Innovation in Mexico: NAFTA Is Not Enough[1]

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[1] Pastor (2002) used the title "NAFTA Is Not Enough." This author, however, does not address issues related to innovation policies.

Contents

Figures and Tables

1. Introduction

This chapter examines the evolution of Mexican technological progress in the past few decades, with special attention given to the role of trade, foreign direct investment, and the national innovation system. The main message is that trade liberalization and NAFTA are helpful but they are not enough to help Mexico catch-up to the levels of innovation and the pace of technological progress observed in its North American partners, especially the United States. In fact, the evidence reviewed here suggests that, given its level of development, Mexico suffers from low levels of research and development expenditures and low levels of patenting activity, and it severely under-performs when compared to successful economies, such as Korea, needless to mention the U.S. In addition, its national innovation system – how the private sector, universities, and public policies interact to produce economically meaningful innovation – is inefficient. Without addressing these deficiencies, it is unlikely that NAFTA alone will be sufficient for Mexico to catch-up with the pace of innovation in North America.

Most of the analyses presented in this chapter are quantitative, relying on internationally comparable indicators of various aspects of innovative activity and technological progress provided by Lederman and Sáenz (2003). We also attempt to compare Mexico's performance in the various dimensions of innovation to a set of countries and regions.

In addition to international comparisons, this chapter also relies on econometric analyses of various aspects of innovation. In particular, we look at the empirical determinants of patenting activities and the economic returns of research and development expenditures (R&D) and licensing payments. In addition, our analysis of Mexico's innovation system also relies on estimates of the evolution of sector-level "revealed comparative advantage in innovation," as well as on more qualitative discussions of the incentives faced by Mexican researchers and firms. The hope is that the combination of analytical approaches presented herein will suffice to convince the reader that in the long-run, Mexico needs to make substantial policy improvements in order to help it catch-up with the pace of innovation in North America – NAFTA is not enough.

The rest of the chapter is organized as follows. Section II reviews the basic facts concerning Mexican innovation and technological progress since the 1960s by examining the evolution of various indicators of innovation and technological progress. Section III reviews the literature linking growth, innovation, trade, and FDI. Sections IV and V are the core of the analysis on Mexican innovation, they attempt to answer two essential policy questions: does Mexico need to raise the level of R&D or licensing efforts and does it need to improve the efficiency of its National Innovation System (NIS) in order to raise the innovation outputs of its R&D inputs?. The final section VI summarizes the main policy recommendations of this chapter.

1.2 Mexican Innovation and Technological Progress since the 1960s

At the outset of any analysis of innovation performance it is necessary to discuss how innovation and technological progress can be assessed. In fact, there are numerous potential indicators of innovation. The following paragraphs discuss some key methodological issues.

A. Measuring innovation and technological progress

Studies of innovation performance usually focus on indicators of outcomes and inputs. One of the most heavily used indicators of outcomes is the level and growth rate of total factor productivity (TFP). This is generally understood to be the portion of the economic growth, or growth of Gross Domestic Product (GDP), which is not explained by the accumulation of raw labor, physical capital, perhaps human capital, ideally after controlling for capacity utilization. Since the pioneering work of Solow (1956, 1957), this indicator has been thought to be driven by technological progress, although as discussed in section III below, it is not clear that technological progress is driven only by worldwide innovation that can be easily adopted by developing countries.

Another commonly used innovation proxy is the number of patents. That is, it is widely believed that patent statistics reflect the flow of innovations covering either adaptations of existing patents or brand new inventions (Griliches 1990; Patel and Pavitt 1995). Measures of the number of patents granted to researchers from around the globe, however, are not without flaws. One particularly important consideration is that costs of applying for patents, the level of intellectual property protection, the pecuniary benefits from patents, and other institutional features vary greatly across countries. Thus patents granted by agencies from one country are not strictly comparable to those granted by others. In what follows we also use the number of patents granted to Mexican residents by the United States Patent and Trademark Office (USPTO) as a proxy for the flow of innovation.[2] The data from the USPTO is attractive due to its global and long time coverage, and especially because it is commonly understood that the U.S. offers perhaps the most advanced levels of intellectual property protection in the world (Maskus 2000). Although the costs of the application process are likely to be higher in the U.S. than in most other countries, the benefits are also likely to be higher. In any case, U.S. patents are our preferred indicator of the flow of innovation worldwide.

B. Evolution of innovation outcomes in Mexico

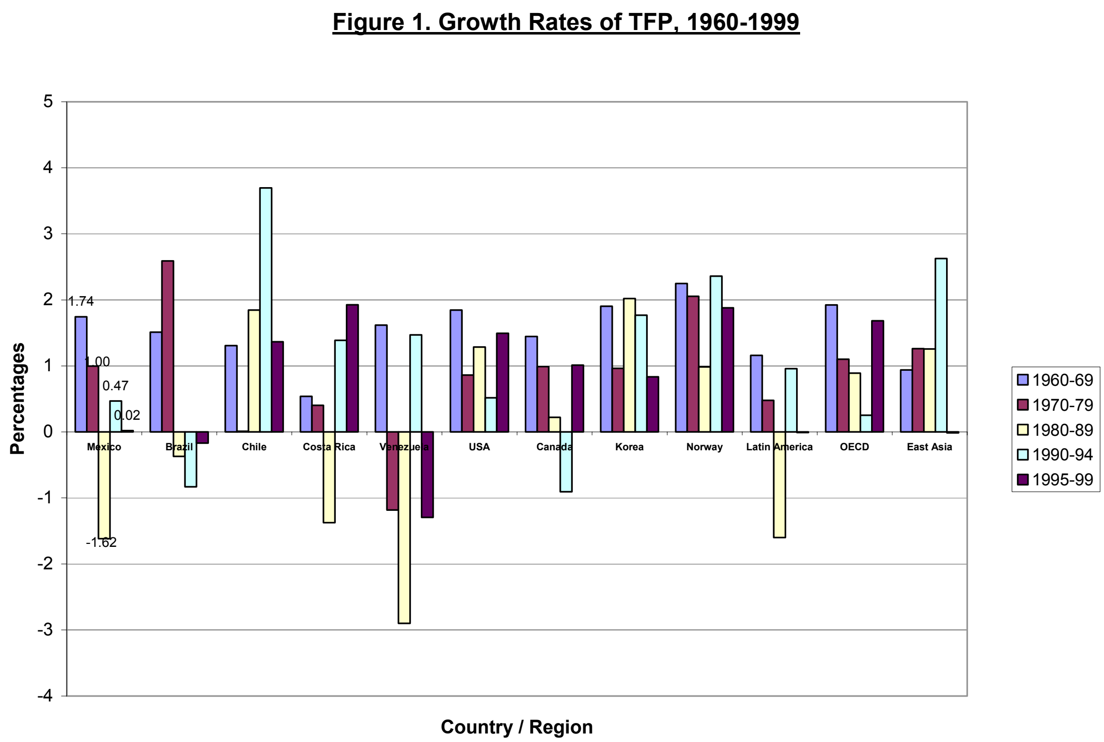
1. TFP growth – an indicator of technological progress

Figure 1 shows the average annual growth rates of TFP for Mexico since the 1960s, compared to Chile, Costa Rica, Latin America as a whole, the high-income

[2] The USPTO demands that the invention be "novel and nontrivial, and has to have commercial application" (Jaffe and Trajtenberg 2002, 3-4).

countries of the OECD, and the East Asia and Pacific region. These estimates were provided by Loayza, Fajnzylber and Calderón (2002). The estimates shown were derived from a growth accounting exercise that assumed that all countries have the same capital and labor shares (30 and 70 percent, respectively). Due to data limitations, these estimates also do not control for fluctuations in capacity utilization or human capital. However, Loayza and his coauthors estimated TFP growth rates for the same period controlling for human capital in various LAC countries. Those estimates follow a very similar pattern as those in Figure 1. In addition, we estimated alternative measures of TFP growth using regression analysis, with and without controlling for years of recessions in order to imperfectly adjust the estimates for severe fluctuations in capacity utilization. The over-time trends of these estimates also followed the patterns shown in Figure 1.

Figure 1. Growth Rates of TFP, 1960-1999



Mexico's TFP performance was highest in the 1960s. As in most of the other countries, except Brazil and the East Asia region as a whole, Mexico's TFP growth rate declined in the 1970s. Most Latin American countries experienced a further decline in the 1980s and moderate recovery in the 1990s. While the fall inproductivity growth in the United States and other high-income countries in the 1970s has been attributed to the oil shock of 1973 and its macroeconomic repercussions (Griliches 1988), it is difficult to blame the fall in productivity in Mexico and other oil exporters on this factor. Also, the East Asia region did not experience such a slowdown, perhaps due to the fact that some EAP countries such as Indonesia are oil exporters, but Korea did experience it. The story of the lost decade of the 1980s is now well understood (Edwards 1995) and it was due to the debt crisis and the subsequent attempts to stabilize the regional economies. The slight recovery in the 1990s is possibly due to the economic reforms implemented in the late 1980s and early 1990s in most LAC countries. Finally it is worth noting that productivity growth in Norway was quite fast for international standards throughout this period. This example illustrates the more general empirical finding that net exporters of natural resources, such as Norway, do not necessarily have lower potentials for productivity growth. On the contrary, Lederman and Maloney (2002) find that natural-resource rich countries tend to experience faster economic growth even after controlling for the contributions of human and physical capital accumulation.

Loayza et al. in assessing the impact of various factors on TFP growth in the region found that for all 20 Latin American countries in the sample, the impact of structural reform policies was positive and for 15 stabilization policies was also positive. They note, however, that the estimated growth combined contribution of the two ranged between 2.5-3%, not insignificant, but not likely to transform the region into Asian or Scandinavian growth miracles. On the other hand, figure 1 suggests that Chile, the most advanced reformer, has performed far above both the Latin American and Asian regional averages for the last two decades. Given the overall similarity in policy packages, there would seem to be nothing in the economic model adopted that intrinsically dictated lower rates of TFP growth.

One possible explanation of the lackluster TFP growth in Mexico may lie in Acemoglu, Aghion, and Zillibotti's idea of there being two stages of technology adoption (see section III below). The first is based on fomenting the accumulation of technology embodied in capital formation even if this required some static efficiency losses through interventionist policies, including, arguably, the period of import-substituting industrialization (ISI) in Latin America. The following stage centered on "innovation" requires a greater structural flexibility and fewer distortions. In their view, Korea, Taiwan, Brazil, Mexico, and Peru all successfully pursued the first stage but the Asian countries were able to make the transition to efficient innovative economies while Latin America was not. The Chilean case, which leads the Mexican in liberalization by roughly 10 years, offers broad support to this diagnosis and offers some reason to suppose that Mexico will experience a similar rebound in TFP in the coming years. It must also be said that, in the light of the successful growth experiences of the relatively open Ireland, Spain, Finland, and Israel across a similar period, it is difficult to argue that the extreme closed ness of the region was necessary or desirable, especially given the difficult political economy problems of moving to a more "innovative" structure later.[3] The various theories linking innovation to economic growth are further discussed below in section III.

