwardness, and limited diffusion of capabilities (Lall, 1984).

110 Firm-specific characteristics, macroeconomic parameters that affect firm performance, market conditions, and new technical information emerging from the international technological frontier, were found to be relevant in determining the rate and direction of technological efforts (Katz, 1984).

determinants, namely the system of information transfer, economic and technical characteristics, and the characteristics of adoption environment (Kemp, 1997).

Building on these analyses, my model incorporated six factors. Sector characteristics were divided into domestic and global levels to reflect two different market conditions in which the Mexican auto sector must operate. Industrial and economic policy was also incorporated, based on various studies on the effects of government interventions. Domestic and external environmental policy was both included, based on environmental technological change analyses, and rationale for government interventions to ameliorate market failure for environmental reasons (Norberg-Bohm, 1996, Lall, 1992, Kemp, 1997). In addition, technology attributes, which were considered important from both general and environmental perspectives, and were included.

6.3.5 Key Observations

The review of various concepts has illustrated a number of widely held, stylized facts regarding technological change as follows:

- Different perspectives and boundaries result in different descriptions of technological change
- Process and factors tend to be sector- and context-specific
- Multiple factors and interactions among them influence the process of technological change

My analysis of technological change for environmental improvement is primarily from the political, environmental, and institutional perspectives. The conceptual model describes factors that influence the process of technological change qualitatively. This approach is in contrast to the more aggregated analysis of technological change.[111]

The most obvious difference between environmental technological change and general technological change is the motivation for the change. For general technological change for processes, efficiency improvement is the primary motivation. For general technological change for products, market advantage is the most important and compelling. For environmental technological change, while environmental performance may generate some market advantage or efficiency gain, the major motivation is to ensure compliance with standards at the lowest possible cost. Indeed, no market advantage has been experienced or reported by the Mexican automobile sector from introducing emission reduction technologies in Mexico. One exception was the limited market advantage for fuel economy improvements that were expected in the low to mid

111 In a recent literature survey conducted, the various sub-areas of the economics of technological change have been identified. These include: theory of incentives for research and development, measurement of innovative inputs and outputs, analysis and measurement of externalities from research, measurement and analysis of productivity growth, diffusion of new technology, effect of market structure on innovation, market failure, innovation, and policy response, economic effects of publicly funded research and patent system, and role of technological change in endogenous macroeconomic growth (Jaffe, Newell et al., 2000).

price level segment.[112] This observation further underscores the importance of environmental policy and institutions to address market failure, and to internalize environmental externalities, in the process of environmental technological change.

The case analysis confirmed that environmental concerns add another dimension of complexity to technological change, resulting in policy conflicts and challenges that had not been observed in general technological change that focuses on economic and industrial results. The most notable example of the policy conflict and fragmentation was seen in the catalytic converter case, where inconsistencies in environmental and industrial policy objectives negatively influenced the ability (and willingness) of the industry to introduce the technology. Another recurring theme is the challenges of coordinating environmental policy goals with energy policy objectives to meet national economic needs. Mexico is a major petroleum producer, and the petroleum sector has significant impacts on the national economy.[113] The commitment to, and impact of, environmental policy can be judged in part by the share of export revenue (in dollars) that PEMEX has allocated to importing gasoline, which increased from less than 1% in the late 1980s to above 10% in 1993 and 1997 (PEMEX, 1998). With the anticipated introduction of advanced technologies that require cleaner gasoline, the coordination challenge to reconcile environmental and economic goals is expected to generate further policy debate in Mexico.

Section 6.4: Summary

This analysis found that introduction of emission control technologies in the Mexican automobile sector could be explained within the framework of conventional technological change, with some key differences. The key differences include: the need to account for environmental policy as a factor that influences environmental technological change, different motivations of private sector actors in acquiring technological capabilities and deploying technology, and interactions and conflicts between environmental policy and other factors, which can create barriers to technological change.

In addition, the model application highlighted the increasing importance of the external factors in environmental technological change. Also, the three cases showed that the technological capability acquisition has been facilitated by the increasing integration of the Mexican automobile manufacturing capability into the regional framework. The findings of case studies and model development are consistent with the findings of the quantitative analyses from Chapter 4, which showed an increasing reliance on external factors for the acquisition of national technological capability, and found that foreign

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[112] The existing literature has shown that purchases of resource conserving technologies tend to use high discount rates in evaluating such investments (Hausman, 1979, Ross, 1990, Ruderman, Levine et al., 1987).

[113] PEMEX has contributed approximately 30% of the Mexican fiscal revenue on average between 1987 and 1998 (PEMEX, 1998).

direct investment and human capacity as two factors that explain the manufacturing performance in Mexico.

Chapter 7. Scenario Analysis

The research described in the previous section identified the key factors for environmental technological change for the Mexican automobile sector. The scenario analysis, as described in this chapter, was the next research step to estimate the levels of private vehicle emissions in the Mexico City Metropolitan Area, and to evaluate the emission and cost effects of the key factors identified in the previous research. The specific objectives of this research component were as follows:[114]

- To build emission projection and cost models for passenger vehicles in the Mexico City Metropolitan Area)[115 116]
- To estimate the levels of pollutant emissions from private vehicles, and emission reduction potential of various policy options
- To evaluate the effect of policy-relevant factors of environmental technological change, particularly timing and pace of the introduction of technology policy options, on emission reduction potential

As this scenario analysis is an on-going research activity, the focus has been placed on developing a robust emission projection model that can be used for further policy analysis.

Section 7.1: Methodology

The research was conducted following the steps described below:

1. Identification of policy and technology options for analysis
2. Development of emission model and cost model
3. Evaluation of emission and cost projections

The analysis period is 25 years, from 2000 to 2025. The emission model includes five priority pollutants included in the 1998 Emissions Inventory of the Mexico City

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[114] Weiss and Heywood's analysis of automotive technologies and their environmental impacts (Weiss, Heywood et al., 2000) provides a conceptual foundation for this analysis.

[115] The MIT Integrated Program on Urban, Regional, and Global Air Pollution has received a contract from the Mexico City Metropolitan Area Environmental Commission (CAM) to conduct a comprehensive review of PROAIRE 2000 - 2010, including emission forecasting and prioritization of policy instruments. The CAM and PROAIRE program are explained in more detail in Chapter 3.

[116] Within this program framework, four bottom-up transportation models are under development. They are: private vehicles as discussed in this chapter, road-based public transportation, freight, and Metro. In addition, three non-transportation models are under development.

Metropolitan Area, including carbon monoxide (CO), sulfur oxides (SO_x), nitrogen oxides (NO_x), particular matters smaller than 10 micrograms (PM_{10}), and non-methane organic hydrocarbons (NMOC) (CAM, 2001). Carbon dioxide (CO_2) emissions were also estimated, due to its importance in the climate change considerations.[117]

7.1.1 Identification of Policy and Technology Options for Analysis

The following policy options have been incorporated into the model for further assessment:

1. Tier 2 emission standards
2. Post Tier 2 emission standards (i.e., California LEV II standards)
3. Emission warranty
4. Fuel economy improvement
5. Low sulfur gasoline introduction
6. Retrofit of in-use vehicles
7. Driving restriction program (*Hoy No Circula*)
8. Scrappage of older vehicles

The analysis has considered policy options that directly reduce emissions as well as options that reduce the vehicle kilometers traveled (VKT) and modal share of private vehicles. Policy options 1 through 6 are considered as emission reduction options. Policy option 7 is considered as a VKT/modal share reduction option, as the model allows users to estimate the maximum potential VKT reduction from a given class of vehicles, as well as a percentage of the private vehicle VKT replaced by other modes of transportation. Policy option 8 is considered as both emission and VKT/modal share reduction option, as the percentage of scrapped vehicles that are not replaced by new vehicles (i.e., VKT is replaced by other modes of transportation) can be specified in the model. Scrappage of older vehicles also reduces emissions. The parameterization of these policy options is tabulated in Table 34.

Each policy option can be analyzed separately in the model. For the scenario analysis, sets of options, referred to as option bundles, which are considered likely to be implemented jointly or successively have been created. To date, seven bundles have been analyzed, as summarized in Table 35. The option bundles are named to reflect key policy goals and objectives. The options shown in italicized bold font follow an aggressive phase-in schedule, meaning greater than or equal to 50% of given technology is phased in during the first year of technology implementation and have aggressive implementation assumptions. Options shown in normal font follow a moderate phase-in schedule, meaning less than 50% is phased in on the first year, and under moderate implementation assumptions.

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[117] As described in Section 3.4, Mexico has ratified the Framework Convention on Climate Change. As a non-Annex I country, Mexico does not have any emission reduction or stabilization obligations, and is only required to report its emission levels.

Table 34: Policy options considered in scenario analysis

Policy options	Parameterization
Tier 2 emission standards	Timing of introduction Phase-in schedule
Post Tier 2 emission standards (i.e., California LEV II program)	Timing of introduction Phase-in schedule (aggressive: following California ZEV introduction schedule, moderate: 50% of ZEV introduction schedule)
Emission warranty improvement (80,000 km warranty as default from 2002)	Warranty coverage (up to 192,000km) Timing of introduction
Fuel quality improvement	Target sulfur concentration (ppm) for Premium and Magna varieties Timing of introduction Phase-in schedule Sulfur effect on HC, NO_x, and CO
Fuel economy improvement	Expected improvement (% increase) Timing of improvement Phase-in schedule
Scrappage of old vehicles	Class of technology to be scrapped (vehicles with no control, 2-way catalyst or less, 3-way catalyst or less) Number of vehicles to be scrapped each year Beginning and end years of program % of scrapped vehicles to be replaced by new vehicles
Retrofit of vehicles (model year 1986 to 1992) to comply with 1993 standards	Beginning and end years of program Number of vehicles to scrapped each year
Driving restriction (*Hoy No Circula*)	Beginning and end years of program Number of years of exemption for new vehicles Number of days of HNC per week % of VKT reduction from HNC-applicable vehicles % increase in vehicle purchase by HNC-applicable fleet

Table 35: Policy option bundles

Policy bundles	**Tier 2**	**Post Tier 2**	**Emission warranty**	**Fuel quality**	**Fuel economy change**	**Hoy No Circula (# of days, exempt yrs)**	**Scrappage**
1- Ref: reference	2006			2006 – 30ppm		-2025 (1,3)	
2- BC: Best	2006	***2010***	2010 150,000km	2006- 30ppm	***2010 55%***	***-2025 (2,0)***	***2000-2010 cars w/no control***
3-RL: realistic	2006	2010	2010 150,000km	2006- 30ppm	***2015 30%***	End in 2005 (1,3)	2003 – 2015 2-way catalyst or less
4-OC: getting older cars off the road	2006			2006- 30ppm		-2025 (2, 5)	2003 – 2025 2-way catalyst or less
5-NT: New technology oriented	2005	***2010***	2010 150,000km	***2005- 30ppm***	***2010 30%***	End in 2005 (1, 3)	
6-B5: best case, 5 yr delay	2011	***2015***	2015 150,000km	2011- 30ppm	***2015 55%***	***-2025 (2, 0)***	***2005 – 2015 cars w/ no control***
7-MR: modified realistic	2006	2012	2012 150,000km	2006- 30ppm	***2017 30%***	-2025 (2,5)	2003 – 2015 2-way catalyst or less

In order to analyze the effect of different timing of policy implementation, bundles with same technology and policy attributes but with different timings have been constructed, such as the best case bundle and best case delayed by 5 years.

7.1.2 Development of Emission Model

The model has been developed to allow users to evaluate various combinations of policy options, as well as to test the changes in the timing and pacing of technology introduction. This model is Microsoft Excel-based. The parameter input table is shown in Appendix D. An earlier model developed for the project by Gibbs provided some important data as well as insight for my model development (Gibbs, 2001). The model schematic is presented in Figure 18.

Data Sources

The primary source of baseline dada as well as the emission estimation methodology came from the 1998 Emissions Inventory, which was compiled by the Secretariat of Environment of the Federal District and Secretariat of Ecology of the State of Mexico (CAM, 2001). The MIT Mexico City project has used the same methodology and data as the Emission Inventory to ensure consistency of analysis, as it is the official document for policy analysis and decision making within the CAM.

Socioeconomic Parameters

The model contains three options to estimate GDP and population growth from 2000 to 2025, which are the two key parameters that influence the vehicle purchasing behavior. The three options are (1) econometric analysis based on historical data, (2) average percent growth rates, and (3) external data specification. My earlier analysis was carried out using the econometric analysis. The analysis currently uses external data specifications developed for the integrated assessment, called the Future Stories (Dodder, Galindo et al., 2001), to ensure consistency across other transportation and non-transportation bottom-up modeling for the integrated analysis. The Future Stories currently makes three projections on socioeconomic data. They have been developed to allow for consistent comparison of emission projections and estimation of drivers across the bottom-up models.

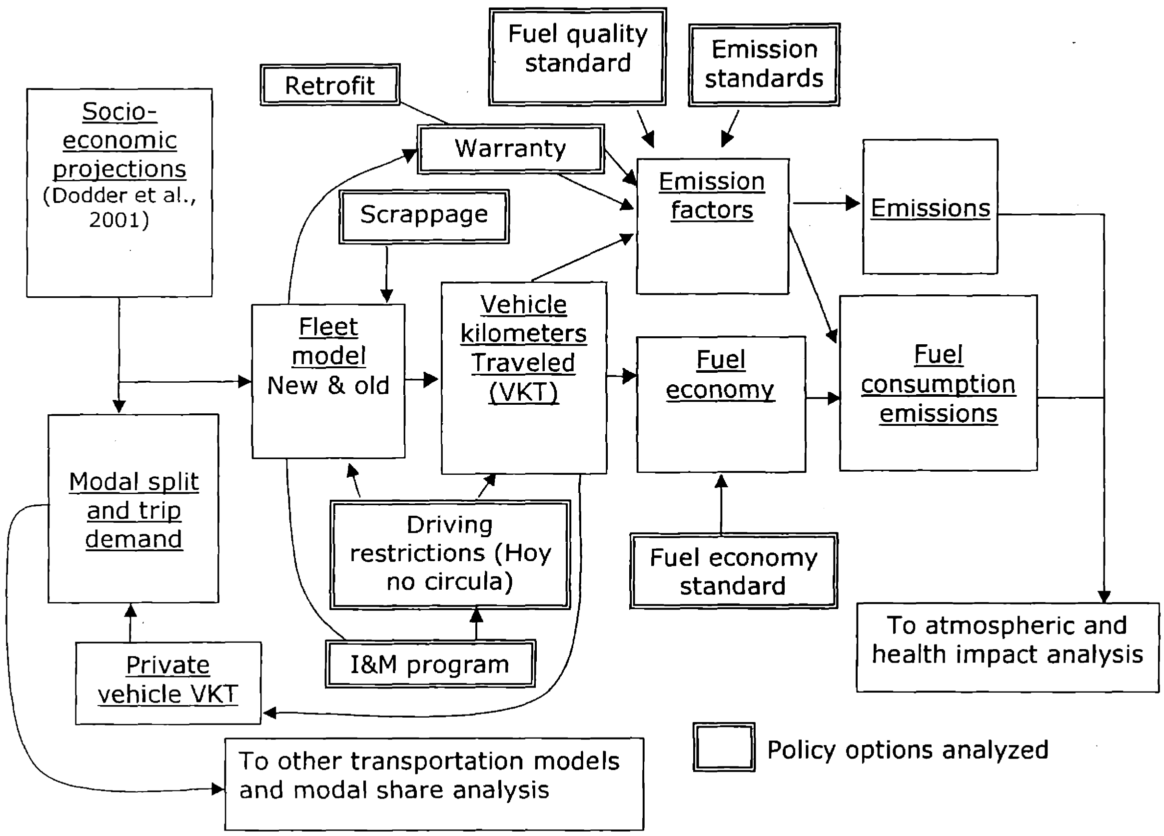

Figure 18: Private transportation model schematic

Emission Calculations

The following equation was used to calculate total emissions of NO_x, NMOC, CO, and PM_{10} on an annual basis. The equations are consistent with those found in the MCMA Emissions Inventory.

$$E = \sum_{i=1}^{n} (EF_i) \bullet (VKT_i) \bullet (FS_i)$$

Where

E:	Emission weight of a particular pollutant (grams/yr)
n:	maximum vehicle age in fleet
i:	Vehicle age
EF_i:	Emission factor of vehicle age i (g/km)
VKT_i:	average annual vehicle kilometer traveled for vehicle age i (km/yr)
FS_i:	number of vehicles with vehicle age i

In addition, the effects of sulfur contained in fuel are reflected in emission factors for new and in-use vehicles, as described in more detail in section on fuel quality.

SO_2 emissions were calculated based on the fuel consumption, using the following equation:

$$E_{So_2} = \sum_{j=1}^{n}(FC_j)\bullet(\rho_j)\bullet(C_{S,j})\bullet\frac{MW_{SO_2}}{AW_S}$$

Where:

E_{so2}:	weight of SO_2 emissions (ton/yr)
FC_j:	volume of annual fuel consumption of fuel type j (m^3/yr)
n:	number of available fuel types (currently 2 in Mexico)
ρ_j:	fuel density (which is 0.73 ton/m^3 for both gasoline types)
$C_{s,j}$:	sulfur content of fuel type j (% weight)
MW_{so2}:	molecular weight of SO_2 (which is 32 g)
AW_s:	atomic weight of sulfur (which is 16 g)

CO_2 emissions were also calculated based on gasoline consumption, using the following equation:

$$E_{Co_2} = \sum_{j=1}^{n}(FC_j)\bullet(C_{CO_2,j})$$

Where:

E_{CO2}:	weight of CO_2 emissions (kg/yr)
FC_j:	volume of fuel consumption of gasoline type i (gallons/yr)
n:	number of available gasoline types (currently 2 in Mexico)
$C_{CO2,j}$:	mass of CO_2 per gallon of gasoline (8.75 kg/gal for both types of gasoline in Mexico)

Model Components

In order to estimate future pollutant emissions using the above equations, it is necessary to project a range of future parameters for each model component. The following sub-sections describe how the projections have been formulated, as well as data availability. When applicable, policy options that affect the model component are also described.

Estimation of Fleet Dynamics

The fleet model comprised of the number of vehicles in each model year over the analysis period, and was divided into the Federal District (DF) and the State of Mexico (EdM). The fleet data from 1974 to 1998, included in the 1998 Emissions Inventory, were used. The two areas (DF and EdM) were analyzed separately, as the changes in socioeconomic conditions are expected to differ between the two, with direct implications on the vehicle purchasing behavior. The model included three mechanisms that affect the fleet size. These are: new vehicle purchase, natural vehicle survival function, and estimation of unregistered fleet.[118] In addition, policy measures that influence the fleet size have been identified.

<u>New vehicles</u>: The model has incorporated two methods of estimating fleet growth from new vehicles. The first one is by specifying an average percent growth rate, and the second one is from a regression analysis of vehicle purchasing behavior. For the first option, different growth rates for DF and EdM can be specified. For the US case, the projected light-duty vehicle sales growth rate for 1997 to 2020 has been reported as 0.5% for the MOBILE6 model, based on the 1999 Department of Energy Annual Energy Outlook (US EPA, 1999a).

For the second option, the fleet growth has been estimated using historical new vehicle sales data and change in GDP per capita from the late 1980s to late 1990s. This regression analysis has used the E-Views Statistical and Econometric Package. The analysis has been conducted separately for DF and EdM. The following regression was estimated using ordinary least square (OLS) to delineate the impact of changes in per capita income on new car sales:

$$DFCAR = c + \beta_1 * \Delta GDPPP + \beta_2 * \Delta GDPPP(-1) + \beta_3 * \Delta GDPPP(-2)$$

Where

DFCAR:	New car sales in DF
ΔGDPPP:	Increase in per capita income in DF of the year of analysis
ΔGDPPP(-1)	Increase in per capita income in DF one year before the analysis period
ΔGDPPP(-2)	Increase in per capita income in DF 2 years before the analysis period

The per capita income increase from 1 and 2 years ago was added, as the vehicle purchasing decision is thought to depend on income growth in years that precede the actual purchase. The regression results are summarized in the table below, with t-statistics values in the parenthesis.

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118 The model currently does not take into account introduction of used vehicles in the MCMA. The number of used vehicles is expected to increase with the phase out of restrictions on used vehicle import from 2009, as stipulated in NAFTA. The incorporation of used vehicle into the fleet model will be explored further.

Table 36: Regression results of new vehicle demand—Federal District

Constant C	ΔGDPPP β_1	ΔGDPPP (-1) β_2	ΔGDPPP(-2) β_3	R^2	F stat
82050 (5.08)	63.47 (2.46)	66.60 (2.31)	60.4 (2.34)	0.631	3.42

Each of the estimated β coefficients is significant at the 5 percent level, as indicated by the t-statistic values. The large F-statistic value allows me to reject the null hypothesis that there is no relationship between the new car purchase and per capita income from the same year, one year before, and two years before.

To estimate the new vehicle purchase in the State of Mexico, the following equation was used:

$$EMCAR = c + \beta_1 * \Delta GDPPP + \beta_2 * \Delta GDPPP(-1)$$

Where

EMCAR: New car sales in EM
ΔGDPPP: Increase in per capita income in EM of the year of analysis
ΔGDPPP(-1) Increase in per capita income in EM one year before the analysis period

Unlike the DF analysis, the income difference from two years ago was not statistically significant in relation to the purchasing decision. The regression results are summarized in the table below, with t-statistics values in the parenthesis.

Table 37: Regression results of new vehicle demand—State of Mexico

Constant C	ΔGDPPP β_1	ΔGDPPP (-1) β_2	R^2	F stat
23978 (17.59)	20.79 (3.42)	16.73 (2.59)	0.68	7.36

These two estimates were considered to be intuitively plausible, as the purchasing decision of a large consumer good has been shown to be correlated with current and past income levels.

Survival function: Vehicles are taken out of circulation due to accidents, theft, breakdown due to old age, and other reasons. As the fleet gets older, more vehicles are expected to leave the fleet. The fleet survival function estimates the percentage of vehicles of a given model year that remain in the fleet over time. The following equation has been used to estimate the survival function for the DF and EdM:

$$y = a \bullet b^{m}$$

Where

y:	% of vehicles left in fleet after m years
a:	coefficient (1 for this analysis)
b:	coefficient (0.96 for this analysis)
m:	vehicle age

Values for "a" and "b" were based on previous analyses within the project, which attempted to match registration data with historical new vehicle purchase data to derive a and b coefficients (Gibbs, 2001). Due to data limitations as well as questions about their accuracy, both coefficients have been approximated. It was also assumed that fleet saturation does not occur in 25 years across the three socio-economic growth scenarios outlined in the Future Stories. To estimate the survival function accuracy, a sensitivity analysis was conducted using various parameterizations and comparison with available data. This is presented in the section on sensitivity analysis.