In Mexico, the overall impact of NAFTA on productivity was positive. Chapter 1 of this report showed that the agreement was associated with convergence in rates of TFP growth among the manufacturing sectors in the U.S. and Mexico. López-Córdova (2002) offers estimates of the whole package of NAFTA-related phenomena, namely lower Mexican tariffs, the preferential tariff margin in the U.S., higher import to output ratio,

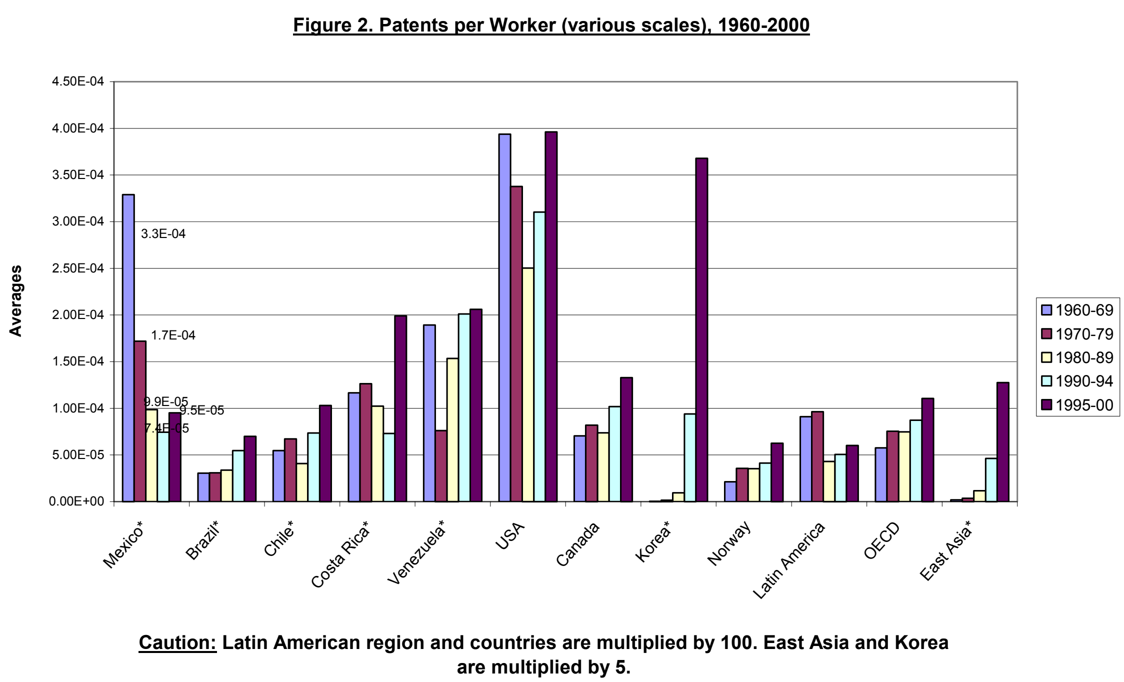
[3] Many resource-rich countries- Sweden, Finland, Australia, Canada- also closed somewhat after the Great Depression, but non to the degree of Latin America (Maloney 2002).

and participation of foreign producers to have increased TFP by 10%. Schiff and Wang (2002) offer a similar estimate of 5.6%- 7.5%. These estimates are broadly consistent with estimates of very large impact of the FTA in Canada. Trefler (1998) argues that, overall, manufacturing TFP rose by .2% per year, or 1 % for the firms most affected by trade, due primarily to plant turnover and rising technical efficiency within plants. Hence it is likely that TFP growth in Mexico and Canada would have been even lower than those shown in Figure 1 if NAFTA and its predecessor, the Canada-US Free Trade Agreement (CUSFTA), had not been implemented. Nevertheless, this does not mean that innovative activity in these countries has improved sufficiently in order to help Mexico catch-up to the levels and even growth rates of productivity observed in the United States. Some of these issues are further explored in sections III below.

2. Patent counts – indicators of innovation flows

As mentioned earlier, the number of patents granted by the USPTO is a reasonable indicator of innovative activity. Patents represent innovations that can be either an adaptation of a previous patent or a brand new invention, but virtually all patent applications in the U.S. cite previous patents as the origins of present inventions. Another indicator of scientific innovation is the number of scientific publications, which can be interpreted as a measure of outcome of basic research, as opposed to applied research. Figure 2 shows the evolution of the number of patents per worker granted to inventors residing in Mexico and the group of comparator countries and regions since 1963.

Figure 2. Patents per worker (various scales), 1960-2000



The evidence shows that Mexico's patenting activity follows a similar pattern over time as its TFP growth rates discussed above. Patent counts for Mexican innovators were highest in the 1960s, declined continuously until the first half of the 1990s, and finally picked up again after the implementation of NAFTA in the second half of the 1990s. This resurgence was, however, quite modest for historical standards. It was also insufficient to make a significant dent in the observed gap with respect to Canada, needless to mention the United States. (Please note that Mexico's patents per worker are multiplied by 100 in Figure 2). Mexico is also still far behind East Asian and especially the Korean levels of patents (which are multiplied by 5 in Figure 2). Moreover, it is also behind Costa Rica and Venezuela. Thus Mexico's rate of innovation, as proxied by its patent counts, seems to be lagging behind its North American partners, several Latin American countries, and high-income and East Asian countries in general.

One potential weakness of the ongoing analysis is that patent counts might be related to the level of development. It is reasonable to expect that patent counts will be higher for richer countries, and thus the following section provides an assessment of where Mexico stands in patent counts relative to the "average" country with the same level of development. In turn, we also look at where Mexico stands in terms of another indicator of innovation outcome, namely the publication of scientific journal articles, with respect to the "typical" (median) country.

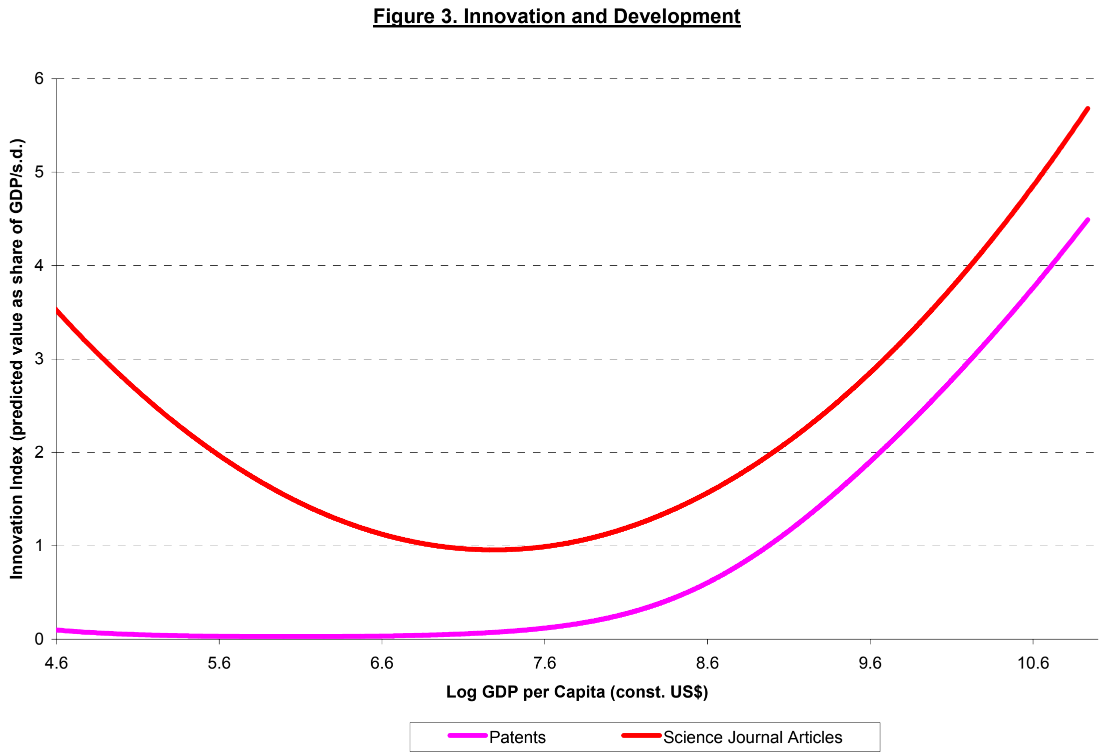
C. Given its level of development, is Mexico still lagging behind in patenting and scientific publishing?

1. How innovation outcomes evolve with the level of development

This section assesses how patent counts and scientific publications evolve with development. We first examine the correlation between these variables and the level of GDP per capita, based on data dating back to the early 1960s until the year 2000, covering a world sample of developed and developing countries from all regions. Figure 3 shows the resulting relationship of these two variables, using a common scale (GDP) and normalizing the econometric predictions resulting from a Tobit model for patents per GDP dollar (of 1995) and a Median Regression estimate of the number of scientific publications per GDP dollar.[4] In both cases, the series were estimated by using the log of GDP per capita and the log of GDP per capita squared as explanatory variables, in order to capture any non-linearities in the correlation between both innovation variables and the level of development. We later present country-specific estimations based on less restrictive specifications.

[4] Both resulting estimated series were normalized by the standard deviation of the predictions. Due to the different methods, the resulting estimates have slightly different interpretations. The predictions on patent counts over GDP based on the Tobit estimator yields the "average" level of patents for a given level of development. The Median Regressions for the scientific publications yield the "median" for a given level of development.

Figure 3. Innovation and Development



The graph in Figure 3 shows that the relationship between these two proxies of innovation outcomes have a strongly non-linear relationship with the level of development. The number of scientific publications, which is best interpreted as a proxy of the output of basic research (i.e. not necessarily applied research) tends to decline initially with development, but rises quickly after a certain point. That is, the variables associated with "pure" scientific investigation seem reasonably high among the very poor. We speculate that this may be due to the fact that many poor countries have a university housing a few scientists of global quality. As a relatively non-innovating private sector grows over time and GDP rises, these effects become diluted and the recovery happens only after the country reaches middle income. In any case, Latin America, and Mexico in particular, have GDP per capita levels found just before the second upturn.