Unregistered vehicles: The model includes an option to specify the number of unregistered vehicles in DF and EdM as percentages of the total fleet. The unregistered vehicles are estimated to have the same model year distribution as the registered fleet.[119]

Policy options: The fleet model is also influenced by two policy options, namely the scrappage program and driving restrictions (*Hoy No Circula*), as shown in Figure 18. The scrappage program removes vehicles with certain technology classes from the fleet, thus decreasing the number of vehicles. The model allows users to specify the number of vehicles removed from the fleet, as well as percentage of induced new vehicle purchases by owners of scrapped vehicles. Previous research on the *Hoy No Circula* program has found evidence that the program has induced new vehicle purchases in a considerable percentage of car owners whose vehicles are newly subject to driving restrictions (Eskeland and Feyzioglu, 1997).[120] The model allows the user to specify this number, with a default value of 22%, as estimated by Eskeland and Feyzioglu.

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[119] Due to the political sensitivity of the topic of unregistered vehicles, this option has not been used for the current analysis.

[120] The *Hoy No Circula* program has been in effect in the MCMA since 1989, as described in Chapter 3. Since the mid 1990s, new vehicles that meet the more stringent inspection requirements (usually determined by vehicle model year, such as 1999 and newer model) are exempt from driving restrictions.

Estimations of VKT and VKT growth

The 1998 Emissions Inventory set the baseline vehicle kilometers traveled (VKT) to 10,324 km (6,453mi) for each model year. This assumption means that there is no decrease in travel distance as the vehicles age.[121] One possible implication of using a constant VKT figure is the over-estimation of emissions from older vehicles. The over-estimation can potentially skew the analysis towards policy options that are geared towards removing the older vehicles from the fleet (i.e., scrappage). While it may not be optimal to use one constant VKT figure for all the model years, the analysis has been conducted using this number in order to maintain consistency with the inventory methodology. An option to specify a VKT – vehicle age degradation function has been put into the model, to compare emission profiles, as discussed in more detail in the sensitivity analysis section.

The constant VKT assumption is in contrast to the US case, where the following VKT-age function has been developed for US EPA's MOBILE6 emission model, based on the 1995 Nationwide Personal Transportation survey conducted by the Department of Transportation (US EPA, 1999b):

$$Y = 15{,}684 \bullet e^{-0.0506X}$$

Where

Y:	annual mileage
X:	vehicle age

The US data indicate that new vehicles travel on average 15,684 miles, or 25,095 km, during the first year. The equation can be applied to estimate the distance traveled in kilometers, by multiplying by 1.6.

To estimate the VKT growth to 2025, the model allows users to specify an annual rate of VKT growth in percentage. For example, the MIT reference bundle of options has assumed an annual VKT increase of 1%, while the best case bundle assumes stable VKT over the 25-year period..

Policy options: One policy option that can influence VKT has been incorporated, which is the driving restrictions (*Hoy No Circula*). To analyze the effect of *Hoy No Circula* on VKT, the maximum VKT reduction potential is calculated from the number of days of restrictions:

$$HNCVKT_i = a \bullet VKT_i \bullet R * \frac{365 days/yr}{7 days/wk}$$

[121] There exists another set of annual VKT versus model year data generated by a private consultant based on odometer readings during inspections. This data did show a decline in VKT as vehicle age progressed. The agencies responsible for the Emissions Inventory decided not to use these numbers, as questions regarding data reliability remain.

Where

$HNCVKT_i$:	VKT reduced by *Hoy No Circula* for model year i
a:	% of VKT reduction actually realized
VKT_i:	Annualized VKT for model year i
R:	Number of days of restrictions per week

The value for "a" ranges from 0% to 100%, where 0% reflects no VKT reduction potential achieved, i.e., policy failure, and 100% reflects the realization of maximum VKT reduction, i.e., complete substitution by other means of transport or by trip reduction. Eskeland and Feyzioglu (1997) estimated the "a" value to be approximately 40%.

Estimations of Fuel economy and Improvement

Fuel economy improvements can reduce greenhouse gas emissions as well as the consumption of fossil fuel. As such, it is important to include it in the emission model. The fuel economy data have not been included or analyzed in the Emissions Inventory. The Emission Inventory included the volume of gasoline sales for passenger vehicles, provided by PEMEX. Mexico currently does not have a fuel efficiency standard, although a recent voluntary agreement between the automakers and the Federal Energy Commission (CONAE) states that the fuel economy information will be made available to consumers at dealerships as well as through a central database.[122]

Due to this lack of data, it was necessary to estimate a historical fuel economy trend. In order to do so, the fuel economy data available in a number of vehicle models sold in both the US and Mexico have been compared (see Table 12). The comparison showed that the official fuel economy data were similar or very close for these vehicle models. While the data were only available for more recent models, it was assumed that the Mexican fleet economy is similar to the US fleet economy as stipulated in the corporate average fuel economy (CAFE) standards. These CAFE numbers were then assigned to 1974 to 1998 model years in the fleet model, and the total fuel consumption volume was calculated, based on the number of vehicles and VKT. The calculated total fuel volume from this bottom-up analysis was approximately 36% less than the gasoline sales volume provided by PEMEX in the Emissions Inventory. This discrepancy was considered relatively high, even taking the difference between ideal and real fuel economy into account. The discrepancy could arise from the following factors:

1. Large number of unregistered vehicles that are not accounted for in the Emissions Inventory exists in the MCMA, accounted for in the gasoline purchase
2. A large number of vehicles registered in surrounding states or in transit purchase gasoline in the MCMA

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[122] The old fuel economy standard was abolished in the early 1990s due to a possible NAFTA infringement. No specific information on standard compliance was available from the authorities or the auto sector.

3. Difference in driving conditions (including congestion effect) between the US and Mexico result in lower fuel efficiency in Mexican vehicles

4. Mexican vehicles, especially models only available in Mexico, have lower fuel economy than the US fleet

Upon discussing these factors within the research program, I decided to attribute the difference to the third factor, and incorporated a user-specified fuel economy adjustment parameter to the model. This parameter can be adjusted, with a default value of 36%.

The next step was to estimate a range of possible fuel economy improvements to 2025. Based on an analysis from the Transportation Research Board, which evaluated three possible future paths of fuel economy improvements and their costs, the upper range was estimated to be 41.7 miles per gallon (National Research Council, 2002). A linear cost curve was developed based on the three improvement paths.

Policy options: One policy option that influence fuel economy is included in the model. They are fuel economy standards.[123]

Estimations of Emission Factors

The Emissions Inventory included emission factors for each model year from 1974 to 1998, which were generated by the Mexican Petroleum Institute (IMP) using the Mobile 5a.3 program from the US EPA. The emission factors were available for five priority pollutants. These were included in the model, as well as a CO_2 conversion factor as described above.

The next step was the estimation of future emission factors per technology class and model year. Neither IMP nor the government agencies responsible for the air quality program have used the new version of the Mobile model (Mobile 6) to estimate future emission factors. It was thus necessary to estimate them using a more simplified approach. As the emission factors in new vehicles change with emission standards, I calculated the percent differences in the succession of emission standards, and then adjusted the emission factors in proportion to the percent difference in standards. For example, if the Tier 2 NO_x standard requires a 93% reduction compared to uncontrolled emissions, the NO_x emission factor for Tier 2 was estimated to be 93% less than the emission factor for uncontrolled emissions, which was included in the Emissions Inventory. The emission control timeline is shown in Table 9.

In order to estimate emission degradation, a linear function between vehicle age and normalized emission factors (i.e., emission factors for different vehicle ages divided by new emission factor) has been developed for each pollutant as follows:

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[123] For the next model version, fuel economy effects of advanced technologies will be included, as alternative fuel and zero emission vehicles embody fuel economy improvements.

$$\frac{EF_x}{EF_{new}} = 1 + \alpha \bullet x$$

Where

EF_x: emission factor for x-year old vehicle
EF_{new}: emission factor for new vehicle
α: coefficient, specific to each pollutant
x: vehicle age

The degradation is assumed to occur from year 1 if there are no emission warranty requirements. With emission warranty, the degradation is assumed to occur after the warranty coverage expired. The maximum emission degradation is set to the emission factor of non-controlled vehicles. Emission factors of CO, NO_x, and HC for different technology classes, as well as degradation functions are attached in Appendix D.

Policy options: Three policy options have been included in the model to influence the emission factors. They are: fuel quality standard, emission standards, and emission warranties. Fuel quality standards are discussed in more detail in the section below. For the emission warranty, the model allows users to specify the warranty coverage in kilometers. The emission factors are maintained at the new vehicle level up to the coverage distance and period, and then start to degrade following the above linear function.

Fuel Quality

The quality of gasoline has a significant impact on emissions. Technology introductions have been contingent on the availability of specific fuel quality in Mexico and other countries, as the case studies have highlighted. One example is the necessity of unleaded fuel for three-way catalyst control, as discussed in the case study analysis. The availability of low sulfur gasoline is necessary to realize the full emission reduction potential of vehicles with advanced emission reduction technologies, such as Tier 2 vehicles.

Sulfur sensitivity is a function of catalyst formulation, vehicle operation conditions, and vehicle aging. In terms of catalyst formation, certain metals, such as palladium, are more sensitive to sulfur. As for operation conditions, catalyst adhesion occurs more thoroughly at lower temperatures (450 to 500F) than at higher temperatures. The regeneration of catalyst after sulfur poisoning requires high operating temperature above 700F as well as rich exhaust or an alternating sequence of rich and lean (US EPA, 1999b).

The sulfur content of gasoline impacts the emission reduction efficiency through three mechanisms: (1) short-term effects, where sulfur is adsorbed onto the catalyst surface, (2) long-term effects, where sulfur has penetrated into the precious metal layer, especially palladium (often used for LEV vehicles) as well as oxygen-storage material, and (3) irreversible effect (US EPA, 2001). The long-term effects occur after vehicles are driven on high sulfur fuel for a few thousand miles, where as the short-term effects were observed after under 100 miles. The irreversible effects are observed when the emission impacts of high sulfur fuel does not reverse after low sulfur fuel is used. The sulfur concentration also affects the speed with which the catalyst performance decreases and improves after poisoning. Table 38 shows the ratio of long- to short-term sulfur sensitivity for LEV and cleaner vehicles for four pollutants. The long-term effect for NO_x is 47% more than the short-term effect. For NMHC, HC and CO, the long term effect is more than twice the short-term effect.

Table 38: Ratio of long-to-short term sulfur sensitivity for LEV and cleaner vehicles

	NMHC	HC	CO	NO_x
Long-to-short term ratio	2.5	2.5	2.36	1.47

(US EPA, 2001)

These three effects of high sulfur gasoline on emissions have been analyzed. The short and long term emission degradation effects for Tier 0, Tier 1, and Tier 2 vehicles have been calculated for both normal and high emitters as defined by EPA. For Tier 0 and Tier 1 vehicles, the reference sulfur content has been set to 390 ppm, which is the current sulfur content of Magna gasoline. The emission levels for Tier 0 and Tier 1 vehicles will thus decrease as the sulfur level decreases The degradation factors for Tier 2 vehicles have been assumed to equal those for LEV and UNEV vehicles, as EPA anticipates Tier 2 vehicles to be at least as sensitive, if not more, to sulfur as LEV and ULEV vehicles (US EPA, 1999a). Due to the higher sulfur impacts for Tier 2 vehicles, the analysis has assumed that newer vehicles will use Premium gasoline, which currently contains 220 ppm of sulfur, lower than Magna. This assumption is consistent with proposals from PEMEX.

Normal emitters refer to vehicles with emissions that are less than or equal to two times the emission standard for NO_X and HC, or less than or equal to three times the emissions standard for CO. High emitters have emissions more than two times the emission standard for NO_X and HC, or three times the emission standard for CO (US EPA, 2001).

Finally, the irreversible effects of sulfur were incorporated to calculate the average sulfur effect, following a methodology used to evaluate the impacts of Tier 2 and sulfur standards (Koupal, 1999, US EPA, 2001).

$$\text{Average sulfur effect} = IR * \text{max effect} + (1-IR) * \text{current effect}$$

Where

IR:	Irreversibility factor for technology class
Max effect:	Short-term sulfur correction coefficient with the maximum sulfur level for the vehicle (i.e., normally vehicle's model year)

Current effect: Sulfur correction coefficient for the modeled calendar year with the current sulfur level, using the short-term sulfur coefficients and multiply by long-term factors as necessary

The irreversibility factor for Tier 0 and Tier 1 vehicles is zero. For Tier 2, the factor is 0.425 (US EPA, 1999b).

Policy options: The fuel quality standard that specifies the gasoline sulfur content was included in the model. The model allows users to enter sulfur contents of two different gasoline blends in ppm, as well as the timing and phase-in schedule of the new fuel quality standard. The sulfur effects are calculated based on the specifications of the fuel quality standard as well as emission standards (i.e., advanced technologies). Since there is no local data on sulfur penalty, the data from the US EPA have been assumed to hold true for the sulfur effects in Mexico.

7.1.3 Evaluation of Change in Timing and Pace of Policy Options

As mentioned earlier, one of the objectives of this analysis has been to determine the effect of changing the timing and pacing of the option introduction.

Adjusting the timing of technology implementation is one way for the environmental authorities to allow the industry to improve the availability and reliability of technologies and suppliers. For example, the voluntary agreement between the Mexican environmental authorities and the auto sector stipulates a 2-year delay between the standard introduction in the Unites States and in Mexico. As explained in Chapter 5, one rationale for such delay is to allow the domestic production facilities to catch up to the international competitors in terms of investments, capacity, and capability. Also, the industry is interested in taking advantage of the anticipated decrease of technology costs associated with learning effect and economy of scale within the US.[124]

In addition, adjusting the pace of technology implementation may be an important option for the authorities to accommodate capacity limitations in production that may arise from changes in the production process or products. For example, the provision of low sulfur gasoline may be subject to capacity restrictions from sequential improvements in the refining facilities.

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[124] The validity of this argument for the learning effect and economy of scale is dependent on the destinations of the Mexican-produced vehicles. If the Mexican production continues to be geared towards the US and Canadian markets, benefits of the learning effect and economy of scale are likely to be realized in the production of vehicles for the domestic market. On the other hand, if the Mexican production gears more towards exportation to other developing countries, or more towards the domestic market, the benefits are likely to be less pronounced.

Section 7.2: Cost Modeling

7.2.1 Costing of Options

The next step was to cost the policy options.[125] The Emissions Inventory contained very limited cost or financial information on policy options. While the PROAIRE document did contain some basic cost figures, the coverage was incomplete. Due to the limited availability of data and analysis, technology costs in Mexico have been assumed to be identical to the US costs, unless specific Mexican data are available. This assumption is considered to be reasonable due to the following three observations:

- Previous cost-benefit analyses carried out by the Mexican environmental authorities have referenced costs from US sources, particularly from the US EPA
- Many of the analyzed options have same technical requirements as the US standards
- Extensive vehicle exportation to the US and growing importation increasingly allow all automakers to have access to identical technologies as the US-based manufacturing facilities at similar prices

All costs have been estimated in 2000 constant US dollars. An average exchange rate of 1 US$ to 10 pesos has been assumed. The reference real discount rate is set to 5%. The depreciation period for technologies, such as emission technologies and fuel improvement technologies, has been set to 10 years. For program costs, items such as patrol cars were depreciated over 5 years. Individual cost elements that have been considered are summarized in Table 39, and described briefly below.

Table 39: Summary of option costing

	Costs included in analysis
Emission control technologies	Technology cost
Fuel efficiency improvement	Technology cost, consumer cost (fuel savings)
Fuel improvement	Technology cost (incremental cost on per gallon basis)
Scrappage	Program cost, consumer cost (partial allocation of I&M cost, program participation cost, vehicle replacement)
Retrofit	Program cost, consumer cost (partial allocation of I&M cost, program participation)
Hoy No Circula	Program cost, consumer cost (allocation of I&M cost, vehicle replacement)

125 The analysis presented in this section is from the first phase of the cost modeling. The model is developed further during the second phase of the project.

Technology improvement: For Tier 1, Tier 2, and post Tier 2 technologies, technology costs were depreciated over 10 years.

Fuel improvement: Fuel improvement costs were calculated using the unit cost increase (i.e., per gallon or per liter) associated with desulfurization. The cost data, provided by US sources, show higher incremental costs in proportion to sulfur concentration reduction. The US unit costs were used for this analysis, as PEMEX likely will continue importing cleaner gasoline to delay or control infrastructure investments on refinery upgrade, in addition to domestic refining. Under such circumstances, infrastructure investments incurred in the US are better reflected as the unit price increase for costing for Mexico. The use of unit costs was thus considered appropriate.

Fuel economy improvement: The costs associated with the fuel economy improvements comprised of two components, namely technology costs and fuel costs. To estimate the technology costs, cost curves for technology development paths, developed by the National Research Council, were used (National Research Council, 2002). To calculate the fuel costs, gasoline cost projections have been made based on historical fuel prices (Vijay, 2001). Total fuel costs were then calculated using the price projections and fuel economy change. In some cases, the savings from fuel economy improvements were greater than the technology costs over the depreciation period, generating a negative cost (savings).

Scrappage: Scrappage costs comprises of administrative costs, program costs of actual payments to consumers, as well as allocation to inspection program fees for consumers. A certain percentage of the consumer costs of inspection (user –specified) is allocated to the scrappage program, as many programs in the US require vehicle owners to get their cars inspected as a condition to participate in scrappage programs and to receive payment.

Retrofit: Retrofit costs consist of administrative costs, technology costs, and allocation to inspection program fees for consumers. Similar to the scrappage program, most US programs require consumer to get their vehicles inspected as a condition to participate in retrofit programs.

Driving restrictions (*Hoy No Circula*): For this option, costs have been divided into program costs and consumer costs. To calculate the cost to consumers, a certain percentage of out of pocket costs associated with the vehicle inspection is attributed to *Hoy No Circula*. The program cost includes personnel and vehicle costs for program implementation. To account for multiple days of driving restrictions, users specify a percent multiplier to estimate the cost increase for each extra day of *Hoy No Circula*. The default value has been set to 15%.

The multi-attribute analysis called for total cost accounting, meaning that all costs associated with vehicle use, including vehicle and fuel costs, are included in the analysis.[126]

Section 7.3: Findings of Scenario Analysis

7.3.1 General Observations

The model estimated emissions from the six pollutants, present value costs, and cumulative VKT of the seven bundles, as summarized in the table below.

Table 40: Summary of scenario analysis results

Private Auto Option "Bundles"	Cumulative Auto VKT	Δ% VKT from Ref.	Cumulative Emissions	Δ % Em. from Ref.	Present Value Cost	Δ% Cost from Ref.
(1) Reference	1338		481.8		42.52	
(2) "Best Case"	810	-39	263.1	-45	61.52	45
(3) "Realistic"	1335	0	457.6	-5	47.92	13
(4) Old Cars Off the Road	1306	-2	462.6	-4	49.11	16
(5) New Auto Techs	1321	-1	437.4	-9	46.05	8
(6) Delayed "Best Case"	810	-39	278.6	-42	50.27	18
(7) Realistic, Older Vehicle Control, Delayed Auto Techs	1315	-2	450.8	-6	49.32	16
	(Billion VKT)		(Million Tonnes)		(Billion 2000 Pesos)	

The results indicate that the technology-oriented options tended to be more effective in cost and emission reduction, compared with options that affect VKT and mode share. For example, a comparison of the fourth bundle, which includes options to restrict and remove older vehicles, and the fifth bundle, which includes options to introduce new technologies, show that the new auto technology bundle can have a larger emission reduction compared to the reference case, 9% reduction as opposed to 4% reduction, at a lower cost, 8% increase as opposed to 16% increase. Another important observation is that the fourth bundle with VKT/mode share reduction options was not effective in reducing the cumulative VKT, compared with the technology bundle (2% decrease as opposed to 1% decrease). This observation is consistent with previous research findings, which observed that policy measures to reduce traveling tend to be not very effective (Howitt, 1999).

Figure 19 depicts a projection of emissions and VKT for the reference case, under the realistic future story, referred to as the keeping up future. The figure shows that emission levels can be stabilized over time, even with substantial VKT increase. This is due to the

[126] In the next phase of the scenario analysis, emission abatement costs, calculated in dollars per ton of pollutants, will be calculated. The emission abatement costs have been widely used to compare cost-benefit performance of various policy options.

advanced technology options, coupled with natural fleet turnover. Similar observations have been made under two other plausible socioeconomic futures.

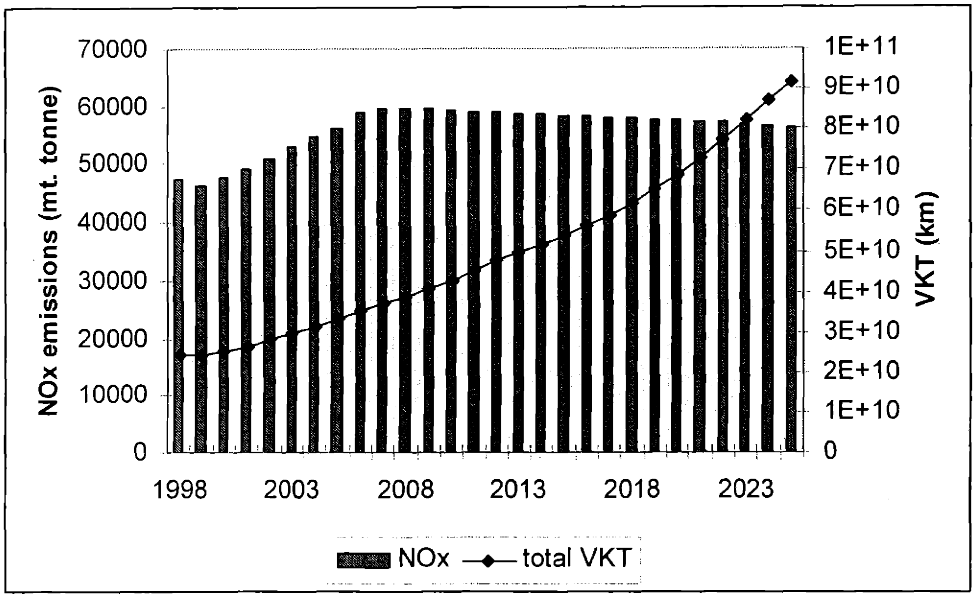

Figure 19: NO_x-VKT projection (reference case)

7.3.2 Sulfur Effect on Emissions

The sulfur effect on three pollutants was calculated, based on the equations presented in the previous section. Representative figures are summarized as Table 41 for normal-emitting Tier 2 vehicles.