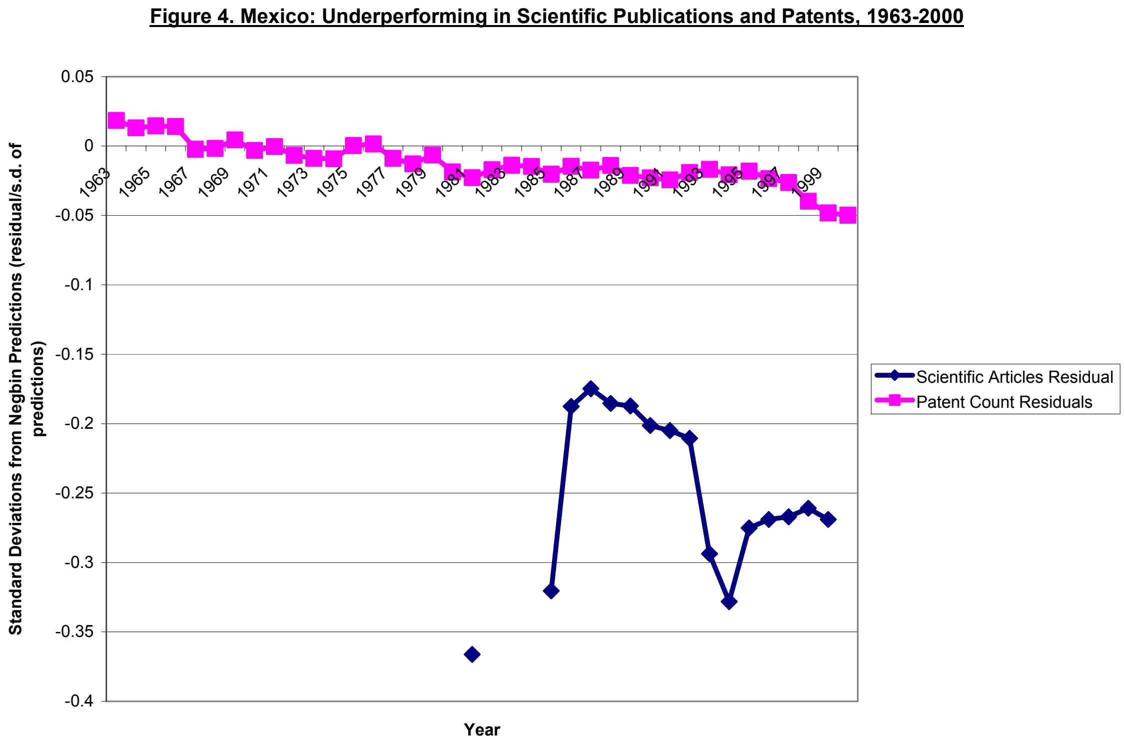
Patent counts over GDP tend to be close to zero among the poorest countries, but they seem to take-off after a certain point. It is interesting that this take-off seems to take place more or less at the same point of inflection observed for the scientific publications. Again, Mexico has a level of development corresponding to the take-off phase. We now turn to addressing the question of whether Mexico is lagging behind in terms of these innovation indicators while controlling for its level of development.

2. Where Mexico stands, given its level of development.

To assess Mexico's relative position in patents and scientific publications, we estimated a more general functional form for each variable of interest. In both cases we used log of GDP, log of GDP squared, log of labor and log of labor squared, and time dummy variables as explanatory variables. For patent counts we also included the log of the value of exports to the U.S. market and this variable squared as additional arguments. This adjustment was necessary due to the fact that we are relying on patents granted by the USPTO and there are strong theoretical reasons to expect that countries that export more to the U.S. will have stronger incentives to patent in this country. The intuition is that when firms export to a particular market they have stronger incentives to patent their ideas in the market of destination in order to reduce the extent of imitation by local competitors. In addition, the method of estimation for both variables is now Negative Binomial regressions, which are designed precisely to deal with count data, such as patents and journal publications (see, among many others, Hausman, Hall, Griliches 1984; Cameron and Trivedi 1998; Winkelmann 2000).

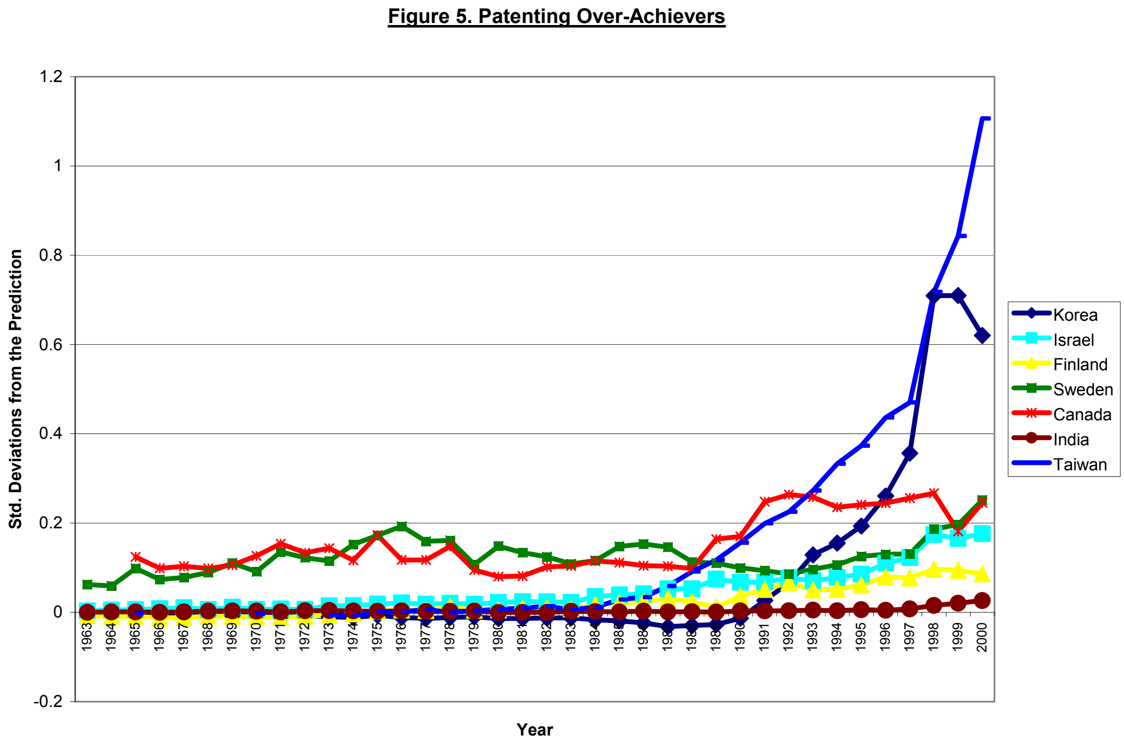
The resulting benchmarking exercises for patents and articles for the case of Mexico are shown in Figure 4. Our estimates indicate that Mexico is currently under-performing in both dimensions of innovation outcomes for its level of development. However, the country has not always under-performed in terms of its patent counts. In fact, consistently with our previous discussion of TFP growth, Mexico seems not only to have patented more in the 1960s than anytime afterwards, but it was performing at more or less the predicted level given the country's development level (and value of exports to the U.S.) during those years. This position steadily deteriorated, beginning in the early 1980s, just prior to the debt crisis and the structural reforms. Yet in spite of the recovery of overall patenting and publication activity in the 1990s, this recovery was not sufficient for Mexico to catch-up with the predicted levels. In other words, Mexico's modest recovery in innovation outcomes in the NAFTA period was not fast enough to bring it back to the levels observed for other countries with similar levels of development (and exports to the U.S. in the case of patents granted by the USPTO).

Figure 4. Mexico: Underperforming in Scientific Publications and Patents, 1963-2000



At this point it is worth highlighting that even if Mexico were to catch-up to the average level of patents and scientific publications for countries with similar characteristics, this would not imply that it has reached optimal levels. In fact, it is possible that high-performing countries with whom Mexico might want to compare itself have above-average patents. One best-practice example is Korea, whose corresponding residuals are shown in Figure 5 below, along with those from a set "patenting over achievers". This group of countries also includes Israel, two natural-resource-rich countries (Finland and Sweden), Canada (who also happens to be an agricultural powerhouse), Taiwan, and India. If Mexico wanted to benchmark itself with high-performers, its goal should thus be way above the average.

Figure 5. Patenting Over Achievers



In order to understand why trade reforms and NAFTA might not have been enough to help Mexico catch-up in innovation and productivity growth, we now turn to a review of the existing theoretical and empirical literature linking growth with innovation, and trade and FDI with innovation.

1.3 How Trade and FDI Affect Innovation and Technological Progress

A. Growth theories: Multiple productivity growth paths

An emerging scientific literature on economic growth suggests that the overall learning capacity of countries is critical for growth and international economic convergence. Acemoglu and Zilibotti (2001) argue that most technologies developed in advanced countries are not as productive in developing countries, because the host countries' low human capital is not appropriate for utilizing innovative production processes. Lloyd-Ellis and Roberts (2002) similarly argue that education and technological progress are not only complements, but dynamic complements with the return to each determined by the growth of the other. Hence logic dictates that technology transfer from the U.S. to Mexico, for example, will not lead to the equalization of productivity levels between these countries as long as Mexico's human capital is deficient relative to that in the U.S. More generally, however, there are strong reasons to think that even if both countries had the same level of human capital, the desired economic convergence would still not be realized due to the low levels of R&D effort in Mexico.

Peter Howitt of Brown University and David Mayer of Mexico's CIDE (2002) offer a "convergence club" theory, which explains why R&D effort is essential for convergence among countries. In a simplified version of their model, these authors trace three possible productivity-growth paths for countries exposed to identical technological progress. Countries with high "innovation-effective" human capital will experience the fastest rates of TFP growth. For these authors, "innovative-effective" human capital is a combination of the level of education and the effort invested by the economy to develop new technologies based on the existing technological frontier. That is, the most dynamic economies would tend to be those that have the necessary human capital and the required learning capacity for pushing the technological frontier forward. Countries with lower learning capacity will tend to rely on the adoption of previously invented technologies in the most dynamic countries. But their pace of TFP growth will be slower than in the leading countries even if they have the same level of capital and human capital per worker, because they will always be working with less efficient technology than the innovation leaders as the transmission of the latest ideas takes time and adoptive effort. Of course, the slowest growing countries will be those that are not exposed to the leaders' technologies or that have inadequate human capital to adopt even old fashioned technologies previously developed by the more dynamic economies. Similar results were previously suggested, among others, by Grossman and Helpman (1991, chapter 8), who proposed a model with multiple growth equilibria resulting from intra-national R & D externalities.

Some of the intuition of these arguments can be illustrated with the standard growth production function (Nelson and Pack 1999, 427). The three development paths discussed above are shown in Figure 6. The vertical axis measures output per worker (Y) and the horizontal measures capital per worker including human capital (K). If the three countries start their development process at point A, the slowest country that chooses to remain in technological autarky will move along the lowest production function to a point such as A'. The horizontal distance KaKf is the increase in capital per worker and the vertical distance YaYa' is the increase in income per worker. The movement along AA' suffers from diminishing returns to scale since there is insignificant technological progress to raise the returns to physical and human capital investments.

Figure 6. Technological Progress and Development Paths

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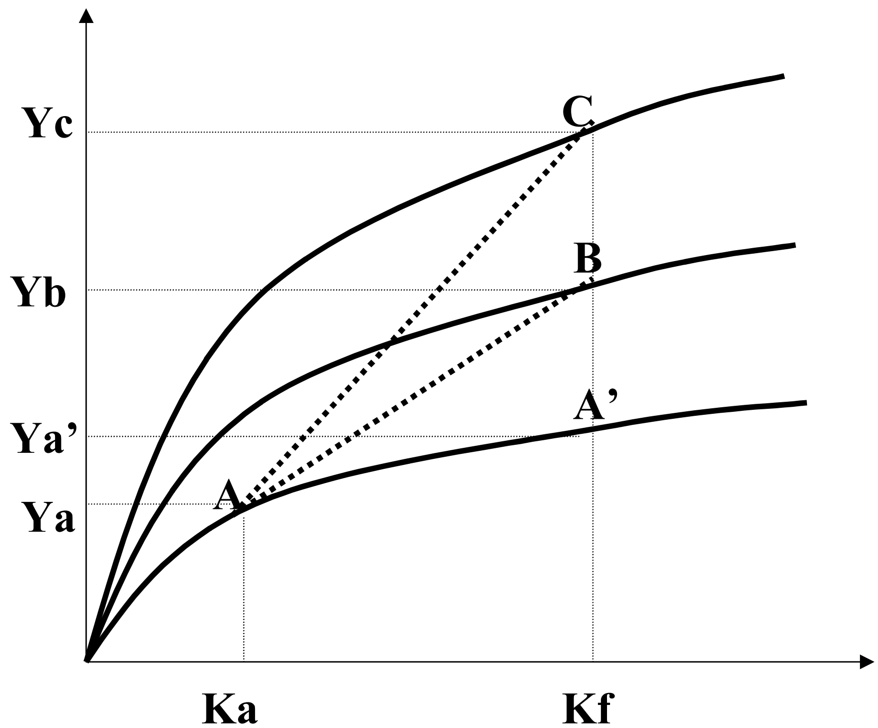

The leading country, in contrast, also accumulates KaKf worth of human and physical capital, but it also invests in developing new technologies. Hence its production function shifts upwards and its income per worker rises from Ya to Yc. The follower country, which also makes the necessary investments in human and physical capital but also imports technological innovations from the leading country also experiences an upward shift of its production. However, since the adopted technology is implemented in the follower country with a lag or because intra-national spillovers predominate over international spillovers, the shift in production is smaller than that of the leading country and the corresponding increase of income is also smaller. The vectors joining points C, B with the initial point A can be interpreted as the long-run productivity growth paths for the leader and the follower. The higher slope of the AC vector relative to AB implies that the leader experiences faster productivity growth in long-run than the follower, which nevertheless performs better than the country that stays on the autarky AA' path. Indeed, it is quite plausible that the three countries described in Figure 6 would not even experience the same increases in physical and human capital, precisely because of the possibility that the returns to physical and human capital investments depend on the production technologies, as argued by Lloyd-Ellis and Roberts (2002) and Acemoglu, Aghion, and Zilibotti (2002). In the Mexican case, our concern is that trade liberalization and NAFTA has allowed Mexico to become the follower, which is not enough to help it catch-up with its leading partners.

B. How trade affects growth: Theory, international evidence, the Mexican experience

1. Theory

In theory, international trade and foreign direct investment might affect the pace of economic growth through various channels, but not all imply an enhancement of a developing country's learning or innovative capacity. In terms of the previously discussed Howitt-Mayer model, trade liberalization and the attraction of the FDI might *not* ensure that Mexico or any other developing country will end up in the high-TFP growth path portrayed in Figure 6.

Generally speaking, trade (and FDI) could potentially have positive effects on factor accumulation and efficiency. Regarding the latter, the efficiency gains can be static or dynamic, the former being a result of resource-reallocation effects, rather than to learning or technological spillovers.

Trade liberalization can increase the rate of factor accumulation in developing countries mainly by reducing the relative price of capital or investment goods. When the cost of investment falls, overall investment rises (Baldwin and Seghezza 1996). Also, capital accumulation might rise as trade liberalization increases the size of the target market, especially for exports (Wacziarg 2001). There might also be an effect on the accumulation of human capital, if imported machines are complementary to human capital, as in the previously mentioned Acemoglu-Zilliboti model. These premia might then provide incentives for household, firms, and governments to increase their human capital investments (see Sánchez-Páramo and Schady 2002; Dömeland 2002). However, these types of effects should not be automatically equated with learning effects. They are qualitatively different primarily because education alone might be insufficient to promote innovation-led TFP growth. Education might obviously have the traditional labor-augmenting effects as skilled labor tends to produce higher output than unskilled labor, and the skills premium might also fall as the supply of skilled workers increases. But this does not ensure that workers and firms will be engaged in a continuous learning process, even if imports of intermediate goods lead to once-and-for-all increases in the level of TFP.

However, trade can have other efficiency gains. One type of efficiency gains could be due to reallocation effects, which result from the reallocation of factors of production across firms and industries. This is the traditional welfare gains from the neoclassical trade theories, but also include the reallocation of factors previously used for rent-seeking activities associated with distorted protectionist regimes (Krueger 1974). These are once-and-for-all static gains, and thus do not lead to a higher TFP growth path based on learning by firms and workers.

Other efficiency gains result from a Schumpeterian process of creative destruction, whereby increased international competition results in the exit of inefficient firms and the survival of efficient firms. These gains are also once-and-for-all if the surviving firms do not engage in learning activities. Thus competitive pressures do not necessarily lead to enhanced learning, even if they have other positive effects on developing countries.

Trade-induced productivity gains based on learning entails the transmission of knowledge regarding production processes via trade in goods. Such knowledge could be captured by the importation of foreign final and especially intermediate capital goods. A related effect might come from learning-by-exporting effects, whereby exporting firms learn about production (or management) processes from its competitors in foreign markets. Whether ideas can be transmitted through trade hinges essentially on whether such knowledge can be appropriated by imitators at low costs. If acquiring knowledge is costly, even if it is based on reverse engineering or any procedure that might help producers in developing countries use the latest technologies, then trade (and FDI) alone might not automatically lead to a sustained development process based on learning (see Grossman and Helpman 1995 for a review of the theoretical literature). If learning is costly, then lackluster R&D effort, can lead to the low TFP-growth development paths suggested by the Howitt-Mayer growth model. In any case, if trade liberalization leads to the importation of ideas via imports or via exports, then NAFTA might have helped Mexican firms improve their productivity, besides the reallocation and factor accumulation effects that were previously discussed.

What does the international evidence say about how trade affects growth? A corollary question of particular importance for this report is how much of the recent upturn in the observed levels of TFP in Mexico can be attributed to once-and-for-all effects (e.g., factor accumulation and reallocation effects) as opposed to learning effects? The factor accumulation effects of trade liberalization are thus once-and-for-all gains, which might take place slowly and thus could empirically appear as economic growth effects. Fortunately, empirical studies discussed below have attempted to identify the channels through which trade enhances economic growth. Interested readers can also consult other literature reviews on these issues, including Navaretti and Tarr (2000) and Saggi (2002).

2. International evidence and the Mexican experience

The questions posited above can only be addressed by looking at the empirical evidence based on cross-country, sectoral, and firm-level studies. Beginning with the first, Loayza et al. (2002) looked at the impact of various indicators of economic reforms, including trade, on the economic growth of countries since the 1960s. Their panel-data estimates indicate that a one percent increase in the portion of the trade-to-GDP ratio that is related to trade policies leads to an increase in the growth rate of GDP per capita ranging between 0.025 and 0.010 percentage points per year.[5] This effect is unlikely to be

[5] The corresponding result from a 30-year cross-section of countries was below this range, falling to 0.005%

large enough to help Mexico and other Latin American economies to catch-up with the world's TFP growth frontier. Even if trade reforms have a dynamic effect on economic performance by lifting the long-run growth rate, it seems that this effect might be quite small.

In another recent cross-country study that also paid careful attention to the treatment of trade-policy variables is Wacziarg (2001).[6] This author found that the most statistically robust channel through which trade positively affects economic growth is via investment, both domestic and foreign. But the stimulus of domestic investment accounts for over 60% of the positive effect of trade on growth. Hence this study indicates that trade reforms might affect growth through the factor accumulation channel, rather than via enhanced learning by firms and workers. The author then speculates that these results are consistent with theories that focus on the pro-competitive effects of trade, because the survival of firms and the entry of new ones after trade liberalization probably requires large fixed capital costs. Finally, it is worth pointing out that this finding that trade spurs growth mainly through capital accumulation had been previously found in the cross-country studies by Levine and Renelt (1992) and Baldwin and Seghezza (1996).

Yet there is an extensive and still growing literature that focuses on the TFP gains from imported inputs. Studies that focused on this channel and examined its role in developing countries include Coe, Helpman, and Hoffmaister (1997), and Schiff and Wang (2002a, 2002b). The larger literature that focuses mainly on developed countries was reviewed by Keller (2001), and Keller (2002) looks at how geography might affect the magnitude of the TFP gains from imported capital goods. In a parallel literature, Eaton and Kortum (2002) have proposed a theory and empirical applications that consider the impact of trade on economic welfare via the increased importation of capital goods. In this case, Eaton and Kortum focus directly on the impact of reductions in the prices of capital goods on the overall economy (i.e., general equilibrium effects, rather than sectoral effects) as a consequence of trade liberalization among *developed* countries.

Overall, the results of this literature indicate that imports of capital or intermediate goods do have a positive effect on the levels of TFP in developing countries. But it is not clear that these are due to enhanced learning by the productive sector. Coe, Helpman, and Hoffmeister (1997) find that the overall level of imports is important for international technology diffusion for 77 developing countries. Keller (2002), looking at industry level data from eight OECD countries, finds that roughly 50% of TFP growth in manufacturing industries is due to own R&D spending, 30% from other domestic industries and a remaining 20% due to R&D expenditures in foreign industries. He speculates that the latter share may be much higher in developing countries where local R&D effort is substantially lower than in the high-income countries of the OECD. For Latin America, Schiff and Wang (2002a) find modestly positive effects of the technology embodied in intermediate inputs on TFP for certain high-R&D industries in Latin

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[6] For a strong critique of cross-country studies that examine the link between trade and economic growth, see Rodríguez and Rodrik (2000).

America.[7] And looking specifically at NAFTA, Schiff and Wang (2002b) find that the roughly 14-18% increase in total imports after NAFTA to Mexico led to between a 5.1 and 7.0% increase in TFP levels in manufacturing industries. The 3% diversion of imports from other OECD countries, whose imports have no impact on TFP, led to another 0.47.[8]