Table 41: Sulfur penalty on Tier 2 vehicles (normal emitters)

Maximum Sulfur content (ppm)	Current sulfur content (ppm)	% increase in HC emissions	% increase in CO emissions	% increase in NO_x emissions
220	220	74%	107%	129%
220	150	62%	88%	107%
220	50	30%	43%	60%
150	50	26%	37%	49%
50	50	17%	16%	25%

The sulfur penalty figures have been calculated using the current maximum sulfur content for Premium gasoline of 220 ppm, and the projected final sulfur content of 50 ppm by 2010. The percent increase figures have been calculated with the reference penalty of 0%

with 30ppm sulfur. As the table shows, the sulfur penalty for all pollutants is quite severe, especially if the vehicle is operated with gasoline with the current level of sulfur content. The NO_x penalty was calculated to be the most severe. Even with 50 ppm sulfur content, which is the projected minimum sulfur content by PEMEX, vehicles can emit 25% more NO_x.

For the emission modeling, the sulfur penalty effects have not incorporated to adjust the final emission figures. One reason is that Tier 2 vehicles are introduced into the Mexican fleet with emission warranties. From the modeling perspective, the incorporation of both the sulfur effect and emission warranties presents a conflict, as the vehicles under warranty are modeled to maintain the new vehicle emission levels until warranty expiration. Another reason is that given the uncertainties associated with the emission factor calculation, the full incorporation of the sulfur penalty is deemed premature, until better emission factors become available. Instead, the results are reported as a range of sulfur penalty.

7.3.3 Trade-off Analysis

The modeling results are used to conduct a multi-attribute trade-off analysis. Such analysis has been carried out for the private vehicle projections, as well as combined with other transportation and non-transportation projections (Connors, Aoki et al., 2002).

Figure 20 shows the trade-off analysis for passenger vehicles. Emission projections of the seven bundles have been estimated with three different socio-economic futures. The realistic future is keeping up (KU), optimistic one is sustainable growth (SU), while the pessimistic one is drag (Drag).

The cost-emission attractiveness of technology options is more pronounced under realistic and optimistic future projections. The reduced attractiveness under the pessimistic projections is attributed to the decrease in new vehicle purchase. These observations indicate that the performance of technology options is favorable, and more pronounced in two out of three plausible futures. In general, the relative performance of private vehicle options appears to be constant under various socio-economic projections. For example, the bundle for restricting and removing older vehicles is consistently the most expensive option bundle across three different projections, whereas as the best case bundle generates the least emissions. To summarize, the relative performances of options bundles is generally robust across different socio-economic futures. This implies that the *relative* option performance will not be influenced significantly by changes in the Mexican economy and/or demographics.

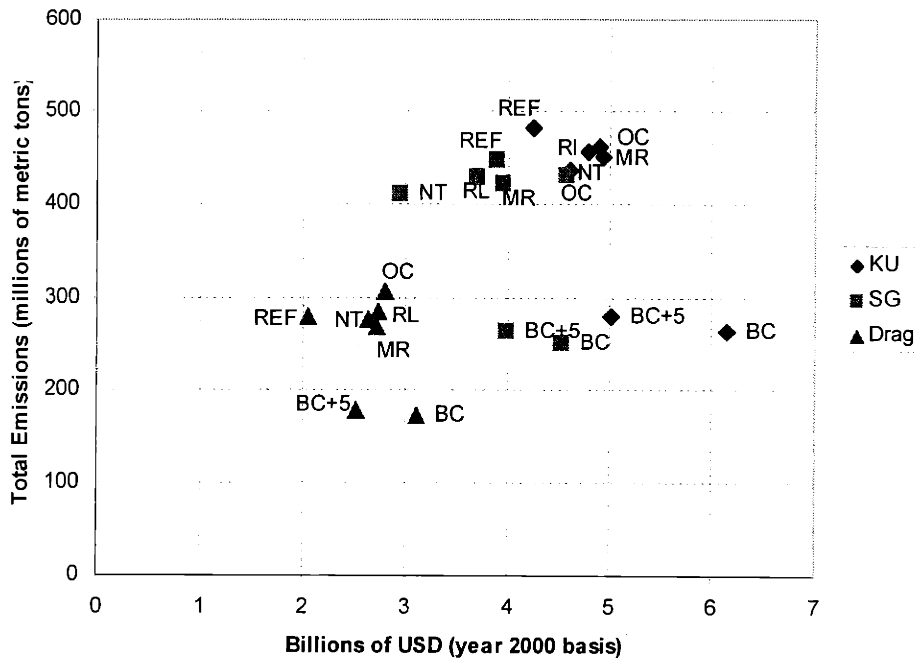

Figure 20: Trade-off graph of policy options

7.3.4 Pace and Timing of Option Implementation

Changing the pace and timing of option implementation generated mixed results on emissions and cost. For example, delaying the best-case option bundle by 5 years resulted in a large decrease in the total costs with a relatively minor increase on the total emissions. Negotiations on the timing and phase-in schedule of options with such characteristics are more likely to be more successful, due to the converging interests of the automakers and the authorities. On the other hand, delaying the option bundle geared towards getting older vehicles off the road by 5 years resulted in higher emissions and higher costs. Due to the emission sensitivity to timing of this option bundle, the delay in implementation is not likely to be acceptable to the authorities, yet preferable to the industry. Further analysis is needed on this subject to provide useful information to the Mexican authorities.

7.3.5 Model Uncertainty and Sensitivity

Uncertainty refers to the variability, or scatter, in model predictions compared with actual emissions (National Research Council, 2000). For this analysis, uncertainties can arise from the following sources:

- Uncertainty associated with underlying emission data used to construct the emission factors
- Uncertainty from input data

- Uncertainty associated with assumptions on model formulation
- Uncertainty from analysis error

One source of uncertainty is the VKT estimation for different vehicle ages. The Emissions Inventory assumed a constant VKT. Since empirical data suggest that older vehicles tend to be driven less as they age, a sensitivity analysis was conducted to determine the impact of changing VKT assumptions on the emissions. A VKT degradation function similar to the US data was fit to the Mexican data, using a degradation coefficient of 4.5%. To ensure comparability, the cumulative VKT for 1998 was held constant. In the original analysis, the VKT is held constant at 10,329 km, and for the sensitivity analysis, the VKT for a new vehicle is estimated as 15,140 km, and decreases as vehicles age.

The emission projections were generated using the two VKT assumptions under the reference case with realistic socioeconomic projections (i.e., keeping up future story). The table below shows differences in emission projections. Assuming a decreasing VKT-age profile resulted in significantly different emission projections, particularly for the ozone precursors of NO_x and HC. The observations indicate that previous analyses may have over-estimated the emissions from older vehicles. Furthermore, the assumption of variable VKT makes options that deal with older vehicles, such as scrappage and retrofit, much more time sensitive. For example, cars equipped with two-way catalysts and less contribute more than 20% of VKT up to 2013, if constant VKT is assumed. However, with VKT degradation, the VKT share by the same fleet goes down to below 20% by 2006. The window for policy application is thus narrower than originally anticipated, if the VKT-age profile is not constant. The analysis is one illustration of how emission projections can vary, due to an uncertainty associated with data assumptions.

Table 42: Emission sensitivity to difference in VKT assumptions

	SO_2 (mt)	CO (mt)	NO_x (mt)	HC (mt)	PM_{10} (mt)	CO_2 (mt)	Total VKT
VKT with degradation	2.420E+4	3.397E+7	1.113E+6	2.013E+6	2.893E+4	4.092E+8	8.419E10
Constant VKT	2.517E+4	4.758E+7	1.486E+6	3.064E+6	3.223E+4	4.296E+8	8.747E10
% difference	4%	29%	25%	34%	10%	5%	4%

One of the main issues associated with vehicular emission control is the control of emissions from older vehicles, as shown in the above analysis of VKT assumptions. Another uncertainty associated with the model that could impact the emission estimate from older vehicles is the vehicle survival function, which was discussed earlier in the chapter. Figure 21 depicts a comparison of various survival functions that have been applied in emission projections in the MCMA, which show a rather large variation from early vehicle age. Compared to other assumptions, the survival function that I used appears to be underestimating the vehicle survival early on, then overestimating as the fleet ages. This implies that current projections are underestimating emissions from newer vehicles, and overestimating emissions from older vehicles.

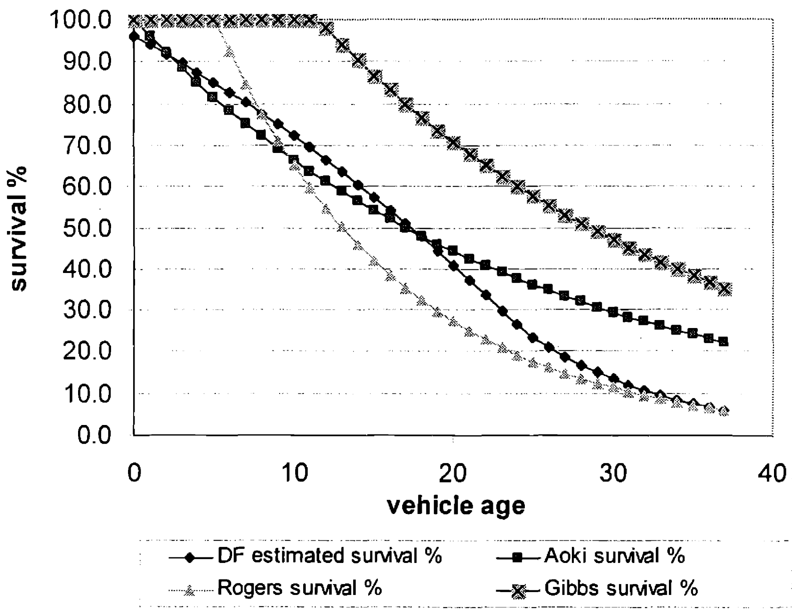

Figure 21: Comparison of survival functions

Data source: Rogers, 2000, CAM, 2001, Gibbs, 2001

7.3.6 Further Model Improvement

The scenario analysis exercise for the Mexico City project is expected to continue throughout 2002. As such, the model will continue to undergo further refinement and improvement. Some of the key areas of model improvement include the following:

- Better costing of options to allow for comparison with existing studies, such as the recent analysis of air pollution mitigation options conduced for the World Bank, which included two passenger-vehicle related options (Cesar, Schädler et al., 2002).

- More refined estimates of emission factors: the current analysis relies on a linear approximation of emission factors from emission standards. The emission factors can be further refined, with actual vehicle emission data analysis and adaptation and application of the Mobile 6 model in Mexico.

- Analysis of options covered under PROAIRE: the scenario analysis presented here is based on options bundles created at MIT. Efforts are underway to characterize emission reduction from options that are specifically referenced in PROAIRE.

Chapter 8. Conclusion

Section 8.1: Review of Research Context

The thesis addressed the following fundamental question: "what are the processes and factors of technological change that promote environmental improvement while contributing to development goals in the Mexican automobile sector?" The motivation for the research stemmed from the need for air pollution mitigation in the Mexico City Metropolitan Area (MCMA). The analysis focused on the emission impacts from passenger vehicles for two reasons. First, they were one of the largest sources of pollution in the MCMA. The second is due to the demonstrated effectiveness of technology options in the mitigation of vehicular emissions.

The analysis for technological change was conducted at the national level because policies that influence the adoption of technologies are set at the federal level. Also, the influence of external factors, such as characteristics of the global automobile sector, was more suited for analysis at the national level. The scenario analysis for emission reduction, on the other hand, was conducted at the metropolitan level, as the air quality improvement is a particular concern within the MCMA.

Section 8.2: Key Findings

This section presents the key findings from the five research steps of this research:

- Sector and country profile development
- Comparative quantitative analysis of technological change
- Case studies of environmental technological change
- Conceptual model development
- Scenario analysis of emission reduction options in MCMA

8.2.1 Sector and Country Profile Development

A profile of Mexican environmental and automobile-related industrial institutions and their legal frameworks in the past 20 years was developed. The analysis identified some key barriers, constraints, and opportunities for policy intervention for air pollution mitigation in the MCMA. In the arena of industrial policy, which has unquestionably impacted the automobile sector structure and performance, a gradual shift from industry protection to export promotion, and then to liberalization has influenced the manufacturing capacity of the auto sector in Mexico. In the environmental policy arena, the emerging political imperative to address the air pollution problem led to institutional strengthening and better definitions of legal mandates at the federal, state, and local level.

8.2.2 Comparative Quantitative Analysis of Technological Change

The statistical and econometric analysis was conducted to evaluate Mexico's technological capability, and to compare the Mexican performance with eight other countries, including the US, Japan, and six developing countries with established automobile or parts and components sector. The statistical analysis found dependence on external sources of technological capability in Mexico, as evidenced by high percentage of non-resident patent applications (99%), and high net inflow of foreign direct investments. While indicators from the early 1980s showed Mexico as a relatively advanced developing economy, Mexico has now been surpassed or outperformed by other developing countries in several aspects, such as R&D expenditures, manufacturing value added, and labor force with tertiary education. Mexico has, however, experienced significant recent growth in high technology exports.

The econometric analysis of manufacturing value added, which was used as a proxy for automobile sector performance, showed that Mexico was the only developing country where a statistically significant relationship was found between manufacturing value added and foreign direct investment. A literate workforce was also found to be statistically significant. This indicates that the Mexican manufacturing performance in the past 20 years could be explained as a function of externally supported manufacturing capability and financing, and workforce quality.

These findings highlighted the reliance of Mexican technological capability acquisition on external factors, as well as the importance of foreign capital for manufacturing performance. These findings were not sufficient to construct a model to describe the process of technological change, or to find points of effective policy interventions. The findings, however, did yield some insights into the significance of external factors that were particular to Mexico, which could inform the qualitative analysis based on case studies.

8.2.3 Case Study Analysis of Environmental Technological Change

The case study analysis examined the introduction of three emission mitigation technologies in the Mexican automobile sector. These cases were catalytic converter introduction (1991 and 1993), Tier 1 technology introduction (1999), and on-board diagnostic (OBD) system introduction (2002). Their analysis generated specific observations on the introduction of environmental technologies.

In the catalytic converter case, differences in technological capability and technology access at the firm level, as well as fuel quality were important factors that constrained the industry's willingness and ability to introduce the technology. These barriers to implementation largely stemmed from inconsistencies in the objectives of the Mexican environmental and industrial policy instruments, as well as the relative institutional weakness of the environmental authorities.

In the Tier 1 case, increasing regionalization of production and supply minimized the firm level differences in technological capacity, which in turn decreased barriers as well as sector resistance to implementation of the technology. The strengthened capacity and credibility of the environmental authorities enabled them to offer meaningful incentives to the auto sector, which resulted in the voluntary introduction of the technology two years before the more stringent legal requirement went into effect.

In the on-board diagnostic (OBD) system case, the industry accepted a voluntary agreement to introduce the OBD technology and to adopt advanced emission standards two years after their introduction in the US and Europe. For the industry, this agreement was a strategic move to reduce uncertainty in the regulatory environment, and to maximize the regulatory consistency over the ten-year agreement period. For some firms that sold OBD-equipped vehicles in Mexico prior to the agreement, the voluntary agreement also leveled the playing field by making other firms to supply vehicles with OBD. The regionalization of production and supply, similar to the Tier 1 case, enabled the firms to implement the technology in vehicles sold in Mexico. From the legal and institutional standpoint, trends towards the harmonization of emission standards with dominant standards (i.e., standards in US and Europe, or standards in export countries) contributed to the environmental authorities' decision to move further away from independent policy formulation. While the introduction of the OBD technology has not begun yet, the industry will likely comply with the agreement, given their existing ability to supply OBD-equipped vehicles in Mexico.

8.2.4 Conceptual Model Development

The case study findings were synthesized and abstracted to develop a conceptual model that shows stylized process and factors of environmental technological change. This model is depicted in Figure 22. The process stages are three key building blocks necessary for technological change to occur. Some of the factors are related to, and in return influenced by, the formulation and development of the process stages. None of the factors exerts influence on all process stages. The process stages and factors are generalized, while the links and descriptions are specific to each technology case.

Three Process Stages

The process of environmental technological change was conceptualized as three iterative stages: legal and institutional framework building, technological capability development, and technology implementation. The legal and institutional frameworks were divided into domestic and external, as the two were found to influence the process of technological change through different factors. These process steps have been identified and accepted in the literature on general technological change.

Six Factors

The synthesis of case studies found six factors that influence the environmental technological change process at different stages. Three domestically oriented factors were identified. These are: domestic environmental policy, domestic industrial and economic policy, and domestic sector structure. Two externally oriented factors were identified as external environmental policy and global sector structure. Finally, one hybrid factor, which was influenced by both domestic and external forces, was termed as technological attributes of the technology being introduced.

Explaining the Cases with Model

The case studies were explained using the model framework, including explanations of how factors influenced the process stages and vice versa, in Figure 15, Figure 16, and Figure 17 in Chapter 6. The model provides a useful explanatory or conceptual lens through which to view each of the cases; and allows these cases to be differentiated on the relative strengths and significance of the factors and stages that influenced each technology outcome.

In the catalyst case, two process stages that required most effort and change were establishing the domestic legal and institutional framework, and developing technological capability in the auto sector. Relevant factors were domestic environmental policy and industrial policy, particularly inconsistencies between them that created barriers to the technology introduction. The domestic sector characteristics, specifically the protected oligopolistic sector structure, and firm level difference in technology access were also considered relevant for this case. These sector characteristics were influenced primarily by industrial policy. The technological attributes, particularly the fuel quality and availability, were also important.

In the Tier 1 case, the external legal and institutional framework, NAFTA in particular, began to have a profound effect, shifting the domestic industrial and economic policy towards liberalization. The domestic legal and institutional framework was equally important, as the institutional strength and credibility enabled the environmental authorities to offer incentives to the auto sector to implement technology ahead of the legal mandate. The external environmental policy, particularly in the US, was relevant as the US Tier 1 emission standards were taken as a prototype for the domestic standards. The global sector characteristics led to the increasing integration of the Mexican sector into the regional manufacturing and supply network, thereby improving the technological capability.

In the OBD case, the external institutional framework was again an important process stage, due to the gradual move away from independent formulation of environmental and industrial policies towards de-facto harmonization with emission standards of the dominant export market. Global sector characteristics continued to influence the domestic sector, similar to the Tier 1 case. As the OBD utilization requires an adequate technology infrastructure, the technological attributes factor was considered important. The technology implementation stage is important yet unclear, as the specifics of how to utilize the OBD technology to achieve emission reduction have not been determined.

Increasing influence of external factors

The model application showed that the relative importance of factors and process stages differ among the three cases. Specifically, the process has been increasingly influenced by external factors. While the domestic factors remain important, they, too, are under profound influence of external factors.

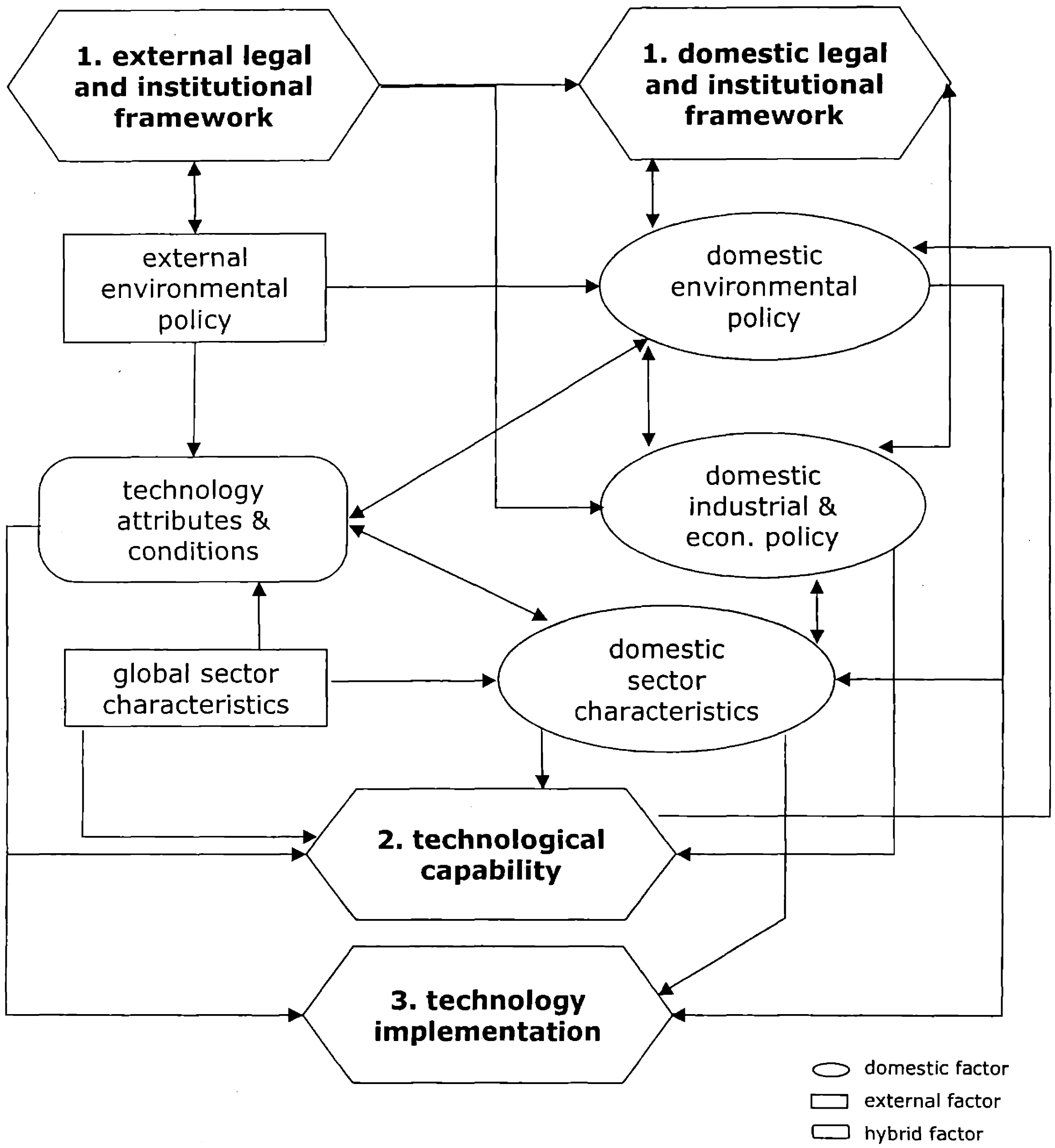

Figure 22: Conceptual model of case analysis

8.2.5 Scenario Analysis of Air Pollution Mitigation Options

The scenario analysis of options for air pollution mitigation from 2000 to 2025 analyzed combinations, or bundles, of options that included vehicle technology improvements and fuel quality changes, as well as options that change vehicle utilization patterns and fleet composition. Compared to options that modify behavior, the analysis found that options that introduce new emission mitigation technologies were more effective in reducing emissions. The scenario performance was analyzed under three different sets of assumptions regarding future socio-economic conditions, including GDP and population projections (Dodder, Galindo et al., 2001). The cost-emission attractiveness of technology options was shown under the three plausible futures, and more pronounced under realistic and optimistic future projections. The reduced attractiveness under the pessimistic projections was attributed to the decrease in new vehicle purchase. These observations indicate that the performance of technology options is favorable, and more pronounced in two out of three plausible futures.