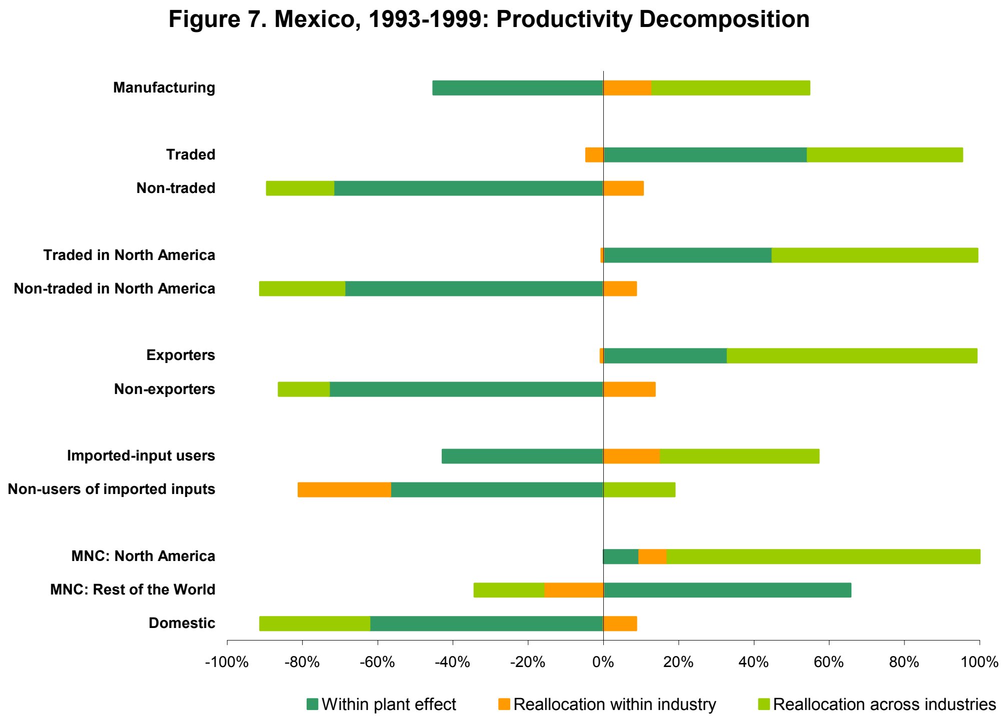
However, the interpretation of these results is not obvious. Seemingly in contradiction with the above studies, Eaton and Kortum (1996), find that bilateral imports do not help to predict bilateral patenting activity, the indicator of international technology diffusion. Based on firm-level data from Mexico, López-Córdova (2002), like Muendler (2002) for Brazil, finds a *negative* impact of imported inputs on manufacturing TFP.[9] Furthermore, Schiff and Wang express doubt about the meaning of their own estimates in the Coe-Helpman-Hoffmaister tradition. The fact that input trade with the U.S. is a good vehicle for technology transfer to Mexico, but apparently trade with other high-income OECD countries has no effect on TFP is counterintuitive. The result is strikingly consistent with Keller (2002) who finds that the impact of trade in intermediate goods decreases with geographic distance between trade partners. In fact, employing Keller's elasticity, the U.S. impact on Mexico should be, and is, roughly 10 times as large as that with respect to the OECD. However, space dependent depreciation of technology embodied in inputs seems unlikely and, as Schiff and Wang suggest, these results might be picking up greater collaborative and subcontracting relationships across the border, rather than an effortless transfer of production knowledge embodied in the intermediate inputs themselves. This in no way undermines the benefits of an open trade stance with respect to the U.S., but it does suggest that the incredibly large TFP-enhancing effects of trade with the U.S. reflect non-trade channels of influence, which might be related to personal and business interactions among businesspeople, firms, and researchers. Thus Mexico's national learning capacity might still be the key for maximizing the potential dynamic gains promised by NAFTA and international trade.

[7] The high-R&D industries are those that have relative high shares of R&D expenditures over sales in the high-income countries. These authors do not look at the sectoral pattern of R&D in the developing countries themselves.

[8] There was no difference between high R&D-intensive industries and low R&D-intensive industries suggesting that industrial composition is not critical to the benefits of NAFTA

[9] Muendler argues that this may be explained by the failure among manufacturers to adjust production practices to the increased availability of imported inputs.

Figure 7. Mexico, 1993-1999: Productivity Decomposition



Source: López-Córdova (2002)

Finally, the study by López-Córdova (2002), also cited in IDB (2002, Figure 11.8(b)), provides a decomposition analysis of the sources of TFP in Mexico's manufacturing firms during 1993-1999. Figure 7 shows the contributions of three types of TFP changes: (1) within-firm changes in TFP, (2) across firms but within industries, and (3) across industries. As mentioned earlier, if NAFTA and trade liberalization lead Mexico towards a learning development path, then most of the improvement in TFP should be due to within-firm improvements, rather than the latter two channels. Figure 7 shows clearly that for the manufacturing industry as a whole, all of the TFP improvement in Mexico was due to reallocation effects, both within sector and across sectors. Although there were differences between firms that operated in sectors with some exports and imports (labeled "traded" in Figure 7) when compared to firms in sectors with less exports or imports. However, it is difficult to interpret these differences, because all manufactures are tradable goods, and thus the differences are not due to lack of international competition in the "nontraded" sectors. The key finding is that manufacturing TFP in Mexico during 1993-1999 was driven mainly by reallocation effects.

It could also be argued that firms learn by exporting in the sense that participation in foreign markets might help firms identify the latest production, management and even marketing techniques. Thus exporters in Mexico could have enhanced their learning capacity during the post-NAFTA and trade liberalization period. Numerous cross sectional studies have shown that Mexican exporters tend to be more technically efficient, presumably because of technological development related to the import of technologies from abroad (see recent work for Mexico by Meza Gonzalez 2002; Alvarez and Robertson 2001). However, the only micro-level panel data spanning the NAFTA period that allows for the determination of causality -- whether exports make a firm more efficient or whether more efficient firms export -- López-Córdova (2002) finds no impact of exporting on TFP growth and actually a *negative* correlation with productivity levels. In Figure 7 above, the author's data indicates that exporters experienced negative within-firm TFP effects. In a recent study, the World Bank (2000) found that years of experience in exporting does seem to be associated with rising TFP levels, although these estimates did not control for unobserved firm-specific characteristics.[10] But in this optimistic study, the act of exporting itself did not come out as a robust stimulus for productivity growth. Hence it seems that exporting alone does not necessarily lead to a sustained learning trajectory.

The absence of a positive finding is consistent with the panel regressions done by Clerides, Lach and Tybout (1998) for Mexico for the early period of liberalization, as well as Colombia and Morocco. These authors found little evidence in any country for firms' cost structures changing after breaking into the export market and argue that the higher productivity is likely to be due to selection of the better firms into exporting – that is, the Schumpeterian reallocation effect. They do find, however, that the presence of exporters may make it easier for non-exporters to break into foreign markets; in Colombia, non-exporters appear to experience cost reductions when export activity increases. These results are also consitent with the analysis of firms in the chemical industry by Kraay, Soloaga and Tybout (2002) of Mexico and Colombia. These authors were not able to establish Granger causality between engaging in international activities -- be it imports or exports -- and indicators of productivity gains.[11] It is worth noting that the disappointing results regarding the lack of a robust positive effect of exporting on TFP growth for Mexico is also apparent with U.S. micro data (Bernard and Jensen 1999). Likewise, a recent study of a panel of Spanish firms concludes that there is only evidence in favor of the (Schumpeterian) firm-selection channel, but the evidence concerning the learning-by-exporting hypothesis is very weak (Delgado, Fariñas, and Ruamo 2001). Similar results were reported for Korean and Taiwanese firms by Aw, Chung, and Roberts (2000).

Canada offers some support for the view that free trade is not enough to remedy low productivity growth. Daniel Trefler (1999a, b) of the University of Toronto has argued that the FTA helped close the gap with respect to the U.S. in some manufacturing activities, but it has risen in some others, such as computers and industrial machinery. Part of this is due to low Canadian R&D (see section IV.B. below) and to deficient basic science. He argues that the presumption that this country can simply rely on basic science from the U.S. is misguided. By the time a seminal innovation is transferred from the U.S., its most valuable applications have already been exploited by U.S. companies. To support

[10] The study used random-effects estimation, rather than fixed-effects.

[11] Intermediate inputs increased marginal costs and quality among rubber producers and fertilizer/pesticide producers. Pharmaceutical producers, imported intermediates, combined with exports or imported capital goods, reduce marginal costs and tend to increase product quality. But these are exceptions to a fairly ambiguous record.

this point, Trefler cites evidence provided by Elhanan Helpman showing that a 5% increase in U.S. R&D is associated with a rise of 6.7% in U.S. productivity, but only with a 2.4% increase in Canadian productivity.

While much additional research should be done to understand the precise channels through which trade affects productivity growth in Mexico and other developing countries, it is difficult to argue based on the macro and micro evidence that trade has enhanced Mexican firms' learning or technological absorptive capacity. Rather, Mexico benefited predominantly from the reallocation effects of international trade, and temporarily from its factor accumulation effects (see Chapter 3). From this vantage point, Mexico faces an important challenge in terms of improving its learning and technological absorptive capacity in order to get on a high-TFP growth development path -- trade and NAFTA are not enough.

C. How FDI affects growth: Theory, international evidence, and the Mexican experience

The impact of FDI on economic performance can also be attributed to factor accumulation and efficiency effects. Exogenous increases in FDI might help capital accumulation directly as long as it does not completely displace domestic investment. FDI might also raise the demand for human capital in the domestic labor market when foreign corporations utilize technologies that require above-average skills. Again, this effect should not be confused with learning effects.

Similar to the previous discussion of the efficiency impacts of trade, FDI can have both reallocation and technological spillover effects. The former entails the exit of previously inefficient firms that are unable to compete with the incoming foreign companies, as well as the survival and perhaps entry of more competitive domestic firms. Hence productive resources get reallocated to more efficient firms. But this is not the same as the technological spillover effects, which would entail learning new production techniques by previously existing domestic firms. Thus spillover effects should be observed in within-firm TFP growth.

There can be little doubt that FDI increases the host country capital stock and contributes the technology embodied in that capital. However, the evidence for technological spillovers to other firms is sparse, but pessimistic. López-Córdova (2002) finds a *negative* direct impact of FDI on the same industry's TFP. This is consistent with numerous other panel studies of other developing and industrialized countries.[12] Other

[12] Lipsey (2002), in a comprehensive review of the literature argues, that the evidence is vast that foreign firms tend to be at least as productive as domestic firms and hence their presence pushes up average productivity. However, the evidence that the presence of foreign firms has positive productivity spillovers is extremely ambiguous. The vast majority of the papers that find strong effects employ cross sectional data which cannot control for unobserved country characteristics. Those using firm level panels frequently find insignificant or, even negative effects (e.g., Aitken and Harrison (1999) for Venezuela). Van Pottelsberghe de la Potterie and Lichtenberg (2001) find that investing in a relatively more technologically advanced country and hence adding foreign production to domestic production increases productivity in the home country. But the reverse case of investment in a technologically less advanced country has insignificant or

literature on Mexico is sparse. Early cross-sectional work by Blomstrom and others using industry-level cross-sectional data finds productivity spillovers. Blomstrom and Wolff (1994) finds that both the rate of local firms' labor productivity growth and their rate of catch up to the multinationals were positively related to the industry's degree of foreign ownership. Further, the rate of convergence of industry labor productivity to the US rate of growth is higher in industries with a higher share of multinationals. They point out, however, that it is difficult to distinguish a rise in within-firm productivity from simply increased competition forcing out less efficient firms thus raising the average rate of growth.

The macroeconomic evidence regarding the role of FDI in spurring TFP growth is also pessimistic. First, most studies of the causality between investment and growth indicate that investment follows growth (see, for example, Loayza et al. 2002). Calderón, Loayza, and Servén (2002) find that in developing countries FDI also follows national growth. Finally, Carkovic and Levine (2002, abstract) conclude that "the exogenous component of FDI does not exert a robust, independent influence on growth."

In sum, our reading of the existing international evidence is that NAFTA might have helped spur trade, FDI, and economic growth. But the trade channel's benefits were mainly driven by reallocation and factor accumulation effects, and FDI was probably stimulated by NAFTA and Mexico's economic recovery, but it did not necessarily lead to enhanced learning capacity in Mexico's private sector.

D. Some evidence on the determinants of adoptive capacity of Mexican firms

In this brief review of the theory and empirical evidence concerning the role of trade and FDI in promoting learning by economic agents we have concluded that NAFTA and its trade and FDI effects are unlikely to lead to a sustained growth path lead by technological progress. Hence our focus now turns to the determinants of adoptive or learning capacity.

López-Acevedo (2002) studied the determinants of various types of technological adoption by Mexican manufacturing firms. The study relied on a series of cross-sectional and panel, random-effects regressions, without controlling for endogeneity. Thus the results should be treated only as suggestive. The findings of this study indicate that firms

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negative results for the host, developing country. Baldwin, Braconier, and Forslid (2000) find mixed results for seven OECD countries and using panel firm level data from Sweden, Braconier, Ekholm, and Midelfart Knarvik (2000) find no spillovers from incoming FDI on productivity and the only variable in their sample affecting TFP is own country R & D. Using global industry level data, Schiff and Wang (2002) find no impact of FDI on TFP. Xu (2000) using panel data on technological transfer from US finds a technology transfer effect by US Multinationals only for advanced countries although a competition effect that does appear to increase productivity. Kinoshita (2000) found, for example, little evidence at the firm-level of positive effects of FDI in the Czech republic from 1995-1998. Smarzynska (2002) finds no direct impact of FDI in Lithuania on firms in the same industry although there was an impact on affiliated upstream suppliers.

that spend more in R&D, train workers, and use highly skilled workers also have higher probabilities of adopting new technologies. In turn, Meza and Mora (2002), also in a cross-sectional analysis found that in 1992, prior to the implementation of NAFTA, R&D investment by firms was positively correlated with the domestic market share of each firm. In a post-NAFTA sample for 1999, import tariffs were negatively correlated with R&D effort, and exports were positively related to R&D. Yet these results are difficult to interpret since it is not clear that R&D effort lead to exporting or that poor R&D effort was associated with lobbying efforts to maintain high tariffs. Thus these analyses do not take us far enough in terms of identifying the policies that can help Mexico get on a development path characterized by learning and fast productivity growth measured by international standards. In the following sections we attempt to answer the key policy questions for the future of Mexican innovation: Does Mexico invest too little in R&D?; does the national innovation system (NIS) suffer from inefficiencies?

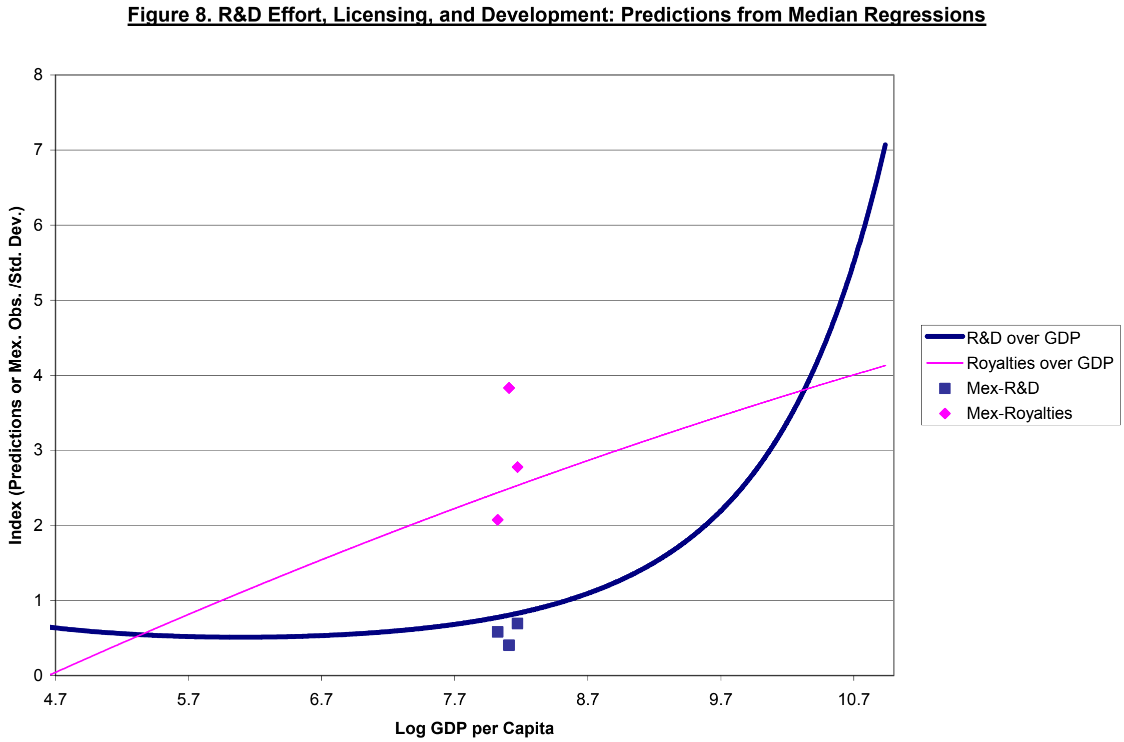
1.4 Should Mexico Invest More in R&D and licensing?

In this section we take the same approach we used for analyzing where Mexico stands in terms of the indicators of innovation outcomes. That is, we first discuss how the rate of R&D and licensing investments tend to move with the process of development. We then assess whether Mexico is under- or over-investing in R&D and licensing given its level of development. Next, we address the same question, but with a different lens: we ask whether Mexico is under- or over-investing in R&D given estimates of the social rates of return to R&D. Based on the work of Jones and Williams (1998) we provide from estimates both the rates of return to R&D and of the optimal levels of R&D investment, which depends on the rate of returns of R&D relative to the rate of return of other capital investment. We conclude this section with a policy discussion of alternatives for stimulating R&D expenditures.

A. How total R&D and licensing payments evolve with development

To derive the relationship between the rate of R&D investment relative to GDP, we estimated a Median Regression where the dependent variable was the log of R&D expenditures over GDP and the arguments were the log of GDP per capita and log of GDP per capita squared. The data was composed of a worldwide sample of developed and developing countries from the early 1960s to 2000. The resulting relationship between the ratio of R&D expenditures and license payment over GDP and the log GDP per capita is shown in Figure 8. This graph also shows where Mexico stands in terms of these two variables. The three Mexican observations correspond to the years 1986, 1993, and 1998.

Figure 8. R & D Effort, Licensing, and Development: Predictions from Median Regressions



It seems that R&D effort follows a similar pattern along the process of development as the previously discussed patent counts. Both exhibit a take-off after a certain level of development, namely around $1100 per capita U.S. dollars of 1995. Clearly Mexico is in the fast upward sloping part of the curve. It is worth noting that only a handful of Latin American countries (Haiti, Bolivia, Honduras, Guyana, and Nicaragua) have not yet reached the take-off point. In any case, for our country of interest it is worth asking whether Mexico is under-performing given its level of development, and the preliminary evidence in Figure 8 indicates that it was under-performing before and after NAFTA.

Figure 8 also suggests that license payments rise almost linearly with the level of development. A cursory look at the data reveals that Mexico had not systematically under-performed in licensing relative to the median. The following section takes a more careful look at this country's relative position in R&D and licensing.

B. Considering the level of development, where does Mexico stand in R&D effort?

Figure 9 presents Mexico's residuals from more general Median Regressions for both R&D and licensing, which included log GDP, log GDP squared, log labor, log labor squared, and time dummies as its arguments. It seems that since the late 1960s, Mexico's R&D effort has been below the level of the median or "typical" country with similar characteristics. The evolution of the licensing residuals shows that since the late 1970s Mexico has been above or right on the predicted typical level.

Figure 9. Mexico's R&D (But Not Licensing) Effort Is Below the Median

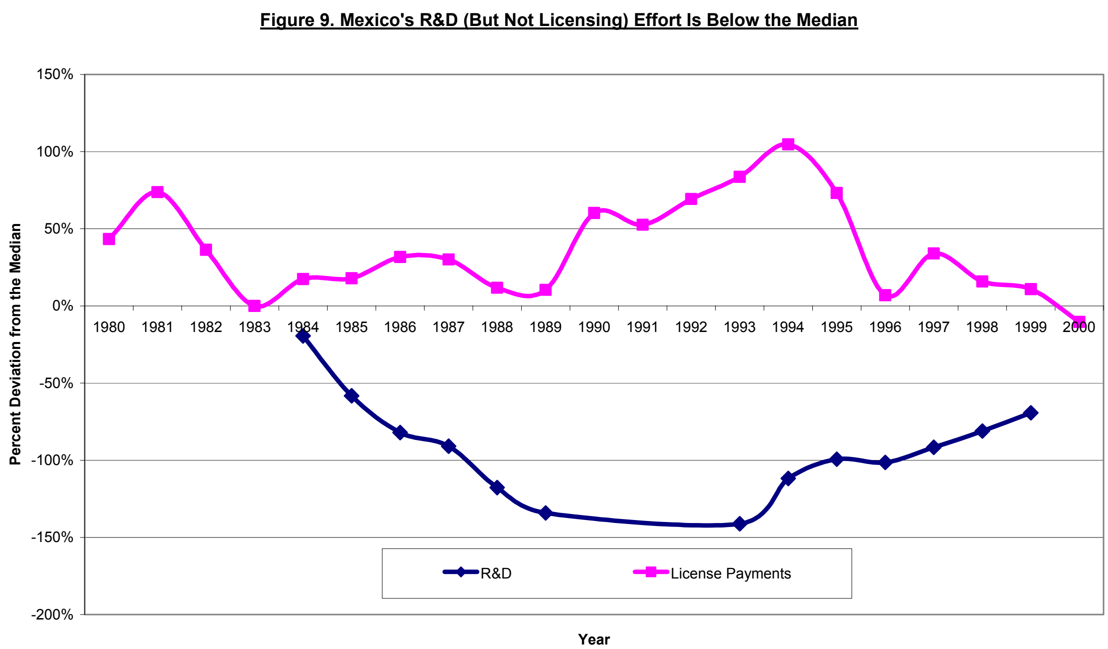
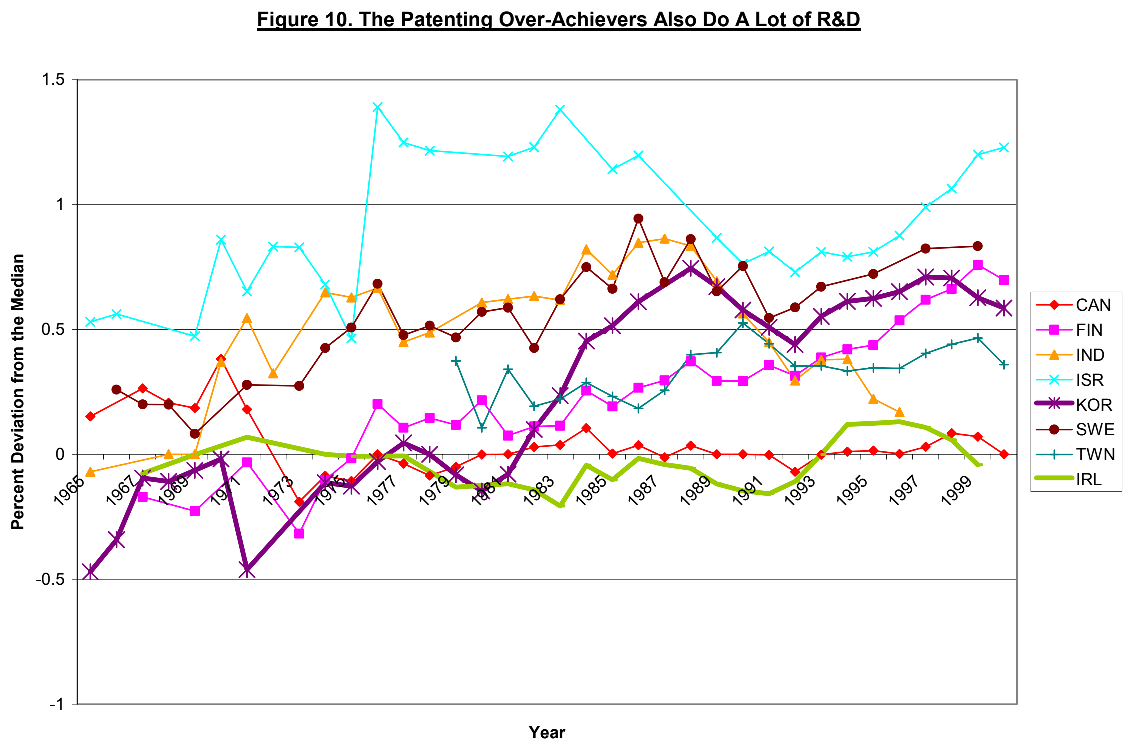