The scenario analysis also indicated that emissions from passenger vehicles could decline or be constant over the next 25 years by applying policy instruments currently under consideration by the environmental authorities. While the emissions may be stabilized, the increase in passenger vehicles results in higher vehicle kilometers traveled (VKT) from lower occupancy modes. As the VKT and vehicle increase inevitably necessitate road infrastructure investments and cause congestion, which in turn increases emissions, it is necessary to consider options that reduce VKT. The model has not incorporated the congestion effect. VKT reduction options include driving restrictions, congestion pricing for road use/access, as well as measures to increase the use of public transportation. These observations highlighted the merits of the integrated approach to analyze air quality management.

8.2.6 Role of Environmental Policy

The research found that environmental policy is a necessary but not sufficient factor to induce technological change in vehicle emission reduction technologies. Emission standards and voluntary agreements on technology introduction *did and do* influence technological change by specifying the pace and timing of the introduction. However, environmental policies *do not* prescribe how the industry would acquire the technological capability necessary to start providing vehicles that meet emission requirements. Technological capability acquisition has been instead mediated by industrial and economic policies, and significantly influenced by sector characteristics. The process-based conceptualization of technological change, shown in Figure 22, shows that any one factor has limited influence in the process, and cannot induce technological change on its own.

The Tier 1 and OBD cases showed the use of incentives by the environmental authorities to promote advanced technology introduction. Because such incentives were offered at the local and state levels, the cases illuminated the importance of policy coordination at the federal, local and state levels. The metropolitan level coordination of incentives from the state and local authorities for national emission standard compliance has occurred for several reasons. The first reason is that air pollution impact is felt at the metropolitan level, requiring policy coordination among the entities that comprise the metropolitan area. The second is the lack of metropolitan level jurisdictional mandates and policy instruments for air pollution control. The third reason is that the MCMA is a convenient place to test the impacts of federal policy, as up the MCMA market accounts for 50% of new vehicles sold in Mexico. Finally, the metropolitan area has assumed a leadership position in air quality management, similar to the State of California in leading the air quality debate in the US. Like California, its leadership position has been spurred by the severity of the air pollution problem it confronts.

Some observations from the case studies are explained by hypotheses in the literature relevant to environmental technological change in developing countries and global markets. While the research did not set out to test these hypotheses empirically, the following qualitative observations and comment can be made.

Competitive advantage of environmental regulation

The motivation of the firms to seek environmental regulation can be explained as competitive advantage of environmental regulation by Porter and van der Linde (1995). In the OBD case, at least one firm introduced vehicles equipped with OBD as soon as the technology was required in the US. This firm asked the environmental authorities to provide incentives for the voluntary introduction of such technologies, or to require the technology to level the playing field. The case studies also indicated that industry response to environmental technologies is influenced in part by the extent to which the technology is integrated in the vehicle's core components. As OBD had many parts that were integrated into the vehicle and engine control, it was difficult to remove. A catalytic converter, by contrast, is a self-contained end of pipe device, which is very easily installed or removed. As a consequence, while automobile manufacturers could simply remove catalytic converters from models sold on the Mexican market, they could hardly do the same with OBD. Opposing tighter emission standards was far easier in the former case than the latter.

Consistency vs. laxity

Some studies have found that multinational enterprises in developing countries tend to seek consistency in environmental regulation and enforcement, rather than laxity (OECD, 1993). The OBD case can be explained in this context, as firms likely agreed to the introduction of emission standards in the US and Europe to minimize uncertainty associated with Mexican policy formulation.

Applicability of competition in laxity

This theory says that states competing for industry engage in a race towards undesirably low levels of environmental regulation (Stewart, 1977, Swire, 1996). Indeed, one main concern for NAFTA was the relocation of industry to Mexico to take advantage of less stringent environmental standards (largely for process-oriented firms). For the Mexican auto sector, no evidence was found to suggest that the theory was applicable. While the early cases showed that a longer phase-in period was successfully negotiated to accommodate firms that lagged in technological capability, it cannot be explained as firms seeking laxity, as more stringent standards were introduced and complied with eventually.

8.2.7 Environmental vs. General Technological Change

The research generated some observations on the differences and similarities between general technological change and technological change for environmental improvement.

The most obvious motivation for or return to general technological change for processes is efficiency improvement. For products, it is market advantage. While environmental performance may generate some market advantages, the major motivation for or return to environmental technological change is to ensure compliance with standards at the lowest possible cost. Indeed, no market advantage has been experienced or anticipated by the Mexican automobile sector from introducing emission reduction technologies *in* Mexico (as noted however, the ability to provide vehicles with such technologies was required to operate in key export markets). One exception was the limited market advantage for fuel economy improvements that were expected in the low to mid level price segment. However, limited availability of information on fuel economy, compounded by the lack of fuel economy standard in Mexico, makes it difficult for consumers to make informed decisions.

This research also found more specific differences. For example, the catalytic converter case study found that inconsistencies between domestic environmental policy and industrial and economic policy objectives created barriers to environmental technological change. This observation suggests that interactions between environmental policy and other factors significantly influence the process of environmental technological change. Another difference is that environmental technological change must happen within a specific time period stipulated by policy. Indeed, the timing of technology introduction was identified as a main concern for the Mexican automobile sector, particularly due to past episodes of sudden environmental policy changes, both real and threats, that compelled the auto industry to mobilize or negotiate with the authorities. This observation suggests the importance of flexible implementation schedule management, which requires cooperation between the government and industry.

There were also some similarities between the two types of technological change. The process of environmental technological change followed the similar process stages as the process of general technological change. In particular, the importance of technological capability acquisition was underscored in the catalytic converter case. The process-based approach was equally applicable for the two. Some of the factors were also similar for the two types of technological change, such as the sector characteristics. Based on these observations, the cross application of the theories of technological change to the environmental case was warranted.

Finally, while innovation spurred by technology forcing standards has played a role in environmental technological change in developed countries, there was little evidence of major innovation in the Mexican auto sector, except for incremental innovations for technology adaptations to meet local conditions. The development of technologies adopted in Mexico has been carried out in the dominant countries and export destinations, i.e., the US and Europe. The individual firms therefore did not, and do not, have the independent innovation capability in Mexico. This observation is consistent with the research findings of the national technological capability, described in Chapter 4.

Section 8.3: Implications of the Research

8.3.1 Specific Implications for Mexico

As stated earlier, the analysis showed that the environmental technological change in the Mexican auto sector is increasingly influenced/dependent upon/contingent on external factors, specifically global sector development and conditions in countries with major auto producers and export markets.

This finding has some implications for the vehicle technology options included in the air quality management program for the Mexico City Metropolitan Area. The new integrated air quality management program (PROAIRE 2002 - 2010) has identified various options for emission mitigation, including transportation, industrial activities, residential sources, informal sector, as well as biogenic sources. The purpose of the integrated assessment has been to characterize technically the options in terms of emission reduction and their costs. For the scenario analysis of passenger automobile emissions, technological options showed better emission reduction potential than other types of options that involved changes in personal behavior. From this standpoint, the implementation of technological options is warranted, and should be facilitated by policy.

Furthermore, each option for emission reduction has different levels of political and institutional feasibility as well as acceptability by the public.[127] When these dimensions are considered, the case for environmental technological change in the automobiles fulfills some of the key requirements of option feasibility, for several reasons.

The first reason is that the acquisition of technological capability needed for vehicle technology implementation is influenced significantly by factors external to the Mexican policymaking domain, as demonstrated by the case studies and the conceptual model. Manufacturing capacity and access to key technologies on the part of the Mexican auto sector have been supported by the liberalization of the sector economy, as well as the sector's export orientation via regional production and supply mechanisms. To put it simply, whether the environmental authorities decide to tighten the emission standards or not, some, if not all, firms will continue to increase the capacity to build cars that meet

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[127] A comparative assessment is needed to understand the political and institutional feasibility of different options, and should include an analysis of the distributional effects of policy, perception of fairness, regressive or progressive nature, and the strength of the actors and institutions impacted by the particular option. Such assessment across different emission sources has not been conducted yet. As such, the above analysis is confined to the vehicle technology options.

more stringent emission standards of the dominant countries, or export markets.[128] The phase-out of the import restrictions on new vehicles will increase the number of vehicles imported from the US and Canada that meet the emission standards from these countries.

In addition, automobile technology options tend to impose a significant share of their cost and burden on external sources, as investment decisions have been made at the global corporate level due to the regional integration of Mexican operations. Technology development will continue to be undertaken in countries with the most stringent emission standards, such as the US and Europe. The two-year delay in standard implementation in Mexico, as specified in the voluntary agreement between the environmental authorities and the auto sector and explained in Chapter 5, allows the Mexican auto sector to benefit from learning and scale economies, to adjust the domestic-oriented models, and to ensure for appropriate fuel availability.

Furthermore, the costs for emission control technologies are borne by a relatively small percentage of population in the upper income category, minimizing the concern over equity, fairness, and distributional impacts of policy. The projected vehicle ownership by 2025 is less than 30% of the MCMA population[129].

Another reason is that the environmental authorities, at different levels, have demonstrated their increasing capability to use incentives and enforcement to persuade car manufacturers to introduce vehicles with key technologies. The use of such incentives has led to the technology phase-in ahead of the legally mandated schedule. The institutional capacity of the environmental authorities have been strengthened to the point which the industry is willing to commit to introduce key technologies that meet the US and European standards, specified in the voluntary agreement as discussed above.

Technology options for automobiles therefore have the key political and institutional feasibilities required for successful implementation. Policy analysts and policymakers need to consider these factors in order to better analyze and prioritize emission reduction options across different emission sources.

The voluntary agreement to introduce US- and European-level technologies, discussed in the OBD case in Chapter 5, is motivated partly by the auto industry's desire to reduce policy uncertainties in Mexico, and partly due to the existing capacity to produce vehicles that comply with US and European standards. This understanding leads to two further observations regarding the introduction of environmental technologies in the future.

The first observation is that policies that require technological change unique to the Mexican fleet are likely to encounter more resistance from the auto sector, especially if such policies call for more stringent emission reductions in Mexico. The sector opposition to the case of the new vehicle tax reform, which was proposed in mid-2001,

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[128] This observation further underscores the importance of the role of environmental policy to set the time and pacing of technology introduction for the entire sector.

[129] The projected vehicle ownership figures in 2025 under three plausible projections of socioeconomic conditions were all under 30%. The vehicle ownership figure in 2000 is approximately 15%.

may be explained in this context. The tax reform proposal by the Secretariat of Finance had the objective of promoting the introduction of low NO_x emitting vehicles in Mexico, by setting the tax rates of vehicle models based on their NO_x emission level.[130] NO_x reduction has been considered as a potential policy priority with the emergence of scientific information on local conditions of ozone formation: research has shown that ozone formation in the MCMA is NO_x limited, i.e., the reduction in NO_x emissions is likely to lead to reduction in ozone formation (Molina, Molina et al., 2002). The tax reform proposal was met with strong opposition by the automobile sector for several reasons.[131] Among them, the sector was most opposed to the requirement of more stringent NO_x control in Mexico compared to other countries. The industry argued that the proposed taxation based on NO_x emissions amounted to a de-facto emission standard revision, as the auto makers would need to offer different vehicle models in Mexico, and require technological change in current models sold in Mexico in order to minimize tax increase. From the industry's perspective, the proposal went against the move towards policy consistency and harmonization with the US and Europe. This example underscores the importance of accurate scientific and technical knowledge of local conditions, as such information facilitates policymakers to formulate policies that target specific local problems more effectively. On the other hand, the example also highlights the need to recognize and reconcile differences that arise between local concerns and the overall policy framework and direction.

The second observation is that if the export destination changes to countries with less stringent emission standards, then the willingness and the ability of the firms to adopt emission mitigation technologies will decrease in the long run. While the change in export orientation is unlikely to affect the entire sector, considering the current high level of integration into the North American supply market, it may influence specific firms which have more diversified export orientations or with stronger domestic market focus. With less export to countries with more stringent emission standards, such firms are less likely to upgrade all of their Mexican manufacturing facilities to have the capability to produce cleaner vehicles. Furthermore, such firm level differences reduce the willingness for some firms to agree on sector-wide consensus on environmental issues, which in turn negatively affects the ability of the environmental authorities to reach agreements with the sector as whole.

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[130] The proposal for the new vehicle tax reform aimed to reflect the environmental performance of vehicles by reducing the ad valorem tax by 50%, and replacing it with environmental tax based on the NO_x emission level. The environmental portion of the tax was to be based on the relative performance of the vehicle to the fleet average NO_x emission value, i.e., vehicles that emit more than the fleet average are taxed higher, while vehicles with lower than fleet average NO_x emissions are taxed lower. The proposal called for a gradual phase out of the ad valorem portion of the tax from 50% in the first year of the tax reform to 10% by the fifth year (SHCP and SAT, 2001). This proposal was the first tax reform in Mexico to reflect air pollution concerns.

[131] Other reasons for the opposition to the proposal include the general opposition to the new vehicle tax, which the automakers blame for slowing the fleet turnover and lack of opportunities for negotiations with the authorities. In addition, automakers stated that minimizing NO_x emissions might lead to an increase in emissions of other pollutants, with potentially negative overall effect.

8.3.2 Future Research

The above findings and implications of the research give rise to issues that merit further analysis. These include additional research agenda that the Mexico City project can undertake.

Better Quantification and Qualification of Relative Factor Importance

The relative importance of the factors and process stages were determined qualitatively, based on the interviews and survey results. While the attempt was made to quantify the factor importance through the use of numerical scales (i.e., 1 through 5 or 7) in the survey, the small sampling size of the automakers rendered the data unsuitable for statistical or quantitative analysis. Also, because the model conceptualization requires stylization of the factors and process, rigorous quantification of factors may not generate much further insight into the problem. Nevertheless, the analysis and the model accuracy may be improved by including a larger number of companies, and by obtaining multiple responses.

Analysis of New Firms or Models into the Mexican Market

The case studies and model development was based on those firms with a long history of operations in Mexico, plus some new firms that established manufacturing capacity in Mexico in the past 10 years. There exist a large number of new vehicle models and firms that have entered the Mexican market in the last several years. With the phase-out of import restrictions, this trend is expected to increase. Because their entry to the market is likely to be based on importation and not domestic manufacturing, their response to domestic environmental policy may differ. This issue should be investigated further.

Investigation of Model Applicability for Other Technologies or Countries

The model may be applied and adjusted for other emission reduction technologies, alternative industrial sectors that produce high-impact products, or in other developing countries with automobile production capacity.

Improvement of Scenario Analysis

The scenario analysis will continue as part of the Integrated Program on Local, Regional and Global Air Pollution at MIT. Both the emission and cost models will be updated as additional data and analysis become available, and results will be evaluated with atmospheric modeling and health impact analysis. Some of the key model refinement needs are described in Chapter 7. The results of the integrated assessment will be submitted to the Metropolitan Environment Commission (CAM) by the end of 2002, and used to inform policy prioritization. In addition, more comprehensive economic analysis of air pollution mitigation options in the MCMA may be warranted to analyze the impacts of air pollution mitigation on the national and regional economy. This analysis may require more sophisticated modeling effort, outside the realm of the scenario analysis.

Inclusion of Congestion Effect into Emission Modeling

Congestion impacts on emission characteristics of vehicles were not taken into account for the scenario analysis. The emission impacts of congestion include both short term and long term. For the short term, the relationship between vehicle speed and emissions show a substantial increase in emissions as the vehicle speed decreases below 10 to 20 miles per hour. In the long term, vehicle use patterns may change to result in reduced vehicle kilometers traveled, as citizens may switch to public transportation to avoid congestion. It would be worthwhile to investigate such measures and incorporate them into the scenario analysis.

8.3.3 Policy Recommendations

This research was the first known systematic analysis of environmental technological change in the Mexican auto sector. As the introduction of vehicle emission mitigation technologies will continue to be an important part of air quality management in the Mexico City Metropolitan Area, this research informs policymakers about the following key points:

- Policymakers should be cognizant of how environmental policy impacts the process of technological change, and be aware that environmental policy does not itself develop technological capability within industry. Environmental policy can impact the process of technological change by specifying the pace and timing of technology introduction. Environmental policy instruments can also be used to provide incentives to the industry for technological change.
- Policymakers should strive to minimize policy fragmentation and conflict, which undermine the implementation of emission reduction options. Coordination between the environmental, industrial, economic, energy and fuel, and transportation policy is critical, and should be further promoted. The real and perceived strength of institutions that address these issues remains highly variable. Weaker institutions should be strengthened further with financial and political commitment and human capacity development to facilitate more integrated policy formulation and implementation.
- Vehicle emission control technology options should be considered further and more aggressively, due to their effectiveness in emission reduction, as well as their political and institutional feasibility.
- Any integrated assessment of air pollution management options must consider the political and institutional feasibility of technology options, in addition to their cost and emission control efficacy. For vehicle emission control technologies, understanding the increasing dominance of the external factors is important in evaluating such feasibility.
- The environmental authorities are likely to encounter opposition to technology options that require Mexico-specific emission control requirements, particularly if they are more stringent than the US or Europe. Also, the authorities are less likely to encounter opposition if technology options that have already been implemented in export countries are pursued. Similarly, if primary export

markets shift towards other markets with emission control standards less stringent than those of North America, the authorities' ability to secure deployment of future emission control technologies will be negatively influenced.

- The environmental authorities should explore the possibility of supporting the auto industry to establish manufacturing capacity for vehicles with advanced emission mitigation technologies in Mexico, in cooperation with the Secretariat of Economy.

The research findings may also provide some insight to other developing countries that are dealing with air pollution problems and contemplating the introduction of emission control technologies, particularly for countries with automobile manufacturing capacity.

8.3.4 Further Observations

The main contribution of this research for sustainable development is the application of theories and concepts that explain technological change as a component of national industrial development to the case of environmental technological change. The research found that introduction of emission control technologies in the Mexican automobile sector could be articulated within the framework of conventional technological change, with some key differences. The key differences include: the need to account for environmental policy as a factor that influences environmental technological change, different motivations of private sector actors in acquiring technological capabilities and deploying technology, and interactions and conflicts between environmental policy and other factors, which can create barriers to technological change.

The research has shown that policy and institutional development have preceded environmental technological change in Mexico. The role of institutional and policy frameworks, recognized in the general theories of technological change, becomes more critical in the case of environmental technological change that is mandated by policy. The phase-out of independent emission standard formulation by the environmental authorities and the move towards standard harmonization should not be mistaken for diminished need for environmental institutions. On the contrary, Mexico's current strategy of following the US and European environmental standards requires the Mexican environmental institutions to have comparable and compatible capacity and strength as the US and European environmental institutions. Such institutional strengthening requires resource allocation and human capacity building, which should be recognized and supported.

The research also found that environmental performance does not, and is not projected to, provide market advantage to the automakers, as there is no demand for cleaner vehicles from the Mexican consumers. Market signals alone are insufficient to result in the change in demand for environmentally superior products. This observation points to the need for policy intervention to internalize the environmental externalities, which requires appropriate environmental policy formulation and implementation. Such policy formulation again points to the need for strong and competent environmental institutions.

The increasing availability of scientific and technical knowledge will have positive impacts on formulating appropriate policy instruments for air quality management in the future. The emergence of knowledge on the local conditions and ensuing policy re-formulation needs to recognize, and reconcile with, the current policy direction, which has been strongly influenced by the sector dynamics and authorities.

Finally, there is a need to minimize fragmentation in the Mexican policymaking arena. Environmental technological change in the past had been hampered by policy and institutional inconsistencies, as shown in the case studies. This point is especially pertinent with the projected introduction of advanced technologies that require cleaner gasoline. In particular, policies that govern PEMEX will increasingly influence both technological capability acquisition and technology implementation in the future. The Mexican government agencies need to recognize that policy and institutional fragmentation will undermine the efficacy of emission mitigation options. The research has shown that technological change for environmental improvement has, in part, been a political process, which has required policy and institutional change. The future of the Mexican air quality management will also depend on improving institutional and policy coordination.

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Appendix A. NAFTA Instruments for Auto Sector

Summary of auto sector commitment

- Phase out of tariffs on cars and lights trucks that meet rules of origin by 2003
- Phase out of trade balance requirements by 2004
- Phase out of import restrictions on non-Mexican producers by 2004
- Elimination of market share restrictions immediately
- Reduction and elimination of local content requirements by 2004
- Phase in of rules of origin requirement
- Phase-out of embargo on used vehicles that meet the NAFTA rules of origin starting in 2009 over 10 years
- Use of import licenses to monitor NAFTA provisions until 2004 only
- Use of import licenses to restrict used vehicle entry until 2009
- Use of import licenses to monitor the age of vehicle imports during the used vehicle restriction phase-out (2009 – 2019)

Rules of origin (regional content measurement)

	Light vehicles	**Other vehicles**
1994 – 1997	50% of net cost	50%
1998 – 2001	56%	55%
2002 -	62.5%	60%

Tariffs

For vehicles not meeting the NAFTA rule of origin, the tariff remains at 20%.
For vehicles meeting the NAFTA rule of origin (regional content measurement), the following table is applicable:

	Pre-NAFTA	1/1/94	1/1/95	1/1/96	Annual decrease	Elimination date
Passenger vehicles	20%	10%	8.8%	7.7%	1.1% annually	1/1/2003
Light trucks	20%	10%	7.5%	5.0%	2.5% annually	1/1/1998
Heavy trucks[1]	20%	18%	16%	14%	2%	1/1/2003

1. Vehicles weighing over 8,864 kg, cab chassis, truck tractors, buses and specialty vehicles

Trade balance requirements and quotas

Export requirements on vehicle assemblers for $1.00 worth of cars and light trucks imported are set as follows:

	Pre-NAFTA	1/1/94	1/1/95	1/1/99	1/1/2003	Elimination date
Requirement	$2.00	$0.80	$0.772	$0.661	$0.550	1/1/2004

Market share restrictions have been eliminated (in 1993, imports of finished cars and light trucks limited to 20% of each producer's sales).
Heavy vehicles assemblers can import 50% of the number of vehicles produced in Mexico, provided the assembler maintains 40% of local content.
Non-assemblers may import less than 15% of total production for 1994 – 1995, no less than 20% in 1996, and no less than 30% for 1997 – 1998. The quota is allocated through an auction.

Used vehicles import ban

Mexico has maintained a ban on used vehicle import. The exception to this import ban is the border zones, which can import cars that are 4 to 15 model years old with similar tariffs as above. The trade embargo will be phased out starting 2009, for cars that meet the NAFTA rule of origin (US Department of Commerce, 1999, Veloso et al., 1998).

Appendix B. Summary Statistics

COMPARISON OF TECHNOLOGICAL CAPABILITY INDICATORS: SCIENCE AND TECHNOLOGY

1980 - 1998 average and ranking (unless otherwise noted)

	Mexico	United States	Korea, Rep.	Brazil	Argentina	Thailand	India	Singapore	Japan
R&D expenditure (% GNP)	0.35	2.67	1.71	0.82	0.38	0.24	0.75	0.75	2.73
ranking	**8**	**2**	**3**	**4**	**7**	**9**	**6**	**5**	**1**
R&D expenditure (1995 US$)	1.07E+09	1.63E+11	6.07E+09	5.69E+09	9.64E+08	1.99E+08	1.79E+09	4.27E+08	1.18E+11
ranking	**6**	**1**	**3**	**4**	**7**	**9**	**5**	**8**	**2**
Scientists & Engineers in R&D (per million persons)	198	3420	1394	275	433	105	140	1265	4881
ranking	**7**	**2**	**3**	**6**	**5**	**9**	**8**	**4**	**1**
Technicians in R&D (per million persons)	172	n/a	545	59	193	42	101	421	823
ranking	**5**	**n/a**	**2**	**7**	**4**	**8**	**6**	**3**	**1**
S&T journal articles	931	139,370	1,182	1,993	1,250	n/a	9,210	458	32,888
ranking	**7**	**1**	**6**	**4**	**5**	**n/a**	**3**	**8**	**2**
Non-resident patent applications	32,904	111,210	41,366	28,146	5,035	4,780	6,632	33,935	63,439
ranking	**5**	**1**	**3**	**6**	**8**	**9**	**7**	**4**	**2**
Resident patent applications	409	118,846	34,255	1,816	824	221	5,908	4,202	346,174
ranking	**8**	**2**	**3**	**6**	**7**	**9**	**4**	**5**	**1**
% of resident patent applications	1.2	51.6	30.1	6.4	14.1	4.4	20.0	11.2	84.5
ranking	**9**	**2**	**3**	**7**	**5**	**8**	**4**	**6**	**1**
High technology export (% GNP), 1991 to 1998 average	2.56	1.82	6.00	0.23	0.12	5.62	0.22	53.84	2.16
ranking	**4**	**6**	**2**	**7**	**9**	**3**	**8**	**1**	**5**
High technology export (1995 US$), 1991 to 1998 average	9.75E+09	1.29E+11	2.84E+10	1.54E+09	3.12E+08	8.65E+09	7.95E+08	4.54E+10	1.13E+11
ranking	**5**	**1**	**4**	**7**	**9**	**6**	**8**	**3**	**2**
rank average	6.4	2.00	3.2	5.8	6.6	7.78	5.9	4.7	1.8
ranking of rank average	**7**	**2**	**3**	**5**	**8**	**9**	**6**	**4**	**1**

source: World Bank (2000)

COMPARISON OF TECHNOLOGICAL CAPABILITY INDICATORS: ECONOMIC STRUCTURE

1980 - 1998 average and ranking (unless otherwise noted)

	Mexico	United States	Korea, Rep.	Brazil	Argentina	Thailand	India	Singapore	Japan
Manufacturing value added (% GDP)	20.0	19.4	29.3	28.4	25.3	26.0	16.3	25.9	27.5
ranking	**7**	**8**	**1**	**2**	**6**	**4**	**9**	**5**	**3**
Manufacturing value added (1995 US$)	5.05E+10	1.14E+12	7.71E+10	1.36E+11	5.96E+10	2.78E+10	3.97E+10	1.45E+10	1.07E+12
ranking	**6**	**1**	**4**	**3**	**5**	**8**	**7**	**9**	**2**
Gross domestic investment (% GDP)	22.6	18.3	32.7	20.8	18.9	33.6	22.7	39.3	29.8
ranking	**6**	**9**	**3**	**7**	**8**	**2**	**5**	**1**	**4**
Gross domestic investment (1995 US$)	6.88E+10	1.01E+12	9.78E+10	1.41E+11	4.63E+10	3.75E+10	6.26E+10	2.02E+10	1.24E+12
ranking	**5**	**2**	**4**	**3**	**7**	**8**	**6**	**9**	**1**
Domestic Credit (% GDP)	29.4	83.9	56.4	63.8	41.4	76.2	47.8	68.2	127.5
ranking	**9**	**2**	**6**	**5**	**8**	**3**	**7**	**4**	**1**
Domestic Credit (1995 US$)	9.86E+10	5.17E+12	1.92E+11	3.95E+11	9.44E+10	8.44E+10	1.27E+11	3.80E+10	5.72E+12
ranking	**6**	**2**	**4**	**3**	**7**	**8**	**5**	**9**	**1**
Manufacturing Exports (% GDP)	9.3	5.2	26.1	4.1	2.3	14.1	4.0	94.6	9.8
ranking	**5**	**6**	**2**	**7**	**9**	**3**	**8**	**1**	**4**
Manufacturing Exports (1995 US$)	3.41E+10	3.25E+11	8.49E+10	2.51E+10	5.25E+09	1.78E+10	1.17E+10	5.63E+10	4.24E+11
ranking	**5**	**2**	**3**	**6**	**9**	**7**	**8**	**4**	**1**
FDI net inflow (% GDP)	1.5	0.9	0.4	0.9	1.2	1.6	0.2	9.9	0.03
ranking	**3**	**6**	**7**	**5**	**4**	**2**	**8**	**1**	**9**
FDI net inflow (1995 US$)	5.37E+09	5.77E+10	1.47E+09	5.85E+09	2.93E+09	1.99E+09	7.22E+08	5.42E+09	1.29E+09
ranking	**4**	**1**	**7**	**2**	**5**	**6**	**9**	**3**	**8**
Telephone lines (per 1,000 persons)	66.1	535.4	267.3	67.6	113.5	31.0	7.9	383.7	424.0
ranking	**7**	**1**	**4**	**6**	**5**	**8**	**9**	**3**	**2**
average ranking	5.7	3.6	4.1	4.5	6.6	5.4	7.4	4.5	3.3
ranking of average rank	**7**	**2**	**3**	**4**	**8**	**6**	**9**	**4**	**1**

source: World Bank (2000)

COMPARISON OF TECHNOLOGICAL CAPABILITY INDICATORS: EDUCATION

1980 - 1998 average and ranking

	Mexico	United States	Korea, Rep.	Brazil	Argentina	Thailand	India	Singapore	Japan
Education Expenditure (% GNP)	4.2	5.8	3.9	3.9	2.4	3.8	3.4	3.5	4.8
ranking	**3**	**1**	**5**	**4**	**9**	**6**	**8**	**7**	**2**
Labor force with primary education (% labor force)	55.1	17.1	26.7	60.4	n/a	83.4	35.0	25.9	27.0
ranking	**3**	**8**	**6**	**2**	**n/a**	**1**	**4**	**7**	**5**
Labor force with secondary education (% labor force)	16.0	39.5	41.9	n/a	n/a	2.3	9.5	30.8	47.2
ranking	**5**	**3**	**2**	**n/a**	**n/a**	**7**	**6**	**4**	**1**
Labor force with tertiary education (% labor force)	16.4	43.3	17.6	23.0	n/a	8.1	4.0	27.9	24.8
ranking	**6**	**1**	**5**	**4**	**n/a**	**7**	**8**	**2**	**3**
Primary school enrollment (% population in age group)	99.7	96.4	99.9	86.0	97.8	90.2	74.1	96.6	99.9
ranking	**3**	**6**	**1**	**8**	**4**	**7**	**9**	**5**	**1**
Secondary school enrollment (% population in age group)	63.6	95.3	87.1	54.0	69.3	30.4	52.8	70.2	96.0
ranking	**6**	**2**	**3**	**7**	**5**	**9**	**8**	**4**	**1**
Tertiary school enrollment (% population in age group)	14.6	75.1	44.4	11.5	36.7	18.4	6.0	23.6	34.8
ranking	**7**	**1**	**2**	**8**	**3**	**6**	**9**	**5**	**4**
Literate workforce (# of workers)	2.62E+07	1.24E+08	1.85E+07	5.09E+07	1.18E+07	2.84E+07	1.76E+08	1.18E+06	6.32E+07
ranking	**6**	**2**	**7**	**4**	**8**	**5**	**1**	**9**	**3**
average ranking	4.88	3.00	3.88	5.29	5.80	6.00	6.63	5.38	2.50
ranking of average rank	**4**	**2**	**3**	**5**	**7**	**8**	**9**	**6**	**1**

Econometric Analysis:

Summary Statistics of Log-Transformed Data

	LNVAM	LNFDI	LNDOMCRE	LNLITWORKER	LNTEL	LNIMDUTY	LNEXDUTY
Mean	25.08383	21.54567	26.27741	17.15783	4.630910	1.729958	-1.024218
Median	24.74518	21.66721	25.67151	17.26101	4.608879	1.959846	-0.991639
Maximum	28.08964	25.96239	29.63425	19.29656	6.494222	3.971649	2.729046
Minimum	22.77999	15.46550	23.15215	13.67529	1.137944	-1.454075	-6.557999
Std. Dev.	1.428198	1.803977	1.808756	1.411724	1.455928	1.189918	2.003147
Skewness	0.749843	-0.364718	0.772061	-0.942399	-0.692358	-0.642415	-0.202323
Kurtosis	2.695519	3.707278	2.240954	3.498766	2.570633	3.474198	2.909898
Jarque-Bera	15.80692	7.183221	20.47653	26.92541	14.97529	12.26989	0.587179
Probability	0.000369	0.027554	0.000036	0.000001	0.000560	0.002166	0.745582
Observations	162	167	166	170	171	157	82

Covariance Matrix of Log-Transformed Data

	LNVAM	LNFDI	LNDOMCRE	LNLITWORKER	LNTEL	LNIMDUTY	LNEXDUTY
LNVAM	0.418664	0.536806	0.362282	0.003674	0.463692	-0.159219	-0.292591
LNFDI	0.536806	2.480679	0.233486	-0.692593	1.491838	-0.900803	-1.062703
LNDOMCRE	0.362282	0.233486	0.515453	0.245240	0.195241	0.001547	-0.460001
LNLITWORKER	0.003674	-0.692593	0.245240	0.835772	-0.730100	0.473440	-0.291755
LNTEL	0.463692	1.491838	0.195241	-0.730100	1.294554	-0.672186	-0.528274
LNIMDUTY	-0.159219	-0.900803	0.001547	0.473440	-0.672186	0.532580	0.360312
LNEXDUTY	-0.292591	-1.062703	-0.460001	-0.291755	-0.528274	0.360312	3.511571

Correlation Matrix of Log-Transformed Data

	LNVAM	LNFDI	LNDOMCRE	LNLITWORKER	LNTEL	LNIMDUTY	LNEXDUTY
LNVAM	1.000000	0.526744	0.779865	0.006211	0.629849	-0.337185	-0.241311
LNFDI	0.526744	1.000000	0.206482	-0.481004	0.832485	-0.783704	-0.360061
LNDOMCRE	0.779865	0.206482	1.000000	0.373640	0.239010	0.002952	-0.341912
LNLITWORKER	0.006211	-0.481004	0.373640	1.000000	-0.701904	0.709625	-0.170303
LNTEL	0.629849	0.832485	0.239010	-0.701904	1.000000	-0.809537	-0.247770
LNIMDUTY	-0.337185	-0.783704	0.002952	0.709625	-0.809537	1.000000	0.263472
LNEXDUTY	-0.241311	-0.360061	-0.341912	-0.170303	-0.247770	0.263472	1.000000

Summary Statistics: Normal Data

	VAM	FDI	DOMCREDIT	LITWORKER	TEL	IMDUTY	EXDUTY
Mean	2.32E+11	7.25E+09	1.04E+12	54079637	189.2861	10.07689	0.648025
Median	5.33E+10	2.34E+09	1.27E+11	29280775	84.44161	7.141679	0.019177
Maximum	1.58E+12	1.08E+11	6.87E+12	2.40E+08	643.7173	53.07197	11.31474
Minimum	7.82E+09	-1.63E+09	1.13E+10	869168.2	3.120347	0.000000	0.000000
Std. Dev.	3.99E+11	1.76E+10	2.02E+12	58521934	188.2570	11.47004	1.789783
Skewness	1.868252	3.812402	1.874652	1.470693	0.775151	2.104130	4.283068
Kurtosis	4.848684	17.30451	4.787376	4.159333	2.169586	6.894334	22.86094
Jarque-Bera	104.9987	1587.488	104.2308	60.39131	18.68702	198.6215	2826.506
Probability	0.000000	0.000000	0.000000	0.000000	0.000088	0.000000	0.000000
Observations	145	145	145	145	145	145	145

Covariance Matrix of Normal Data

	VAM	FDI	DOMCREDIT	LITWORKER	TEL	IMDUTY	EXDUTY
VAM	1.58E+23	4.38E+21	7.96E+23	7.24E+18	5.26E+13	-1.30E+12	-1.11E+11
FDI	4.38E+21	3.06E+20	2.02E+22	2.99E+17	1.83E+12	-4.43E+10	-3.59E+09
DOMCREDIT	7.96E+23	2.02E+22	4.06E+24	3.58E+19	2.62E+14	-6.31E+12	-5.97E+11
LITWORKER	7.24E+18	2.99E+17	3.58E+19	3.40E+15	-6.28E+08	4.31E+08	-12728912
TEL	5.26E+13	1.83E+12	2.62E+14	-6.28E+08	35196.30	-1176.575	-86.21827
IMDUTY	-1.30E+12	-4.43E+10	-6.31E+12	4.31E+08	-1176.575	130.6545	1.787579
EXDUTY	-1.11E+11	-3.59E+09	-5.97E+11	-12728912	-86.21827	1.787579	3.181230

Correlation Matrix of Normal Data

	VAM	FDI	DOMCREDIT	LITWORKER	TEL	IMDUTY	EXDUTY
VAM	1.000000	0.628162	0.991909	0.311902	0.703793	-0.285797	-0.156072
FDI	0.628162	1.000000	0.573351	0.293400	0.557754	-0.221421	-0.114896
DOMCREDIT	0.991909	0.573351	1.000000	0.304769	0.692333	-0.273916	-0.166213
LITWORKER	0.311902	0.293400	0.304769	1.000000	-0.057364	0.647184	-0.122371
TEL	0.703793	0.557754	0.692333	-0.057364	1.000000	-0.548667	-0.257664
IMDUTY	-0.285797	-0.221421	-0.273916	0.647184	-0.548667	1.000000	0.087681
EXDUTY	-0.156072	-0.114896	-0.166213	-0.122371	-0.257664	0.087681	1.000000

While the Jarque-Bera statistics are greater than the critical value of the chi square distribution with 95% of 5.99, which lead me to reject the normal distribution hypothesis, the log transformed data follow the normal distribution more closely than the normal, non-transformed data. The correlation matrix shows that there is a strong correlation between the dependent variable (VAM) and some explanatory variables (FDI, telephone availability, and domestic credit). Similar observations can be made with the normal, non-transformed correlation matrix. Also, the number of observations of EXDUTY is much lower than the other parameters. The treatment of EXDUTY is discussed in more detail in the main section.

First Regression (Equation 1)

Dependent Variable: LNVAM
Method: Least Squares
Date: 12/21/00 Time: 14:28
Sample(adjusted): 4 133
Included observations: 66
Excluded observations: 64 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	5.821484	1.172540	4.964850	0.0000
LNFDILAG	0.015697	0.039607	0.396318	0.6933
LNLITWORKER	0.482553	0.074641	6.464985	0.0000
LNDOMCRE	0.311309	0.058372	5.333168	0.0000
LNTEL	0.612964	0.075493	8.119438	0.0000
LNIMDUTY	0.013022	0.076214	0.170857	0.8649
LNEXDUTY	0.087443	0.018514	4.723044	0.0000

R-squared	0.884015	Mean dependent var	24.63356
Adjusted R-squared	0.872220	S.D. dependent var	0.598493
S.E. of regression	0.213939	Akaike info criterion	-0.146247
Sum squared resid	2.700425	Schwarz criterion	0.085989
Log likelihood	11.82617	F-statistic	74.94789
Durbin-Watson stat	0.299084	Prob(F-statistic)	0.000000

Adjusted Regression (Equation 2)

Dependent Variable: LNVAM
Method: Least Squares
Date: 12/18/00 Time: 15:33
Sample(adjusted): 4 166
Included observations: 117
Excluded observations: 46 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	3.535767	0.479313	7.376740	0.0000
LNFDILAG	0.062370	0.019925	3.130283	0.0022
LNDOMCRE	0.507670	0.045854	11.07155	0.0000
LNLITWORKER	0.296248	0.061855	4.789400	0.0000
LNTEL	0.364297	0.046164	7.891425	0.0000
LNIMDUTY	0.124672	0.048674	2.561361	0.0118

R-squared	0.966041	Mean dependent var	25.04131
Adjusted R-squared	0.964511	S.D. dependent var	1.371352
S.E. of regression	0.258341	Akaike info criterion	0.180851
Sum squared resid	7.408175	Schwarz criterion	0.322501
Log likelihood	-4.579804	F-statistic	631.5292
Durbin-Watson stat	0.200621	Prob(F-statistic)	0.000000

White's Test on basic equation

White Heteroskedasticity Test:

F-statistic	1.966453	Probability	0.044193
Obs*R-squared	18.30866	Probability	0.049975

Test Equation:
Dependent Variable: RESID^2
Method: Least Squares
Date: 12/18/00 Time: 23:26
Sample: 4 166
Included observations: 117
Excluded observations: 46

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	5.528544	4.174086	1.324492	0.1882
LNFDILAG	0.063217	0.095092	0.664806	0.5076
LNFDILAG^2	-0.001439	0.002255	-0.638403	0.5246
LNDOMCRE	-0.359497	0.353224	-1.017760	0.3111
LNDOMCRE^2	0.006622	0.006454	1.026097	0.3072
LNLITWORKER	-0.204032	0.223933	-0.911130	0.3643
LNLITWORKER^2	0.006397	0.006480	0.987168	0.3258
LNTEL	0.154329	0.081479	1.894090	0.0609
LNTEL^2	-0.018052	0.008513	-2.120666	0.0363
LNIMDUTY	0.021935	0.032740	0.669981	0.5043
LNIMDUTY^2	-0.005143	0.011263	-0.456577	0.6489

R-squared	0.156484	Mean dependent var	0.063318
Adjusted R-squared	0.076907	S.D. dependent var	0.097308
S.E. of regression	0.093492	Akaike info criterion	-1.812592
Sum squared resid	0.926511	Schwarz criterion	-1.552900
Log likelihood	117.0366	F-statistic	1.966453
Durbin-Watson stat	0.323785	Prob(F-statistic)	0.044193

Equation 2 with heteroskedasticity-consistent errors

Dependent Variable: LNVAM
Method: Least Squares
Date: 12/18/00 Time: 23:29
Sample(adjusted): 4 166
Included observations: 117
Excluded observations: 46 after adjusting endpoints
White Heteroskedasticity-Consistent Standard Errors & Covariance

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	3.535767	0.404969	8.730953	0.0000
LNFDILAG	0.062370	0.019385	3.217479	0.0017
LNDOMCRE	0.507670	0.048113	10.55163	0.0000
LNLITWORKER	0.296248	0.064929	4.562641	0.0000
LNTEL	0.364297	0.037230	9.785038	0.0000
LNIMDUTY	0.124672	0.055210	2.258166	0.0259

R-squared	0.966041	Mean dependent var	25.04131
Adjusted R-squared	0.964511	S.D. dependent var	1.371352
S.E. of regression	0.258341	Akaike info criterion	0.180851
Sum squared resid	7.408175	Schwarz criterion	0.322501
Log likelihood	-4.579804	F-statistic	631.5292
Durbin-Watson stat	0.200621	Prob(F-statistic)	0.000000

Durbin-Watson Test for Serial Correlation

For the overall data, the Durbin-Watson statistic was 0.200. With k = 5, and 100 observations at the 95% confidence interval, the following values of D_l and D_u were taken from the table:

$D_l = 1.57$, $D_u = 1.78$.

$0<DW<D_l$.

As the Durbin-Watson statistic falls between zero and $D_l = 1.78$, the null hypothesis of no serial correlation is rejected, and a positive serial correlation exists.

Auto-correlation adjustment with Ochrane-Orcutt on Basic Equation

The residuals from the original equation are used to perform the following regression:

$$e_t = \rho^* e_{t-1} + v_t$$

The above equation yielded a new estimate of $\rho = 0.85$, as shown below.