Figure 9 also highlights an interesting pattern related to the lost decade of the 1980s. The crisis of the 1980s was associated with a fast decline in Mexico's relative position in R&D effort. Thus it is possible that one of the channels through which the process of adjustment during the 1980s hampered productivity growth might have been through the reduction of R&D investments. Moreover, since R&D is both a means for adapting foreign technologies to domestic circumstances and for creating new technologies and products, seemingly transitory collapses in R&D effort might have long-term consequences. In other words, in the multiple equilibria growth model discussed earlier, it could be argued that countries like Mexico in part now face a challenge for stimulating long-term growth due to the lost opportunities of the past in terms of not having been able to move into the highest productivity growth path.

Subsequently, during the NAFTA period, Mexico's R&D effort rose, although it has not yet reached the median. From this viewpoint, Mexico needs to do more to stimulate R&D investments. This becomes even more obvious when we look at the high-innovation countries discussed in the section on patents. Their residuals for the R&D effort regression are shown in Figure 10. Of these, only Canada did not experience either a boom or a continuously high level of R&D effort relative to the median. The Canadian result is consistent with the discussion in section III and the cited studies by Trefler, who has concluded that this country is risking falling into a lower growth equilibrium if it does not push up its R&D effort. The Korean and Finnish cases are remarkable in that they went through a period of very rapid improvements in their relative R&D effort, and by the early 1980s they were both well above the median. Thus these countries had exactly the opposite experience of Mexico (and many other LAC countries) that experienced very rapid declines in their R&D efforts relative to the typical country at those levels of development. Nevertheless, benchmarking relative to the median is only one way of assessing whether a country invests sufficiently in R&D. In the following section we estimate social rates of return to R&D and then we assess whether Mexico could benefit from policies aimed at increasing its R&D investment.

Figure 10. The Patenting Over-Achievers Also Do a Lot of R & D



C. Given the returns, how much should Mexico spend on R&D?

Is Korea and Finland's departure from the benchmark a key element in their rapid catch up, or evidence of a wasteful high-tech white elephant? Another way of phrasing the question is whether the returns to R&D can justify these above-median R&D expenditures. Most estimates of the impact of R&D spending on TFP in selected US firms and industries is astronomical, ranging from 30 to 120 percent which, compared to a return on capital of 7% implies the U.S. should invest more by a multiple of at least 4 -- see Table 1 and Box 1.[13]

[13] Griliches (1992) estimates social returns to R & D in the U.S. of between 20-60%. In fact, for the US, Jones and Williams (1998) confirm that rates of return are at least 30% and calculate that the optimal resources that should be devoted to R & D could be 4 times the present level in the U.S.

Table 1. Estimates of the Rates of Return to R&D in the U.S.					
		Return (own)	Spillovers	Social Return	S*/S
Sveikauskas (1981)	1981	.17			2.4
Griliches (1994)	1994	.30			4.3
Griliches and Lichtenberg	1984	.34			4.9
Terleckyj	1980	.25	.82	1.07	11.7
Scherer (1982)	1982	.29	.74	1.03	10.6
Griliches Lichtenberg	1984	.30	.41	0.71	5.9
Jones and Williams	1998	.35			5.0

Jones and Williams (1998)

On the other hand, poor countries may invest less in R&D because returns might be lower. Table 2 presents estimated *social* returns for a panel of countries provided by Lederman and Maloney (2003). Not only are the estimated returns of 40% of the same order of magnitude found in previous studies, but it appears that they *decrease* with development. The return in the average OECD country is somewhere between 20-40%. As figure 11 shows, for a country at Mexico's level of development, the return would be around 60%. This makes sense if we suppose that a dollar's worth of R&D buys much greater increases in productivity for countries far from the technological frontier than for innovating countries who must invent the new technological advance. In a sense, this simply confirms the intuition of numerous convergence regressions in the Barro (1991) tradition, which are consistent with the neo-classical growth theory mentioned in Chapter 1 of this report.

Figure 11 also plots the estimated return to physical capital and the ratio of the two returns. For the US, the gap of 2.25 is somewhat more moderate than that offered by Jones and Williams but consistent with the speculative nature of these exercises. Latin America's gap rises slightly, but, due to the rise in the returns to physical capital, it remains under 2.5. If instead, we were to assume free access to international capital markets and the 20th century's return on the US stock market of roughly 7%, as suggested by Jones and Williams, the gap for Mexico would rise to about 8.

Table 2. Returns to R&D

Dependent Variable: Growth of GDP (constant PPP), five-year averages from 1960-2000
Methodology: GMM system estimator

	(1)	(2)	(3)	(4)	(5)	(6)
Countries	53	43	43	43	43	43
Observations	162	107	107	107	107	107
Initial level of gdp per capita	0.03461 ***	0.00059	-0.0088 **	0.00026	0.00116	0.0877 ***
Investment/GDP	1.29895 ***	0.18948 ***	0.32838 ***	0.23743 ***	0.2713 ***	0.88322 ***
Labor growth	0.50922 ***	0.59981 ***	0.49541 ***	0.7535 ***	0.48368 ***	0.7708 ***
R&D/GDP	3.19316 ***	1.38194 ***	0.51829 ***	1.02247 ***	9.62216 ***	9.29019 ***
Tertiary Enrollment ratio			0.05567 ***	0.02778 *	0.05302 **	0.02258 **
NR-Leamer				0.00106 **	-0.0059 ***	-0.0056 ***
R&D*(gdp per capita)	-0.3 ***				-1.029 ***	-0.9924 ***
R&D*(NR-Leamer)					0.37071 ***	0.32784 ***
Investment/GDP*(gdp per capita)	-0.1307 ***					-0.0792 ***
Wald test for joint significance(p-value)	0	0	0	0	0	0
Sargan Test(p-value)	0.326	0.437	0.703	0.372	0.485	0.917
1st order serial correlatin	0.002	0.007	0.005	0.005	0.005	0.004
2nd order serial correlation	0.23	0.984	0.625	0.721	0.798	0.885

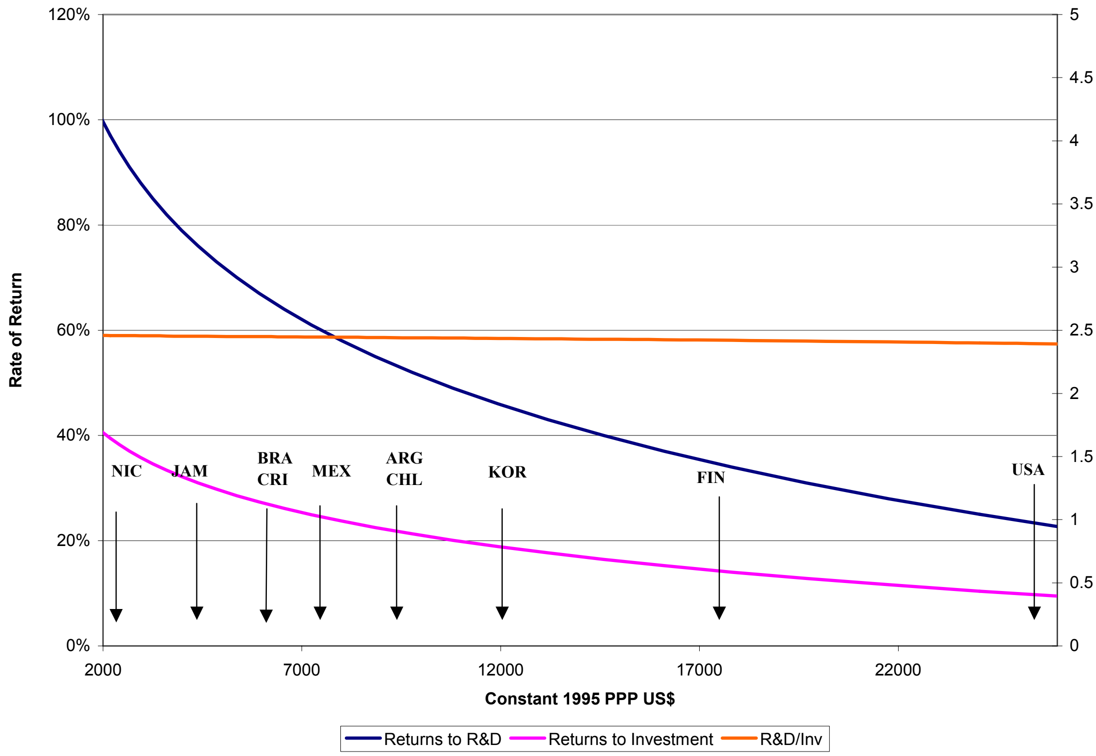
Levels of significance: *** 1%, ** 5%, * 10%

Another important finding merits mention. Not only do natural resource abundant economies (captured by the ratio of net exports of natural resources, labeled "NR-Leamer" in the table), such as Mexico, appear to grow faster than others (see also Lederman and Maloney 2002), but the interaction with R&D spending is significantly positive. That is, consistent with the previous discussion, we may be able to explain the better performance of, for instance, Scandanavia or Australia in their exploitation of natural resources compared to Mexico and other Latin American economies by their much higher commitment to innovation.

The fact that social returns are high does not ensure that private returns are high because unattended market imperfections tend to reduce the equilibrium marginal private returns to R&D.[14] These market failures are discussed in the following section. In turn, the final section of this chapter explores the determinants of R&D expenditures in an attempt to explain why rich countries invest more than poor nations.

[14] For an intuitive discussion of the determinants of the equilibrium private marginal rate of return, see David et al. (2000). Briefly, the equilibrium return is determined by the marginal costs of and returns to R&D. Some of the market failures affect the costs (i.e., capital markets might be incomplete) and others affect the returns (i.e., the non-appropriability problem).

Figure 11. Estimated Returns to R&D Expenditures and R&D Gap



D. Why, if returns are so high, is R & D so low in Mexico and elsewhere?

Knowledge is especially susceptible to market failures that lead to an under-investment in R&D and other innovation-related activities.