Dependent Variable: EE
Method: Least Squares
Date: 12/22/00 Time: 08:25
Sample(adjusted): 5 163
Included observations: 105
Excluded observations: 54 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
EELAG	0.853641	0.041485	20.57721	0.0000

R-squared	0.801726	Mean dependent var	-0.017855
Adjusted R-squared	0.801726	S.D. dependent var	0.241494
S.E. of regression	0.107532	Akaike info criterion	-1.612570
Sum squared resid	1.202575	Schwarz criterion	-1.587295
Log likelihood	85.65994	Durbin-Watson stat	1.473380

Dependent Variable: LNVAMSTAR2
Method: Least Squares
Date: 12/22/00 Time: 08:42
Sample(adjusted): 5 163
Included observations: 105
Excluded observations: 54 after adjusting endpoints
White Heteroskedasticity-Consistent Standard Errors & Covariance

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.841232	0.128892	6.526641	0.0000
LNFDILAGSTAR2	0.001038	0.010040	0.103383	0.9179
LNLITWORKSTAR2	0.665268	0.059010	11.27391	0.0000
LNDOMCRESTAR2	0.185490	0.053116	3.492168	0.0007
LNTELSTAR2	0.665772	0.062146	10.71298	0.0000
LNIMDUTYSTAR2	-0.016671	0.038796	-0.429693	0.6684

R-squared	0.860386	Mean dependent var	3.801840
Adjusted R-squared	0.853335	S.D. dependent var	0.194822
S.E. of regression	0.074611	Akaike info criterion	-2.297624
Sum squared resid	0.551107	Schwarz criterion	-2.145969
Log likelihood	126.6253	F-statistic	122.0198
Durbin-Watson stat	0.844288	Prob(F-statistic)	0.000000

Calculation of beta zero:

$C = \beta_0 (1-\rho) = 0.84$, with $\rho = 0.85$, $\beta_0 = 0.84/(1-0.85)$ $\beta_0 = 5$.

Country data for selecting best method

Available upon request.

Appendix C. Survey of Mexican Automakers

CUESTIONARIO – INDUSTRIA AUTOMOTRIZ

Este cuestionario es una actividad del Programa Integral de Contaminación del Aire, Global, Regional, y Urbano: tomando a la Ciudad de México como estudio de caso, en el Instituto de Tecnología de Massachusetts (MIT por sus siglas en inglés). El estudio tiene el propósito de entender qué factores afectan la introducción de tecnologías de mitigación de la contaminación en los vehículos de pasajeros en México en los últimos diez años. Se necesita tal conocimiento histórico para evaluar la posible introducción futura de tecnologías de mitigación de la contaminación en México. Sus respuestas contribuirán también al análisis de escenarios para la reducción de la contaminación del aire generada por las fuentes de transporte, que actualmente lleva a cabo el MIT.

Este estudio tiene dos secciones. Sección 1 contiene una serie de preguntas con respecto a los casos anteriores de introducción de tecnologías para el control de la contaminación del aire. Sección 2 contiene preguntas con relación a la dirección futura del sector automotriz en México.

Dado que entendemos sus preocupaciones acerca de la confidencialidad de esta información, hemos tomado medidas para asegurar que sus respuestas permanezcan como confidenciales. Sólo un grupo pequeño de investigadores del proyecto en MIT tendrá autorización para ver sus respuestas directamente. Sus respuestas no serán utilizadas para identificar cualquier violación a la ley y sus reglamentos (si las hubiera) y su observancia por parte de las autoridades federales o estatales (si fuera el caso). Con el propósito de asegurar su confidencialidad, el reporte final no incluirá ninguna información que pudiera revelar la identidad de los encuestados. Todos los resultados serán presentados en forma de estadísticas agregadas. Su participación es voluntaria, y ustedes pueden declinar contestar cualquier pregunta o suspender el cuestionario.

Su cooperación es muy importante para nosotros. Si ustedes tienen cualquier pregunta acerca de este estudio o los objetivos del programa, por favor póngase en contacto con nosotros. Así mismo, lo invitamos a visitar la página web de nuestro programa y obtener mayor información a: http://eaps.mit.edu/megacities

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Sección 1 Factores que afectan la adopción de tecnología

En los últimos diez años, los vehículos de pasajeros en México han sido equipados con tecnologías de control de emisiones cada ves más avanzadas como una respuesta a los problemas de contaminación del aire. Esta sección se enfoca en tres casos de adopción de tecnología para la mitigación de contaminación del aire. Estos casos son: (1) convertidores catalíticos de tres vías, (2) vehículos Tier 1, y (3) diagnósticos a bordo (OBD). Desde 1993, se requirieron convertidores catalíticos de tres vías, y en 1999 se introdujeron normas Tier 1. OBD, que ya se ha instalado en algunos vehículos mexicanos, será obligatoria su introdución en los vehículos en el año 2005.

1.1 Convertidores Catalíticos de Tres Vías

1.1.1. ¿Cuál(es) fue(ron) la(s) fuente(s) de abastecimiento de los convertidores catalíticos de tres vías para vehículos fabricados en México **para el mercado doméstico, cuando las nuevas normas de emisiones cobraron efecto en 1993**? Por favor escriba el porcentaje de convertidores catalíticos de tres vías que fueron producidos localmente por compañías mexicanas, % de convertidores catalíticos de tres vías que fueron producidos localmente por compañías multinacionales o con inversión extranjera mayoritaria, y % de convertidores catalíticos de tres vías que fueron importados. La suma de % deberá ser igual a 100%.[132]

Fuente de abastecimiento de la tecnología	% de convertidores
Tecnologías producidas localmente por compañías mexicanas	
Tecnologías producidas localmente por compañías multinacionales o con inversión extranjera mayoritaria	
Tecnologías importadas	

1.1.2. ¿Cuál(es) fue(ron) la(s) fuente(s) de abastecimiento de los convertidores catalíticos de tres vías para vehículos fabricados en México **para el mercado de exportación, cuando las nuevas normas de emisiones cobraron efecto en 1993**? Por favor escriba el porcentaje de convertidores catalíticos de tres vías que fueron producidos localmente por compañías mexicanas, % de convertidores catalíticos de tres vías que fueron producidos localmente por compañías multinacionales o con inversión extranjera mayoritaria, y % de convertidores catalíticos de tres vías que fueron importados. La suma de % deberá ser igual a 100%.

Fuente de abastecimiento de la tecnología	% de convertidores
Tecnologías producidas localmente por compañías mexicanas	
Tecnologías producidas localmente por compañías multinacionales o con inversión extranjera	

[132] En este estudio, las compañías mexicanas se refieren a empresas que operan en México con una inversión mexicana mayor al 50%. Las compañías multinacionales o con inversión extranjera mayoritaria se refieren a empresas que operan en México con una inversión mexicana menor al 50%. No obstante que muchas compañías multinacionales se establecen como corporaciones mexicanas, estas se categorizan como compañías multinacionales para este estudio si la porción de inversión mexicana es menor del 50%.

mayoritaria	
Tecnologías importadas	

1.1.3. ¿Cuál(es) es(son) la(s) **fuente(s) actuales** de abastecimiento de los convertidores catalíticos de tres vías para vehículos fabricados en México **para el mercado doméstico**? Por favor escriba el porcentaje de convertidores catalíticos de tres vías que son producidos localmente por compañías mexicanas, % de convertidores catalíticos de tres vías que son producidos localmente por compañías multinacionales o con inversión extranjera mayoritaria, y % de convertidores catalíticos de tres vías que son importados. La suma de % deberá ser igual a 100%.

Fuente de abastecimiento de la tecnología	% de convertidores
Tecnologías producidas localmente por compañías mexicanas	
Tecnologías producidas localmente por compañías multinacionales o con inversión extranjera mayoritaria	
Tecnologías importadas	

1.1.4. ¿Cuál (es) es (son) la(s) **fuente(s) actuales** de abastecimiento de los convertidores catalíticos de tres vías para vehículos fabricados en México **para el mercado de exportación**? Por favor escriba el porcentaje de convertidores catalíticos de tres vías que son producidos localmente por compañías mexicanas, % de convertidores catalíticos de tres vías que son producidos localmente por compañías multinacionales o con inversión extranjera mayoritaria, y % de convertidores catalíticos de tres vías que son importados. La suma de % deberá ser igual a 100%.

Fuente de abastecimiento de la tecnología	% de convertidores
Tecnologías producidas localmente por compañías mexicanas	
Tecnologías producidas localmente por compañías multinacionales o con inversión extranjera mayoritaria	
Tecnologías importadas	

1.1.5. Cuando las nuevas normas de emisiones que cobraron efecto en 1993 fueron inicialmente propuestas, las autoridades ambientales organizaron reuniones de consulta y negociación con los fabricantes de automóviles y otros actores involucrados para discutir la propuesta. Durante estas reuniones, la industria automotriz externó sus preocupaciones acerca de la norma propuesta, tal como se listas en la tabla de abajo. Utilizado la escala de 1 a 5 que se muestra abajo, por favor indique la evaluación de su compañía en relación a la importancia de estas preocupaciones durante de las negociaciones.

Extremadamente importante	Bastante importante	Algo importante	Ligeramente importante	No importante
1	2	3	4	5

Preocupaciones	Escala (1-5)	Preocupaciones	Escala (1-5)
Carencia o disponibilidad limitada de tecnología en México		Carga financiera en sector automotriz	
Tecnología no apropiada para condiciones locales (se explica abajo)		Carencia o disponibilidad limitada de combustible apropiado	
Estrategias inconsistentes del gobierno en relación los objetivos de desarrollo industriales y ambientales(se explican abajo)		Desarrollo de capacidad tecnológica requerida en ingenieros y obreros (ej. capacitación, personal adicional)	
Cambio tecnológico requerido en las unidades de producción (ej. líneas nuevas de producción, ajustes)		Incremento proyectado en precio del vehículo	
Instrumentación muy rápida de la tecnología		Otro (por favor especifique)	

1.1.6. ¿Cuál fue el nivel de participación de la oficina corporativa mundial (en EUA, Japón, Alemania) con la gerencia mexicana en las diferentes etapas de toma de decisiones sobre la introducción de tecnología a fin de cumplir con las normas de 1993? Utilizando la escala de 1 a 5 se muestra abajo, por favor indique su evaluación del nivel de participación de la oficina corporativa mundial.

Extremadamente participativa	Bastante participativa	Algo participativa	Ligeramente participativa	Sin participación
1	2	3	4	5

Etapa de la toma de decisiones	Escala (1-5)	Etapa de la toma de decisiones	Escala (1-5)
Propuesta de nuevas normas por parte de autoridades ambientales		Decisión de aceptar la propuesta de las normas	
Evaluación de la posición de la compañía en relación con la propuesta de las normas		Decisión en inversiones necesarias para cumplir con las normas	
Interacciones con otros fabricantes en México para determinar posición del sector automotriz		Determinación de fuentes de abastecimientos de la tecnología necesaria así como de sus partes y componentes	
Negociaciones con autoridades ambientales		Dterminación de destinos de vehículos producidos	

1.1.7. ¿Qué cambios reales, en su caso, fueron necesarios en su compañía para producir vehículos equipados con convertidores catalíticos de tres vías? Por favor explique en la tabla de abajo. Si tales cambios requirieran inversiones, por favor escriba las cantidades monetarias aproximadas de las inversiones así como el tiempo en que fueron aplicadas. Para mejoras en la línea de producción o introducciones, por favor proporcione el número aproximado de la producción del vehículo al año de cada línea de producción.

Categoría	Descripción	Inversión (dólares EUA)	Tiempo de aplicación
Ejemplo	Ejemplo: reformulación de convertidores para combustibles locales (con proveedores de convertidores catalíticos) Ejemplo: capacitación de obreros para la instalación de convertidores catalíticos	\$400,000 \$15,000	90-92 91-92
Mejoramiento de líneas de producción existentes			
Introducción de nuevas líneas de producción			
Cambio en partes y proveedores del componentes			
Adaptación de tecnologías para cumplir con condiciones locales			
Capacitación para ingenieros, gerentes y obreros			
Otro (por favor describa)			

1.1.8. Esta pregunta nos ayudará a entender qué factores pudieron tener efectos en la introducción real de convertidores catalíticos de tres vías en México. Estos factores se dividen en dos grupos y están tabulados de manera separada abajo: un grupo con efecto directo en introducción de tecnología, y otro grupo de factores más indirectos que han ayudado a crear las condiciones que permitan una introducción de tecnología más fácil así como su instrumentación. Por favor califique el efecto de cada variable, utilizando la escala de 1 a 7 se muestra abajo.

Efecto fuertemente positivo	Efecto bastante positivo	Efecto ligeramente positivo	Sin efecto	Efecto ligeramente negativo	Efecto bastante negativo	Efecto fuertemente negativo
1	2	3	4	5	6	7

Tabla de factores con impacto directo					
Factor	Califi-cación	Factor	Califi-cación	Factor	Califi-cación
Normas de emisiones de vehículos en México		Normas de emisión de vehículos en el mercado de exportación		Directivo de las oficinas corporativas mundiales en EUA, Japón, Alemania	
Normas de calidad del aire en México		Normas de calidad del aire en el mercado de exportación		Cambios estructurales globales en sector automotriz	
Entrada en vigor de normas de las emisiones		Normas económicas de los combustibles en el mercado de exportación		Cambio de estrategias al nivel de la compañía hacia regionalización o globalización	
Disponibilidad de nuevas tecnologías de vehículos de proveedores mexicanos		Disponibilidad de nuevas tecnologías de vehículos de proveedores extranjeros que producen en México		Cambio de estrategias al nivel de la compañía hacia la especialización (ej. modelos específicos de unidades para el mercado doméstico)	
Disponibilidad de combustibles más limpios (ej. bajos contenidos de azufre, gasolina sin plomo)		Disponibilidad de tecnología de vehículos importada		Conducta estratégica de la industria en relación con el marco regulatorio (ej. acciones oportunas con el próximo cambio de administración)	
Preferencia del consumidor por vehículos más limpios en México		Preferencia del consumidor por vehículos más limpios en el mercado de exportación		Lograr consenso con el sector automotriz en relación con tecnologías requeridas	
Impuestos sobre automóviles nuevos (ISAN)		Requisitos simplificados de inspección y mantenimiento para los vehículos nuevos		Facilidad de incorporación de tecnologías en proceso de ensamble de vehículo	
Impuesto a valor agregado (IVA)		Otro (por favor especifique)			

Tabla de factores indirectos para crear las condiciones apropiadas					
Factor	Califi-cación	Factor	Califi-cación	Factor	Califi-cación
Disponibilidad de local financiera y crediticia para expansiones y modernizaciones de la planta		Condiciones y ayudas por partes de instituciones multilaterales (ej. Banco Mundial, GEF)		Inversión foránea directa para expansiones y modernización de la planta	
Preparación de la infraestructura (ej. transporte, telecomunicaciones, etc.)		Condiciones y ayuda de instituciones bilaterales (ej. GTZ, JICA, USAID)		Capacidad de gestión en la industria automotriz	
Capacidad institucional de las oficinas del gobierno		Condiciones comerciales (ej. TLCAN)		Disponibilidad de fuerza de trabajo capacitada localmente	
Capacidad local científica y de ingeniería para la adaptación de tecnología a fin de cumplir con las condiciones locales (ej. geografía)		Consideraciones del cambio climático global hacia CO_2 y emisiones de gases de efecto invernadero		Bajo costo de la mano de obra	
Capacidad doméstica de investigación y desarrollo		Cambio en la política industrial hacia la exportación y la liberalización comercial		Imagen corporativa, voluntad	

1.2 Vehículos Tier 1

1.2.1. ¿Cuál(es) fue(ron) la(s) fuente(s) de abastecimiento de las tecnologías de mitigación de emisiones necesarias para cumplir con las normas Tier 1 para vehículos fabricados en México **para el mercado doméstico, cuando las nuevas normas de emisiones cobraron efecto en 1999?** Por favor escriba el porcentaje de tecnologías Tier 1 que fueron producidos localmente por compañías mexicanas, % de tecnologías Tier 1 que fueron producidos localmente por compañías multinacionales o con inversión extranjera mayoritaria, y % de tecnologías Tier 1 que fueron importados. La suma de los porcentajes deberá ser igual a 100%.

Fuente de abastecimiento de la tecnología	% de tecnologías Tier 1
Tecnologías producidas localmente por compañías mexicanas	
Tecnologías producidas localmente por compañías multinacionales o con inversión extranjera mayoritaria	
Tecnologías importadas	

1.2.2. ¿Cuál(es) fue(ron) la(s) fuente(s) de abastecimiento de las tecnologías de mitigación de emisiones necesarias para cumplir con las normas Tier 1 para vehículos fabricados en México **para el mercado de exportación, cuando las nuevas normas de emisiones cobraron efecto en 1999?** Por favor escriba el porcentaje de tecnologías Tier 1 que fueron producidos localmente por compañías mexicanas, % de tecnologías Tier 1 que fueron producidos localmente por compañías multinacionales o con inversión extranjera mayoritaria, y % de tecnologías Tier 1 que fueron importados. La suma de los porcentajes deberá ser igual a 100%.

Fuente de abastecimiento de la tecnología	% de tecnologías Tier 1
Tecnologías producidas localmente por compañías mexicanas	
Tecnologías producidas localmente por compañías multinacionales o con inversión extranjera mayoritaria	
Tecnologías importadas	

1.2.3. ¿Cuál(es) es(son) la(s) **fuente(s) actuales** de abastecimiento de las tecnologías de mitigación de emisiones necesarias para cumplir con las normas Tier 1 para vehículos fabricados en México **para el mercado doméstico**? Por favor escriba el porcentaje de tecnologías Tier 1 que son producidos localmente por compañías mexicanas, % de tecnologías Tier 1 que son producidos localmente por compañías multinacionales o con inversión extranjera mayoritaria, y % de tecnologías Tier 1 que son importados. La suma de los porcentajes deberá ser igual a 100%.

Fuente de abastecimiento de la tecnología	% de tecnologías Tier 1
Tecnologías producidas localmente por compañías mexicanas	
Tecnologías producidas localmente por compañías multinacionales o con inversión extranjera mayoritaria	
Tecnologías importadas	

1.2.4. ¿Cuál(es) es(son) la(s) **fuente(s) actuales** de abastecimiento de las tecnologías de mitigación de emisiones necesarias para cumplir con las normas Tier 1 para vehículos fabricados en México para **el mercado de exportación**? Por favor escriba el porcentaje de tecnologías Tier 1 que son producidos localmente por compañías mexicanas, % de tecnologías Tier 1 que son producidos localmente por compañías multinacionales o con inversión extranjera mayoritaria, y % de tecnologías Tier 1 que son importados. La suma de % deberá ser igual a 100%.

Fuente de abastecimiento de la tecnología	% de tecnologías Tier 1
Tecnologías producidas localmente por compañías mexicanas	
Tecnologías producidas localmente por compañías multinacionales o con inversión extranjera mayoritaria	
Tecnologías importadas	

1.2.5. Cuando las normas de emisiones Tier 1 fueron inicialmente propuestas, las autoridades ambientales organizaron reuniones de consulta y negociación con los fabricantes de automóviles y otros actores involucrados para discutir la propuesta. Durante estas reuniones, la industria automotriz externó sus preocupaciones acerca de las normas propuestas, tal como se listas en la tabla de abajo. Utilizado la escala de 1 a 5 que se muestra abajo, por favor indique la evaluación de su compañía en relación a la importancia de estas preocupaciones durante de las negociaciones.

Extremadamente importante	Bastante importante	Algo importante	Ligeramente importante	No importante
1	2	3	4	5

Preocupaciones	Escala (1-5)	Preocupaciones	Escala (1-5)
Carencia o disponibilidad limitada de tecnología en México		Carga financiera en sector automotriz	
Tecnología no apropiada para condiciones locales (se explica abajo)		Carencia o disponibilidad limitada de combustible apropiado	
Estrategias inconsistentes del gobierno en relación con los objetivos de desarrollo industriales y ambientales (se explican abajo)		Desarrollo de capacidad tecnológica requerida en ingenieros y obreros (ej. capacitación, personal adicional)	
Cambio tecnológico requerido en las unidades de producción (ej. líneas nuevas de producción, ajustes)		Incremento proyectado en precio del vehículo	
Instrumentación muy rápida de la tecnología		Otro (por favor especifique)	

1.2.6. ¿Cuál fue el nivel de participación de la oficina corporativa mundial (en EUA, Japón, Alemania) con la gerencia mexicana en las diferentes etapas de toma de decisiones sobre la introducción de tecnología a fin de cumplir con las normas Tier 1 de 1999? Utilizando la escala de 1 a 5 se muestra abajo, por favor indique su evaluación del nivel de participación de la oficina corporativa mundial.

Extremadamente participativa	Bastante participativa	Algo participativa	Ligeramente participativa	Sin participación
1	2	3	4	5

Etapa de la toma de decisiones	Escala (1-5)	Etapa de la toma de decisiones	Escala (1-5)
Propuesta de nuevas normas por parte de autoridades ambientales		Decisión de aceptar la propuesta de normas	
Evaluación de la posición de la compañía en relación con la propuesta de normas		Decisión en inversiones necesarias para cumplir con las normas	
Interacciones con otros fabricantes en México para determinar posición del sector automotriz		Determinación de fuentes de abastecimiento de la tecnología necesaria así como de sus partes y componentes	
Negociaciones con autoridades ambientales		Dterminación de destinos de vehículos producidos	

1.2.7. ¿Qué cambios reales, en su caso, fueron necesarios en su compañía para producir vehículos equipados con las tecnologías Tier 1? Por favor explique en la tabla de abajo. Si tales cambios requirieran inversiones, por favor escriba las cantidades monetarias aproximadas de las inversiones así como el tiempo en que fueron aplicadas. Para mejoras en la línea de producción o introducciones, por favor proporcione el número aproximado de la producción del vehículo al año de cada línea de producción.

Categoría	Descripción	Inversión (dólares EUA)	Tiempo de aplicación
Ejemplo	Ejemplo: nuevas líneas de producción para vehículos modelo XYZ, dos líneas de producción (2 mil vehículos por año por línea)	$400,000 $15,000	90-92 91-92
Mejoramiento de líneas de producción existentes			
Introducción de nuevas líneas de producción			
Cambio en partes y proveedores del componentes			
Adaptación de tecnologías para cumplir con condiciones locales			
Capacitaron para ingenieros, gerentes y obreros			
Otro (por favor describa)			

1.2.8. Esta pregunta nos ayudará a entender qué factores pudieron tener efectos en la introducción real de tecnologías de reducción de emisiones para cumplir con las normas Tier 1 en México. Estos factores se dividen en dos grupos y están tablados de manera separada abajo: un grupo con efecto directo en introducción de tecnología, y otro grupo de factores más indirectos que han ayudado a crear las condiciones que permitan la introducción de tecnología más fácil así como su instrumentación. Por favor califique el efecto de cada variable, utilizando la escala de 1 a 7 como se explica a continuación.

Efecto fuertemente positivo	Efecto bastante positivo	Efecto ligeramente positivo	Sin efecto	Efecto ligeramente negativo	Efecto bastante negativo	Efecto fuertemente negativo
1	2	3	4	5	6	7

Tabla de factores con impacto directo					
Factor	Califi-cación	Factor	Califi-cación	Factor	Califi-cación
Normas de emisiones de vehículos en México		Normas de emisión de vehículos en el mercado de exportación		Directivo de las oficinas corporativas mundiales en EUA, Japón, Alemania	
Normas de calidad del aire en México		Normas de calidad del aire en el mercado de exportación		Cambios estructurales globales en sector automotriz	
Entrada en vigor de normas de las emisiones		normas económicas de los combustibles en el mercado de exportación		Cambio de estrategias al nivel de la compañía hacia regionalización o globalización	
Disponibilidad de nuevas tecnologías de vehículos de proveedores mexicanos		Disponibilidad de nuevas tecnologías de vehículos de proveedores extranjeros que producen en México		Cambio de estrategias al nivel de la compañía hacia la especialización (ej. Modelos específicos de unidades para el mercado doméstico)	
Disponibilidad de combustibles más limpios (ej. bajos contenidos de azufre, gasolina sin plomo)		Disponibilidad de tecnología de vehículos importada		Conducta estratégica de la industria en relación con el marco regulatorio (ej. acciones oportunas con el próximo cambio de administración)	
Preferencia del consumidor por vehículos más limpios en México		Preferencia del consumidor por vehículos más limpios en el mercado de exportación		Lograr consenso con el sector automotriz en relación con tecnologías requeridas	
Impuestos sobre automóviles nuevos (ISAN)		Requisitos simplificados de inspección y mantenimiento para los vehículos nuevos		Facilidad de incorporación de tecnologías en proceso de ensamble de vehículo	
Impuesto a valor agregado (IVA)		Otro (por favor especifique)			

Tabla de factores indirectos para crear las condiciones apropiadas					
Factor	Califi-cación	Factor	Califi-cación	Factor	Califi-cación
Disponibilidad de local financiera y crediticia para expansiones y modernizaciones de la planta		Condiciones y ayudas por partes de instituciones multilaterales (ej. Banco Mundial, GEF)		Inversión foránea directa para expansiones y modernización de la planta	
Preparación de la infraestructura (ej. transporte, telecomunicaciones, etc.)		Condiciones y ayuda de instituciones bilaterales (ej. GTZ, JICA, USAID)		Capacidad de gestión en la industria automotriz	
Capacidad institucional de las oficinas del gobierno		Condiciones comerciales (ej. TLCAN)		Disponibilidad de fuerza de trabajo capacitada localmente	
Capacidad local científica y de ingeniería para la adaptación de tecnología a fin de cumplir con las condiciones locales (ej. geografía)		Consideraciones del cambio climático global hacia CO_2 y emisiones de gases de efecto invernadero		Bajo costo de la mano de obra	
Capacidad doméstica de investigación y desarrollo		Cambio en la política industrial hacia la exportación y la liberalización comercial		Imagen corporativa, voluntad	

1.3 Diagnósticos a Bordo (OBD)

1.3.1. ¿En qué año su compañía comenzó a vender en el mercado mexicano vehículos equipados con OBD y que fueron producidos en México? ¿Qué porcentaje de vehículos producidos localmente por su compañía en ese año estaban equipados con OBD?

Año: % de vehículos:

1.3.2. ¿En qué año su compañía comenzó a importar vehículos equipados con OBD para el mercado mexicano? ¿Qué porcentaje de vehículos importados por su compañía en ese año estaban equipados con OBD?

Año: % de vehículos:

1.3.3. ¿En qué año su compañía comenzó a exportar vehículos equipados con OBD que fueron producidos en México? ¿Qué porcentaje de vehículos exportados por su compañía en ese año estaban equipados con OBD?

Año: % de vehículos:

1.3.4. ¿Cuál(es) fue(ron) la(s) fuente(s) de abastecimiento de OBD **cuándo su compañía comenzó a vender en el mercado mexicana vehículos equipados con OBD que fueron producidos en México**? Por favor escriba el porcentaje de sistemas/tecnologías OBD que fueron producidos localmente por compañías mexicanas, % de OBD que fueron producidos localmente por compañías multinacionales o con inversión extranjera mayoritaria, y % de OBD que fueron importados. La suma de los porcentajes deberá ser igual a 100%.

Fuente de abastecimiento de la sistema/tecnología	% de OBD
Tecnologías producidas localmente por compañías mexicanas	
Tecnologías producidas localmente por compañías multinacionales o con inversión extranjera mayoritaria	
Tecnologías importadas	

1.3.5. ¿Cuál(es) fue(ron) la(s) fuente(s) de abastecimiento de OBD para vehículos fabricados en México **para el mercado de exportación, cuándo su compañía comenzó a exportar vehículos equipados con OBD**? Por favor escriba el porcentaje de sistemas/tecnologías OBD que fueron producidos localmente por compañías mexicanas, % de OBD que fueron producidos localmente por compañías multinacionales o con inversión extranjera mayoritaria, y % de OBD que fueron importados. La suma de los porcentajes deberá ser igual a 100%.

Fuente de abastecimiento de la sistema/tecnología	% de OBD
Tecnologías producidas localmente por compañías mexicanas	
Tecnologías producidas localmente por compañías multinacionales o con inversión extranjera mayoritaria	
Tecnologías importadas	

1.3.6. ¿Qué porcentaje de vehículos producidos localmente por su compañía para el mercado doméstico están actualmente equipados con OBD?

% de vehículos:

1.3.7. ¿Cuál(es) es(son) la(s) **fuente(s) actuales** de abastecimiento de OBD para los vehículos que fueron producidos en México **para el mercado doméstico**? Por favor escriba el porcentaje de sistemas/tecnologías OBD que son producidos localmente por compañías mexicanas, % de OBD que son producidos localmente por compañías multinacionales o con inversión extranjera mayoritaria, y % de OBD que son importados. La suma de los porcentajes deberá ser igual a 100%.

Fuente de abastecimiento de la sistema tecnología	% de OBD
Tecnologías producidas localmente por compañías mexicanas	
Tecnologías producidas localmente por compañías multinacionales o con inversión extranjera mayoritaria	
Tecnologías importadas	

1.3.8. ¿Qué porcentaje de vehículos importados por su compañía para el mercado de exportación están actualmente equipados con OBD?

% de vehículos:

1.3.9. ¿Cuál(es) es(son) la(s) **fuente(s) actuales** de abastecimiento de OBD para los vehículos que fueron producidos en México **para el mercado de exportación**? Por favor escriba el porcentaje de sistemas/tecnologías OBD que son producidos localmente por compañías mexicanas, % de OBD que son producidos localmente por compañías multinacionales o con inversión extranjera mayoritaria, y % de OBD que son importados. La suma de los porcentajes deberá ser igual a 100%.

Fuente de abastecimiento de la sistema/tecnología	% de OBD
Tecnologías producidas localmente por compañías mexicanas	
Tecnologías producidas localmente por compañías multinacionales o con inversión extranjera mayoritaria	
Tecnologías importadas	

1.3.10 ¿Qué porcentaje de vehículos producidos localmente por su compañía para el mercado doméstico están actualmente equipados con OBD?

% de vehículos:

1.3.11. Cuando el requerimiento de OBD para 2005 fue propuesto recientemente, las autoridades ambientales organizaron reuniones de consulta y negociación con los fabricantes de automóviles y otros actores involucrados para discutir la propuesta. Durante estas reuniones, la industria automotriz externó sus preocupaciones acerca de la norma propuesta, tal como se listas en la tabla de abajo. Utilizado la escala de 1 a 5 que se muestra abajo, por favor indique la evaluación de su compañía en relación a la importancia de estas preocupaciones durante de las negociaciones.

Extremadamente importante	Bastante importante	Algo importante	Ligeramente importante	no importante
1	2	3	4	5

Preocupaciones	Escala (1-5)	Preocupaciones	Escala (1-5)
Carencia o disponibilidad limitada de tecnología en México		Carga financiera en sector automotriz	
Tecnología no apropiada para condiciones locales (se explica abajo)		Carencia o disponibilidad limitada de combustible apropiado	
Estrategias inconsistentes del gobierno en los objetivos de desarrollo industriales y ambientales(se explican abajo)		Desarrollo de capacidad tecnológica requerida en ingenieros y obreros (ej. capacitación, personal adicional)	
Cambio tecnológico requerido en las unidades de producción (ej. líneas nuevas de producción, ajustes)		Incremento proyectado en precio del vehículo	
Instrumentación muy rápida de la tecnología		Otro (por favor especifique)	

1.3.12. ¿Cuál es el nivel de participación de la oficina corporativa mundial (en EUA, Japón, Alemania) con la gerencia mexicana en las diferentes etapas de toma de decisiones sobre la propuesta de OBD requerido? Utilizando la escala de 1 a 5 se muestra abajo, por favor indique su evaluación del nivel de participación de la oficina corporativa mundial.

Extremadamente participativa	Bastante participativa	Algo participativa	Ligeramente participativa	Sin participación
1	2	3	4	5

Etapa de la toma de decisiones	Escala (1-5)	Etapa de la toma de decisiones	Escala (1-5)
Propuesta de nueva norma por parte de autoridades ambientales		Decisión de aceptar la propuesta de norma	
Evaluación de la posición de la compañía en relación con la propuesta de norma		Dcisión en inversiones necesarias para cumplir con la norma	
Interacciones con otros fabricantes en México para determinar posición del sector automotriz		Determinación de fuentes de los abastecimientos de la tecnología necesaria así como de sus partes y componentes	
Negociaciones con autoridades ambientales		Dterminación de destinos de vehículos producidos	

1.3.13. ¿Qué cambios reales, en su caso, son o fueron necesarios en su compañía para producir vehículos equipados con OBD? Por favor explique en la tabla de abajo. Si tales cambios requirieran inversiones, por favor escriba las cantidades monetarias aproximadas de las inversiones así como el tiempo en que fueron aplicadas. Para mejoras en la línea de producción o introducciones, por favor proporcione el número aproximado de la producción del vehículo al ano de cada línea de producción.

Categoría	Descripción	Inversión (dólares EUA)	Tiempo de aplicación
Ejemplo	Ejemplo: los sensores de oxígenos adicionales para modelos del vehículo AB (nuevo proveedor y cambio en la línea de producción)	$40/vehículo	In proceso
Mejoramiento de líneas de producción existentes			
Introducción de nuevas líneas de producción			
Cambio en partes y proveedores del componentes			
Adaptación de tecnologías para cumplir con condiciones locales			
Capacitaron para ingenieros, gerentes y obreros			
Otro (por favor describa)			

1.3.14. Esta pregunta nos ayudará a entender qué factores pudieron tener efectos en la introducción real de OBD en México. Estos factores se dividen en dos grupos y están tablados de manera separada abajo: un grupo con efecto directo en la introducción de tecnología, y otro grupo de factores más indirectos que han ayudado a crear las condiciones que permitan la introducción de tecnología más fácil así como su instrumentación. Por favor califique el efecto de cada variable, utilizando la escala de 1 a 7 como se explica a continuación.

Efecto fuertemente positivo	Efecto bastante positivo	Efecto ligeramente positivo	Sin efecto	Efecto ligeramente negativo	Efecto bastante negativo	Efecto fuertemente negativo
1	2	3	4	5	6	7

Tabla de factores con impacto directo					
Factor	Califi-cación	Factor	Califi-cación	Factor	Califi-cación
Normas de emisiones de vehículos en México		Normas de emisión de vehículos en el mercado de exportación		Directivo de las oficinas corporativas mundiales en EUA, Japón, Alemania	
Normas de calidad del aire en México		Normas de calidad del aire en el mercado de exportación		Cambios estructurales globales en sector automotriz	
Entrada en vigor de normas de las emisiones		normas económicas de los combustibles en el mercado de exportación		Cambio de estrategias al nivel de la compañía hacia regionalización o globalización	
Disponibilidad de nuevas tecnologías de vehículos de proveedores mexicanos		Disponibilidad de nuevas tecnologías de vehículos de proveedores extranjeros que producen en México		Cambio de estrategias al nivel de la compañía hacia la especialización (ej. modelos específicos de unidades para el mercado doméstico)	
Disponibilidad de combustibles más limpios (ej. bajos contenidos de azufre, gasolina sin plomo)		Disponibilidad de tecnología de vehículos importada		Conducta estratégica de la industria en relación con el marco regulatorio (ej. acciones oportunas con el próximo cambio de administración)	
Preferencia del consumidor por vehículos más limpios en México		Preferencia del consumidor por vehículos más limpios en el mercado de exportación		Lograr consenso con el sector automotriz en relación con tecnologías requeridas	
Impuestos sobre automóviles nuevos (ISAN)		Requisitos simplificados de inspección y mantenimiento para los vehículos nuevos		Facilidad de incorporación de tecnologías en proceso de ensamble de vehículo	
Impuesto a valor agregado (IVA)		Otro (por favor especifique)			

Tabla de factores indirectos para crear las condiciones apropiadas					
Factor	Califi-cación	Factor	Califi-cación	Factor	Califi-cación
Disponibilidad de local financiera y crediticia para expansiones y modernizaciones de la planta		Condiciones y ayudas por partes de instituciones multilaterales (ej. Banco Mundial, GEF)		Inversión foránea directa para expansiones y modernización de la planta	
Preparación de la infraestructura (ej. Transporte, telecomunicaciones, etc.)		Condiciones y ayuda de instituciones bilaterales (ej. GTZ, JICA, USAID)		Capacidad de gestión en la industria automotriz	
Capacidad institucional de las oficinas del gobierno		Condiciones comerciales (ej. TLCAN)		Disponibilidad de fuerza de trabajo capacitada localmente	
Capacidad local científica y de ingeniería para la adaptación de tecnología a fin de cumplir con las condiciones locales (ej. geografía)		Consideraciones del cambio climático global hacia CO_2 y emisiones de gases de efecto invernadero		Bajo costo de la mano de obra	
Capacidad doméstica de investigación y desarrollo		Cambio en la política industrial hacia la exportación y la liberalización comercial		Imagen corporativa, voluntad	

Sección 2. La Dirección Futura: 2000 a 2020

Esta sección se enfoca hacia la dirección futura del sector automotriz en México en el año 2020, tal como el crecimiento esperado de varias categorías de vehículos, instrumentos de política y su eficacia percibida. En la medida en que sabemos que los pronósticos de largo plazo son difíciles, su evaluación del futuro del sector es muy importante para nuestro análisis, así como sus perspectivas basadas en su experiencia y conocimiento del sector.

2.1. ¿En su opinión, cuáles son las tasas de crecimiento anual esperadas de nuevos vehículos en las siguientes tres categorías de vehículos en México entre el año 2000 y 2010, y entre 2010 y 2020? Por favor conteste en porcentaje en la siguiente tabla. Si usted lo prefiere, por favor escriba un rango de tasas de crecimiento, como 8 - 10%, 3 - 5%, etc.

Categoría del vehículo	Tasa de crecimiento anual esperada (%): 2000 – 2010	Tasa de crecimiento anual esperada (%): 2010 – 2020
Vehículos grandes, tales como SUVs, camionetas y vans		
Vehículos medianos		
Vehículos compactos		

2.2. Esta pregunta nos ayudará a entender acerca de los posibles países de origen de los vehículos en las tres categorías de arriba disponibles en México entre el año 2000 - 2010, y 2010 - 2020. Para cada categoría, por favor indique el porcentaje de vehículos (en circulación en México) que serán producidos localmente, en los Estados Unidos, Japón, Europa, y en otros países. Las respuestas en cada categoría deben sumar 100%.

	Países de producción del vehículo: 2000 – 2010				
Categoría del vehículo	México (%)	EUA (%)	Japón (%)	Europa (%)	Otro (%) – por favor especifique
Vehículos grandes, tales como SUVs, camionetas y vans					
Vehículos medianos					
Vehículos compactos					

	Países de producción del vehículo: 2010 – 2020				
Categoría del vehículo	México (%)	EUA (%)	Japón (%)	Europa (%)	Otro (%) – por favor especifique
Vehículos grandes, tales como SUVs, camionetas y vans					
Vehículos medianos					
Vehículos compactos					

2.3. ¿En su opinión, cuál es la contribución porcentual de cada tipo de vehículo en México en el año 2010 y en 2020? Por favor califique la participación porcentual de cada tipo de vehículo comparada con el nivel del año 2000, utilizando la escala de 1 a 7 tal como se explica abajo. Si usted piensa que la tecnología no será introducida en el año 2010 o 2020, por favor escriba N/D.

% de flota extramada-mente grande	% de flota bastante grande	% de flota ligeramente grande	Sin cambio en la porción de flota	% de flota ligeramente pequeño	% de flota muy pequeño	% de flota extramada-mente pequeño
1	2	3	4	5	6	7

Tipo de Vehículo	2010 % de flota	2020 % de flota	Tipo de Vehículo	2010 % de flota	2020 % de flota
Vehículos a gasolina			Vehículos híbridos gasolina - eléctrico		
Vehículos diesel			Vehículos duales diesel – GNC		
Vehículos a gas natural comprimido			Otros vehículos híbridos		
Vehículos a gas LP			Vehículos eléctricos		
Vehículos a metanol			Vehículos impulsados por celdas de combustible (hidrogeno)		
Vehículos a etanol			Otro (por favor especifique)		

2.4. Esta pregunta nos ayudará a entender qué tipos de incentivos y regulaciones son necesarios para introducir y adoptar nuevas tecnologías automotrices en México. Los incentivos y regulaciones están divididos en dos grupos y se presentan en las tablas de abajo: un grupo de incentivos y regulaciones con efecto directo en la introducción y adopción de la tecnología, y otro grupo de efectos más indirectos para crear condiciones más favorables para la introducción y adopción de la tecnología. Por favor califique el efecto de cada incentivo y regulación, utilizando la escala de 1 a 7 como se explica abajo:

Efecto fuertemente positivo	Efecto bastante positivo	Efecto ligeramente positivo	Sin efecto	Efecto ligeramente negativo	Efecto bastante negativo	Efecto fuertemente negativo
1	2	3	4	5	6	7

Efecto fuertemente positivo	Efecto bastante positivo	Efecto ligeramente positivo	Sin efecto	Efecto ligeramente negativo	Efecto bastante negativo	Efecto fuertemente negativo
1	2	3	4	5	6	7

Tabla de incentivos y regulaciones con impacto directo en la introducción y adopción de tecnología					
Factor	Califi-cación	Factor	Califi-cación	Factor	Califi-cación
Normas de emisiones de vehículos más severas en México		Precios preferenciales para combustibles más limpios (ej. gasolina con bajo contenidos de azufre, GNC, GLP)		Normas de emisiones homologadas en varios países	
Normas de calidad del aire más severas en México		Impuestos reducidos y subsidios para comprar vehículos con combustible alternos y otros vehículos más limpios (ej. ISAN reducido)		Normas de emisiones de vehículos más severas en el mercado de exportación	
Aplicación estricta de normas de emisiones		Requisitos de adquisición de vehículos más limpios con combustibles alternos en oficinas gobiernos y empresas		Normas de calidad del aire más severas en el mercado de la exportación	
Introducción de normas de eficiencia de combustibles en México		Impuesto al valor agregado (IVA) más baja en todas las compras del vehículo		Normas de eficiencia de combustibles más severas en el mercado de exportación	
Requisitos simplificados de inspección y mantenimiento para los vehículos más limpios		*Hoy No Circula* y otras restricciones a la circulación de vehículos más viejos		Aplicación de precios preferenciales de circulación para vehículos más limpios (ej. cuotas en carreteras de cobro)	
Requisitos simplificados de inspección y mantenimiento para los vehículos de combustibles alternos		Disponibilidad de esquemas de financiamiento de automóviles		Otro (por favor especifique)	
Incremento de los derechos por el registro de los vehículos más viejos		Desechar vehículos más viejos en México			

Tabla de incentivos y regulaciones por crear condiciones más favorables					
Factor	Califi-cación	Factor	Calif-icación	Factor	Califi-cación
Medidas económicas para facilitar inversiones domesticas para la producción de tecnologías más limpias		Condiciones comerciales (ej. TLCAN)		Medidas económicas para facilitar inversión foránea directa en plantas nuevas y modificaciones	
Preparación de la infraestructura (ej. gasoductos, estaciones re-abastecimiento y telecomunicación)		Medidas económicas para facilitar importación de tecnologías más limpias (ej. incentivos fiscales)		Programas para desarrollar la capacidad gerencial en la industria automotriz	
Programas para incrementar capacidad institucional de oficinas de gobierno		Condiciones y ayudas de instituciones multilaterales (ej. Banco Mundial, GEF)		Programas para desarrollar la capacidad técnico de ingenieros y obreros	
Apoyo para investigación y desarrollo para la adaptación tecnológica para cumplir con las condiciones locales (ej. geografía)		Condiciones y ayudas de instituciones bilaterales (ej. GTZ, JICA, USAID)		Otro (por favor especifique)	
Programa de demostración de		Tratado del cambio			

Tabla de incentivos y regulaciones por crear condiciones más favorables					
Factor	Califi-cación	Factor	Calif-icación	Factor	Califi-cación
vehículos de combustibles alternos		climático para reducir CO_2 y emisiones de gases de efecto invernadero de las fuentes mobiles			

2.5. Además de los incentivos y regulaciones anteriores, la introducción y adopción de nuevas tecnologías automotrices están pensadas para ser afectadas por otros factores que no necesariamente están vinculados directamente a políticas gubernamentales. La siguiente tabla incluye algunos de estos factores. Por favor califique el efecto de estos factores en la nueva introducción y adopción de tecnología, utilizando la misma escala de 1 a 7.

Factor	Califi-cación (1-7)	Factor	Califi-cación (1-7)	Factor	Califi-cación (1-7)
Preferencia del consumidor en México		Bajo costo de la mano de obra		Cambio de estrategias al nivel de la compañía hacia regionalización o globalización	
Demanda por los vehículos más limpios en mercado doméstico		Facilidad de incorporación de nuevas tecnologías en proceso de ensamble de vehículo		Cambio de estrategias al nivel de la compañía hacia especialización (ej. modelos específicos de unidades para el mercado doméstico)	
Preferencia del consumidor en mercado de exportación		Imagen corporativa, voluntad		Directrices de las oficinas corporativas mundiales en EUA, Japón, Alemania	
Demanda por los vehículos más limpios en mercado de exportación		Cambios estructurales globales en sector automotriz		Otros (por favor especifique)	

2.6. ¿Cual es su evaluación acerca de las fuentes de abastecimiento de tecnologías automotrices avanzadas (ej. Vehículos con combustibles alternos, tecnologías de control de emisiones) en México en 2010 y 2020? Por favor encierre con un circulo sí o no en los cuadros.

Fuente de abastecimiento de la tecnología	2010	2020
Incremento en la producción local de tecnologías avanzadas por compañías mexicanas para la producción domestica de vehículos	Sí No	Sí No
Incremento en la producción local de tecnologías avanzadas por parte de compañías con inversión extranjera mayoritaria con plantas de producción en México	Sí No	Sí No
Incremento en la importación de tecnologías avanzadas para producir vehículos en México	Sí No	Sí No
Incremento en la importación de vehículos avanzados, en lugar de la importación de tecnologías para la producción domestica de vehículos	Sí No	Sí No

2.7. ¿Cuál es **la preferencia de su compañía** en la diferenciación o normalización des modelos de vehículos en México? Por favor encierre con un circulo sí o no en los cuadros.

Vehículo diferenciación ejemplar o regularización	2010	2020
Diferenciación continua de algunos vehículos mexicanos y norteamericanos con diferentes características de emisiones	Sí No	Sí No
Mayor normalización de vehículos mexicanos y norteamericanos con características similares de emisiones	Sí No	Sí No
Mayor normalización de vehículos mexicanos y de países en desarrollo (ej. Latinoamericanos) con características similares de emisiones	Sí No	Sí No
Mayor normalización de vehículos al nivel global con características de la emisión similares	Sí No	Sí No
Otro (por favor especifique)		

2.8. ¿Cuál es su evaluación acerca de la diferenciación o normalización des modelos de vehículos en México **para la totalidad del sector automotriz**? Por favor encierre con un circulo sí o no en los cuadros.

Vehículo diferenciación ejemplar o regularización	2010	2020
Diferenciación continua de algunos vehículos mexicanos y norteamericanos con diferentes características de emisiones	Sí No	Sí No
Mayor normalización de vehículos mexicanos y norteamericanos con características similares de emisiones	Sí No	Sí No
Mayor normalización de vehículos mexicanos y de países en desarrollo (ej. Latinoamericanos) con características similares de emisiones	Sí No	Sí No
Mayor normalización de vehículos al nivel global con características de la emisión similares	Sí No	Sí No
Otro (por favor especifique)		

2.9. Por favor estime el porcentaje de varios destinos posibles de vehículos que son actualmente producidos en México por su compañía, en el año 2010, y en 2020.

Destinos de vehículos	% de producción actual	% estimado de producción: 2010	% estimado de producción: 2020
Vehículos producidos para el mercado doméstico			
Vehículos producidos para el mercado de EUA			
Vehículos producidos para el mercado europeo			
Vehículos producidos para el mercado latinoamericano			
Vehículos producidos para otros mercados (por favor especifique)			

Información personal

¿Cuál es su puesto dentro de su organización? ____________________

¿Años en su puesto actual? ____________

¿Años de experiencia directa en aspectos de la industria automotriz? ____________

Nombre:

Dirección:

Teléfono:

Fax:

Correo electrónico:

GRACIAS POR SU COOPERACION

Appendix D. Scenario Analysis Background Information

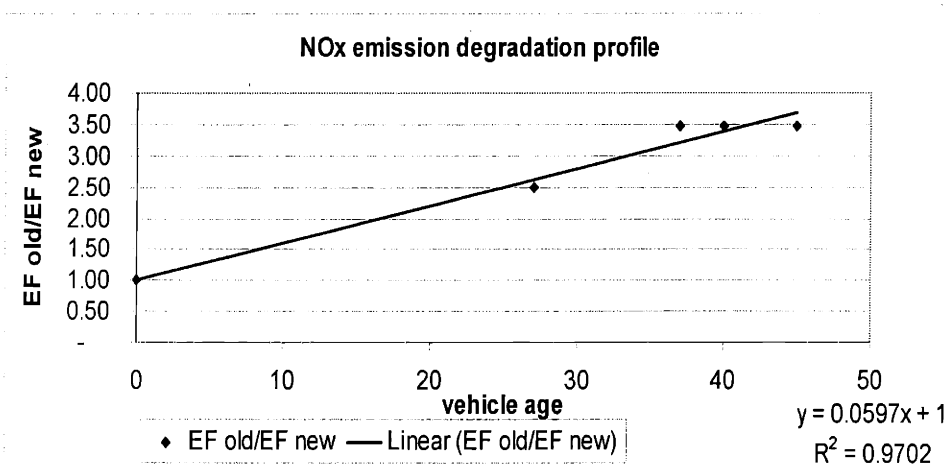
Parameter specification table for emission modeling

	A	B	C
1	**Variables (considered to be policy susceptible)**		
2			
3			
4	**Future stories**		
5	Future story: 1 for keep up, 2 for growth, 3 for drag	1	keep up
6	Inflation rate	6.70%	
7			
8			
9			
10			
11	**Economic variables**		
12	Average national GDP growth rate	3.64%	
13		DF	EdM
14	Share of GDP: fitted equation (F) or % growth (P), or future stories (S)?	S	S
15	If using %, % growth rate	-	-
16	population growth: fitted equation (F) or % growth (P), or future stories (S)?	S	S
17	If P, what annual growth rate? (example: -0.1 to 0.1%, not sure)	0%	0%
18			
19	Fleet growth: regression (F) or % growth (P)?	F	F
20	If using %, % growth rate	-	-
21	% of unregistered vehicles in total fleet	0%	0%
22			
23	**Technological change**		
24	Tier 2: timing of introduction in MCMA	2026	
25	Tier 2: % pacing of phase-in schedule (% of applicable fleet)	25%	
26	Post Tier 2 (LEVII): timing of introduction in MCMA	2012	
27	Post Tier 2:pacing of phase-in schedule: 1 for aggressive, 2 for moderate phase-in schedule	1	
28	Additional emission warranty above 80,000 km: timing of introduction in MCMA (80,000km warranty for Tier 2 and beyond automatically included)	2026	
29	Additional emission warranty: km of coverage (should be greater than 80K km, but less than 192K km)	192000	
30	default coverage year: 10 years or warranty km, whichever comes first	10	
31	**Fuel quality**		
32		PREMIUM	MAGNA
33	Target sulfur concentration (ppm)	50	300
34	timing of fuel quality improvement initiation	2026	2026
35	% pacing of phase-in schedule	25%	25%
36			
37			
38	**Fuel economy**		
39	% difference from US fuel economy trend implied fuel economy in 1998: 17.6 mpg (-36% equals fuel sales data from 98 inventory)	-36%	
40	Expected improvement in fuel economy in % Implied real fuel economy: 18.48 mpg, potential fuel economy: 28.875 mpg	5%	
41	timing of fuel economy improvement	2026	
42	% pacing of phase-in schedule	100%	
43			
44	**VKT growth**		
45	Average annual VKT growth rate	0.00%	
46	Constant VKT (C) or with VKT degradation factor (D)?	C	constant
47	If D, specify the degradation factor (0.045 for US average)	0.045	
48	For C, average VKT (from 98 EI)	10329	
49			
50			
51	**Scrappage**		
52	class of technology to be scrapped 0: no control, 1: non-catalyst control (81-90), 2: 2-way catalyst, 3: 3-way catalyst	2	2-way catalyst and less
53	# of cars to be scrapped each year	0	
54	beginning and end of scrappage program	2003	2010
55	% of scrapped vehicles to be replaced by new vehicles	10%	
56			
57	**Hoy No Circula**		
58	Hoy No Circula starting and ending years	1988	2026
59	HNC exemption change: starting year, and # of years of exemption for new vehicles (I.e, 0 means no exemption, 3 means less than 3 years old)	2026	5

Nox emission factors

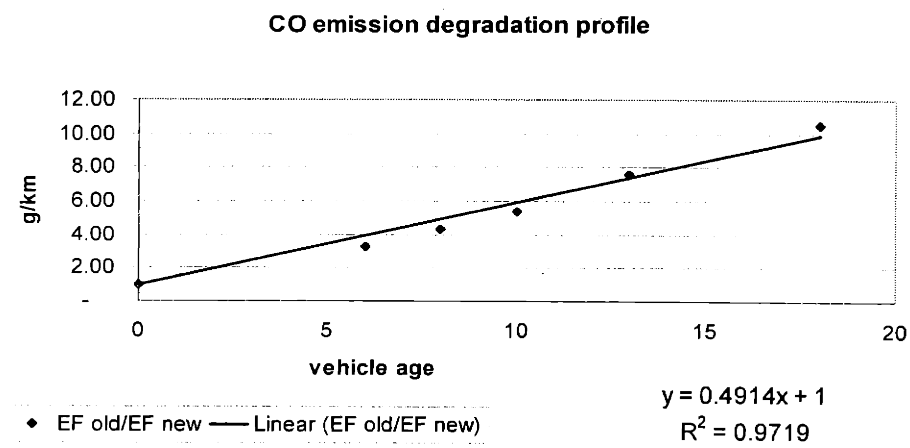
tech class	*warranty*	*beginning*	*end*	**NOx EF in Mexico** g/km	**US standard** g/km	**US** % reduction
		1950	**1974**	**2.1**	**2.30**	
		1975	**1980**	**2.1**		
		1981	**1985**	**2.1**		
		1986	**1988**	**2.1**		
		1989	**1990**	**2.4**		
oxidation	-	**1991**	**1992**	**2.4**		
3-way (Tier 0)	-	**1993**	**1998**	**1.5**	**0.6**	
Tier 1	-	**1999**	2025	0.60	**0.25**	60%
Tier 2	**80,000**	n/a	n/a	0.09	0.03671875	94%
Tier 2	192,000	n/a	n/a	0.11	0.04375	93%
LEV	80,000	n/a	n/a	0.08	0.03125	95%
ULEV	80,000	n/a	n/a	0.08	0.03125	95%
SULEV	80,000	n/a	n/a	0.03	0.0125	98%
ZEV	80,000	n/a	n/a	0.00	0	100%
LEV	192,000	n/a	n/a	0.11	0.04375	93%
ULEV	192,000	n/a	n/a	0.11	0.04375	93%
SULEV	192,000	n/a	n/a	0.03	0.0125	98%
ZEV	192,000	n/a	n/a	0.00	0	100%

Tier 2 standard is an average from 8 final bins - for NOx, I am using 0.07g/mi as that is the ma



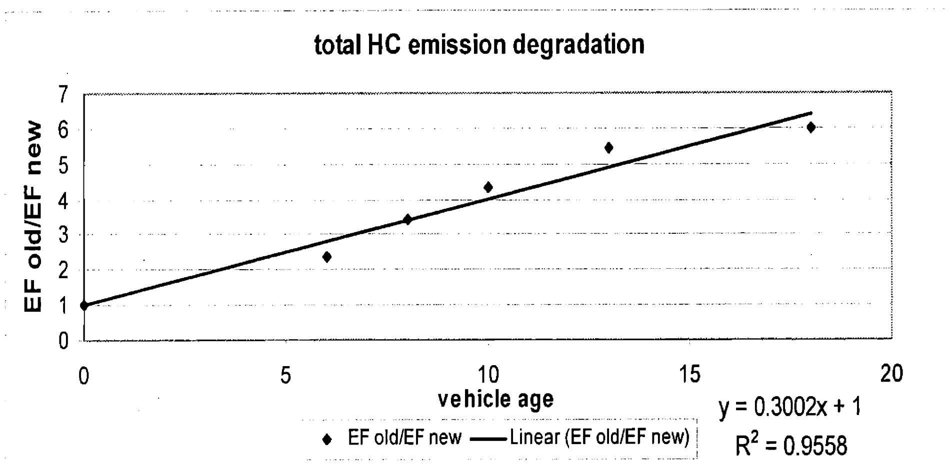
CO Emission Factors

tech class	*warranty*	*beginning*	*end*	CO EF in Mexico g/km	US standard g/km	US % reduction
		1950	1974	76.4	54.000	
		1975	1980	76.4		
		1981	1985	55.6		
		1986	1988	39.6		
		1989	1990	31.4		
oxidation	-	1991	1992	23.7		
3-way (Tier 0)	-	1993	1998	7.3	2.110	
Tier 1	-	1999	2025	7.30	2.110	0%
Tier 2	80,000	n/a	n/a	5.38	1.555	26%
Tier 2	192,000	n/a	n/a	6.24	1.805	14%
LEV	80,000	n/a	n/a	7.35	2.125	-1%
ULEV	80,000	n/a	n/a	3.68	1.063	50%
SULEV	80,000	n/a	n/a	2.16	0.625	70%
ZEV	80,000	n/a	n/a	0.00	0.000	100%
LEV	192,000	n/a	n/a	9.08	2.625	-24%
ULEV	192,000	n/a	n/a	4.54	1.313	38%
SULEV	192,000	n/a	n/a	2.16	0.625	70%
ZEV	192,000	n/a	n/a	0.00	0.000	100%



Hydrocarbon emission factors

tech class	warranty	beginning	end	HC EF in Mexico g/km	US standard g/km	US % reduction
		1950	**1974**	**6.255**	**5.50**	
		1975	**1980**	**6.255**		
		1981	**1985**	**5.684**		
		1986	**1988**	**4.545**		
		1989	**1990**	**3.59**		
oxidation	-	**1991**	**1992**	**2.456**		
3-way (Tier 0)	-	**1993**	**1998**	**1.047**	**0.3**	
Tier 1	-	**1999**	2025	0.65	**0.16**	38%
Tier 2	**80,000**	n/a	n/a	0.15	0.0359375	86%
Tier 2	192,000	n/a	n/a	0.17	0.04140625	83%
LEV	80,000	n/a	n/a	0.20	0.046875	81%
ULEV	80,000	n/a	n/a	0.10	0.025	90%
SULEV	80,000	n/a	n/a	0.03	0.00625	98%
ZEV	80,000	n/a	n/a	0.00	0	100%
LEV	192,000	n/a	n/a	0.24	0.05625	78%
ULEV	192,000	n/a	n/a	0.14	0.034375	86%
SULEV	192,000	n/a	n/a	0.03	0.00625	98%
ZEV	192,000	n/a	n/a	0.00	0	100%



Cost Estimations

Emission technology cost assumptions

parameter	specify	parameter	specify	parameter	specify
Please specify the depreciation period of technologies (years)	10	Please estimate the cost of LEV technology (2000 US$)	872	Opportunity cost or social cost of capital	0%
Please estimate the cost of 2-way catalysts (2000 US$)	307	Please estimate the cost of ULEV technology (2000 US$)	893		
Please estimate the cost of 3-way catalysts (2000 US$)	613	Please estimate the cost of SULEV technology (2000 US$)	953		
Please estimate the cost of Tier 1 technology (2000 US$)	822	Please estimate the cost of ZEV technology (2000 US$)	3822		
Please estimate the cost of Tier 2 technology (2000 US$)	892	Please estimate the cost increase associated with warranty provision	19%	% increase in cost per 10,000km of warranty	1%

The 2-way catalyst, 3-way catalyst, and Tier 1 costs: Faiz, p. 75, adjusted from 1990 to 2000 US dollars.
The Tier 2 costs: Tier 2 Regulatory Impact Analysis by EPA (not inflated).
ULEV and SULEV estimates: Walsh, p. 12
ZEV estimate: CARB estimates $7500 for city EV, and $2000 0 for freeway EV, but these costs are expected to go down substantially.
LEV estimate: guess

Fuel economy cost assumptions

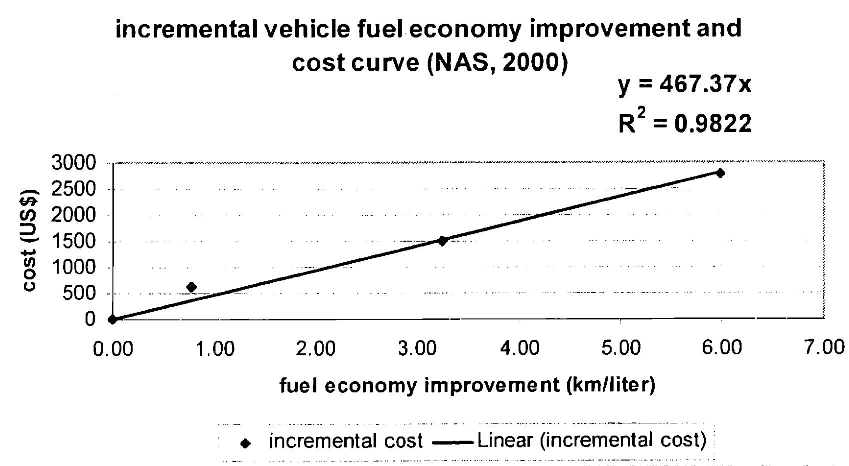
parameter	specify	parameter	specify	parameter	specify
Depreciation in years (use same number as emission technologies)	10	Please estimate the cost of improving fuel economy by 1km in 2000 US$	467	allocated to CO2 for cost benefit analysis (rest allocated to other pollutants)	70%
depreciation in years (use same number as emission technologies)	10	Please estimate the average peso to US$ exchange rate (peso/$)	10	Please specify when fidelcomiso starts	2026
Opportunity cost or social cost of capital	0%	Please specify when fidelcomiso ends	2026	how much fidelcomiso (in 2000US$)	0.03

	miles/gal	km/liter
starting real fuel economy	17.60	7.44
target real fuel economy	18.48	7.81
starting potential fuel economy	27.5	11.62
target potential fuel economy	28.88	12.21

real: actual fuel economy in road conditions, potential: technologically feasible)
(referenced from fuel consumption worksheet)

	Path 1		Path 2		Path 3	
source: National Academy of Sciences (2002), Effectiveness and Impact of CAFÉ standards	average fuel economy (mpg)	average cost (2000 US$)	average fuel economy (mpg)	average cost (2000 US$)	average fuel economy (mpg)	average cost (2000 US$)
subcompact	34.39	465	38.82	1018	46.13	2055
compact	30.75	465	35.33	1088	41.94	2125
midsize	27.9	640	34.6	1642	41.05	3252
large	24.25	972	32.04	2290	37.59	3655
average	29.32	635.5	35.2	1510	41.7	2772

	fuel economy (km/l)	incremental cost		km/l
current	0.00	0	current CAFÉ	11.62
path 1	0.77	635.5		km/l
path 2	3.25	1509.5	slope	467.37
path 3	6.0	2772	Y intercept	0



Retrofit cost assumptions

parameter	specify	parameter	specify
Please estimate the retrofit technology cost per vehicle in 2000 US$	500	Please estimate the % of the annual I&M cost to be attributed to retrofit	10%
Please estimate the administrative cost associated with the program on per vehicle basis in 2000 US$	100	Please estimate the consumer expense of participating in retrofit programs in 2000 US$	150

Retrofit costing notes:
Retrofit programs are normally carried out at county/minicipality levels, with support from municipal and state resources.

Two programs considered for this analysis are San Diego, CA and Maricopa, AZ.

Cost and program references:
Environmental Services Department (2001). Voluntary Vehicle Repair and Retrofit Program, ADEC Contract 99-0089, Mariposa Country, AZ.
http://www.maricopa.gov/envsvc/COMMUNIT/vrr/vvrr-monetary.asp
http://www.neutronics.com/program.htm

Mariposa case	inspection required!		**San Diego case**	inspection required!	
state funds	320,000	(1 year)	state funds	?	
county administrative funds	33,333	(1 year average, 50K for 1 yr.)	contry administrative funds	?	
consumer expense	150	per vehicle	consumer expense		150 per vehicle
technology cost	418	per vehicle	technology cost		500 per vehicle
average admin cost	110	per vehicle	average admin cost	?	

Both programs mentioned the importance of advertising to increase demand. For this purpose, SD has allocated $50,000

Emission Reduction

Mariposa average reduction (2000 report)	HC	CO	NOx
	78%	84%	64%

	avoidance	cost		cost per pollution
normal: calculate reduction	150000		120000	0.8

ours: calculate emissions	normal	retrofit
# of cars	200	200
# of VKT	5000	5000
emission factor	0.3	0.15
emissions	300000	150000
incremental cost	0	600
total cost	0	120000
cost per pollutant	0	0.8

Hoy No Circula cost assumptions

parameter	specify	parameter	specify
Please estimate the annual I&M cost per vehicle in 2000 US$	40	how many days of HNC?	1
Please estimate the % of the annual I&M cost to be attributed to hoy no circula	20%	What is the multiplier on administrative cost with more than 1 day of HNC?	15%

	number	unit cost	depreciation (years)
patrol car	20	(see right chart)	5
personnel	40	10,000	n/a
outreach	1	50,000	n/a
vehicle O&M	20	(see right chart)	n/a

O&M and fuel costs are estimated to be twice as high for patrol vehicles compared to normal vehicles

year of purchase	average annualized vehicle cost (2000$)	average O&M cost (2000$)	average fuel cost (2000$)	total O&M cost (2000$)	average fuel economy (km/l)	average fuel price(2000$/liter)
1988	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
1993	#N/A	#N/A	#N/A	#N/A	7.44	#N/A
1998	$ 2,198	$ 215	$ 1,398	$ 1,613	7.44	0.50
2003	$ 2,345	$ 215	$ 1,398	$ 1,613	7.44	0.50
2008	$ 2,501	$ 215	$ 1,398	$ 1,613	7.44	0.50
2013	$ 2,668	$ 215	$ 1,398	$ 1,613	7.44	0.50
2018	$ 2,846	$ 215	$ 1,398	$ 1,613	7.44	0.50
2023	$ 3,036	$ 215	$ 1,398	$ 1,613	7.44	0.50
2026	$ 3,115	$ 215	$ 1,404	$ 1,619	7.44	0.51