Non-appropriability: Most commonly cited is the inability of innovators to exclude others from using their ideas. This is implicit in the finding that rates of return to R&D tend to be estimated to be roughly 4 times the private rate in the studies cited above. In fact, recognition of this failure has led to an emphasis on public interventions necessary to ensure the socially optimal level of innovation: Temporary monopoly rights are granted through patents and other intellectual property regime (IPR) instruments, research and development (R&D) subsidies are awarded, and so forth.

Lumpiness and scale economies dictate specialization. R&D and innovation are characterized by economies of scale and lumpiness. To be effective, resources need to be concentrated in a manner beyond the capacity of the individual firm. This, combined with the fact that even patents are not effective at resolving the non-appropriability problem in "pure science," provides a rationale for institutions dedicated to R&D and innovation efforts, such as research centers and universities, in their research role. Innovation and knowledge developed by those institutions tend to be non-exclusive and are made available to all and any interested parties, guided by an appropriate allocation of property rights.

Free rider problems impede diffusion as well as innovation. Once an innovation has been developed, its social value is measured not only by that knowledge itself, but also by how many agent-institutions and firms (ultimately embodied in workers) have it and, once it is there, by how fast it is disseminated to others. The more agents have access to it and the faster that access, the higher the social value of that innovation. But the same market failure that impeded discovery of new ideas slows the transmission of existing ones as well. A firm that incurs the costs of tapping into the global stock of knowledge by, for instance, by financing a study tour, will soon find its discoveries adopted by other firms who free-ride on the investment. Historically, this has given rise to institutions ranging from agricultural extension services to technology parks to institutions designed to act as "antennae" for new ideas at the sectoral and national level.

Innovation, diffusion, and application require collaboration among many institutions and firms. Although innovation is sometimes the product of one firm alone, the more common pattern is one of joint efforts, among various firms, or among firms and R&D-related institutions, or among various R&D-related institutions. Further, progress does not proceed linearly from pure science to applied technologies, but moves in both directions (Nelson and Rosenberg 1993); and feedback from frontline users of technology to researchers is essential for the refinement of products and production processes (Nelson & Rosenberg 1993). Finally, as a result of specialization, the full supply chain of knowledge is not fully integrated, either vertically or horizontally. Technological advance is therefore not necessarily evenly diffused throughout the supply chains. In each example, success requires coordination and cooperation across all necessary actors that is subject to coordination failures and transaction costs. In many industrial countries, these issues have given rise to national institutions devoted to fomenting or eliminating impediments to technological collaboration among different institutions.

1.5 Is Mexico's Innovation System Efficient?

The development and necessary interaction and coordination of these market and non-market institutions has led to the concept of National Innovation Systems (NIS) and an extensive literature that we can only touch on here (Nelson et al.1993, OECD 1999, 2001). It is the networks of public and private firms interacting in a concerted way to generate and adopt technologies through which nations can be said to learn. This "national learning capacity," as numerous observers have called it, is what permits nations to adopt and innovate in their initial areas of comparative advantage and helps create new ones (Furman, Porter, and Stern 2002, Romer 1990, Nelson 1993, Wright 1999).

Mexico has numerous innovation-related public institutions to address particular market failures, which are associated with the education ministry (SEP), the National Council for Science and Technology (CONACYT), and the national petroleum company

(PEMEX). However, the idea of a system entails a deliberate design and coherent functioning. In fact, a central tenet of this system or network is that there are no market forces that guarantee that the various components alone will remedy the market failures they were intended to address. By their very nature, many of the institutions developed to remedy market failures are not market based, and as a result they do not respond to market signals. The challenge for public policy is thus not only to help establish research and educational agencies, but also to ensure that these are adequately integrated with the productive sector. That is, ensuring the effective interaction of the available innovation-related factors poses Mexico's other great challenge after remedying the gaps in its stock of innovation-related factors. The following sections provide a diagnosis of the extent to which this country's innovation system suffers from inefficiencies stemming from the lack of quality research institutions and their linkages with the productive economy.

A. How much bang for the buck? The patenting efficiency of Mexican R&D

One measure of how the system functions is how well it converts R&D financing into patenting. This standard of R&D efficiency is superior to our previously discussed estimates of the social returns to R&D, because the returns tend to be high in poor countries, including Mexico, precisely because the overall level of R&D effort is low. As the supply rises, the returns fall. Moreover, the efficiency of R&D should be measured with respect to direct outputs of such efforts, rather than social outcomes, which reflect the impact of economic externalities rather than R&D efficiency.

To assess the efficiency of Mexican and Latin American R&D effort, Figure 12 presents econometric estimates of country-specific patenting elasticities with respect to total R&D investment. These estimates were obtained using a pooled regression of 52 countries over a 15 year period (1985-2000) in a negative binomial regression application of Blundell et al.'s (2002) Pre-Sample Mean estimator, which aims to control of unobserved country-specific characteristics and the likely endogeneity of some of the explanatory variables. The latter include the log of R&D expenditures, log of exports to the US, net exports of natural resources, the log of the pre-sample mean of patents (1963-1985) and the corresponding country dummies interacted with the log of R&D expenditures, leaving the OECD countries as the reference. The differentials shown in the figure are the result of dividing the country dummy by the R&D coefficient for the OECD countries, thus yielding the percent deviation from the OECD average. What is immediately apparent is that Mexico is among the worst performers with its coefficient roughly 6.3% below that of the OECD and far below Korea, and even Costa Rica and Venezuela, two countries that have significantly higher tertiary enrollment rates than Mexico and proportionately higher numbers of adults with some tertiary education (see De Ferranti et al. 2003).

Figure 12. R&D Efficiency, 1985-2000
(% deviation from OECD average)

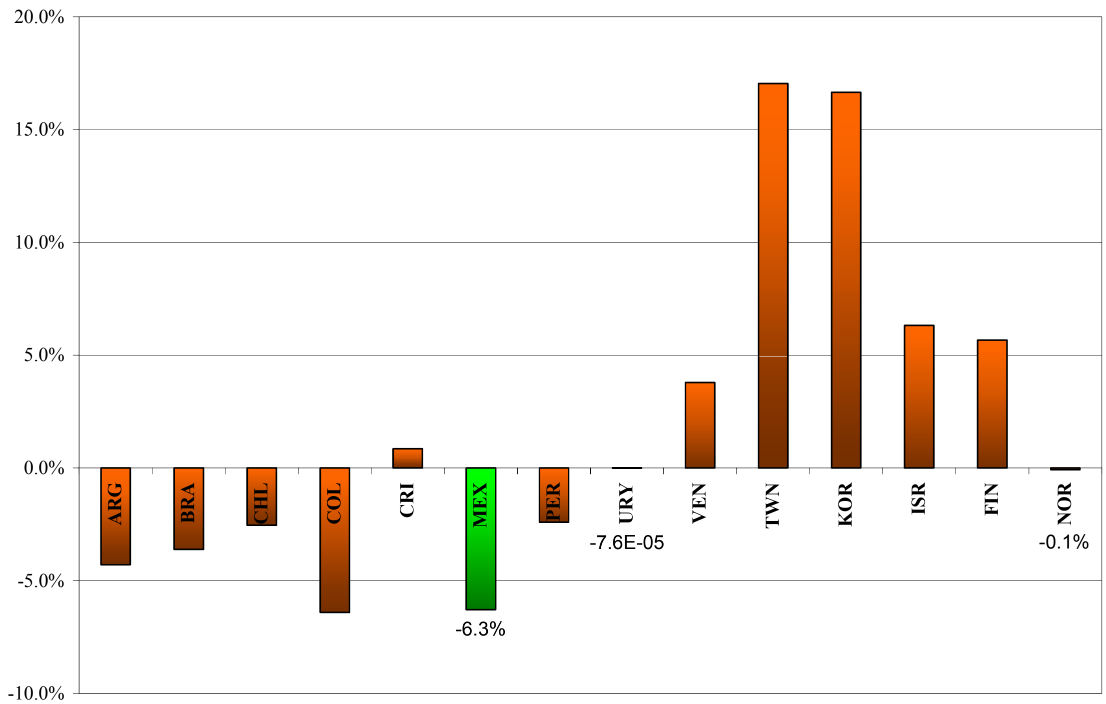


Table 3 presents further econometric estimates of the impact of R&D on patenting activity. The statistical technique used for these estimates shows the impact of R&D on patents (see Box 1 for details) and finds that, there is a close and significant relationship between the two. However, even after adjusting for trade, resource endowments, that might affect patenting in the US independent of the true innovative effort, a Latin American dummy with R&D generates a strongly negative coefficient suggesting that the region performs substantially worse than the norm in converting R&D expenditures into innovation. The results in Table 3 also indicate that the negative Latin American effect disappears altogether when variables that control for the interaction between various research and educational indicators and R&D expenditures. This is the case, for example, with the Global Competitiveness Report's indicators of the quality of scientific and research organizations (i.e., universities and public research institutes) and of the extent of collaboration between the productive sector and universities. In the case of Mexico's inefficiency, only a portion of it is explained by these variables. But these variables, plus the gross enrollment rate in tertiary education are sufficient for explaining Mexico's inefficient R&D expenditures. It is noteworthy that secondary enrollment and the level of development of information and communications technology (ICT) *do not* explain Latin

America's or Mexico's innovation inefficiencies.[15] In sum, Mexico's inefficiency is due to a combination of low enrollment rates in universities and poor quality research and linkages between the universities and the productive sector.

Table 3. Determinants of Patent Counts

Methodology: Negative Binomial, Pre-Sample Mean Estimator										
Presample: 1963-1984										
Observations	512	512	512	512	512	512	328	512	328	295
Countries	53	53	53	53	53	53	52	53	52	49
ln(Average Patents 1963-1984)	0.32 ***	0.40 ***	0.38 ***	0.26 ***	0.33 ***	0.28 ***	0.37 ***	0.23 ***	0.30 ***	0.28 ***
ln(R&D Expenditure)	0.78 ***	0.48 ***	0.48 ***	0.24 ***	0.35 ***	0.31 ***	0.42 ***	0.15 ***	0.29 ***	0.34 ***
ln(Ustrade)		0.37 ***	0.35 ***	0.32 ***	0.30 ***	0.38 ***	0.27 ***	0.37 ***	0.22 ***	0.19 ***
Nrleamer		-0.03 **	-0.03 ***	-0.07 ***	-0.08 ***	-0.10 ***	-0.07 ***	-0.11 ***	-0.09 ***	-0.08 ***
ln(Quality)*ln(R&D)				0.17 ***				0.12 ***	0.09 ***	0.09 ***
ln(Colaboration)*ln(R&D)					0.11 ***			-0.01	0.03 **	0.02
ln(years of Education)*ln(R&D)						0.10 ***		0.08 ***		
Tertiary enrollment*ln(R&D)							0.08 ***		0.07 ***	0.07 ***
Secondary Enrollment*ln(R&D)							0.02		-0.01	-0.01
LAC*ln(R&D)	-0.03 ***	-0.04 ***	-0.04 ***	0.00	-0.01	-0.01 ***	-0.02 ***	0.01	0.00	0.00
MEX*ln(R&D)	0.00	-0.04 ***	-0.04 ***	-0.02 ***	-0.03 ***	-0.03 ***	-0.03 ***	-0.02 **	-0.01	0.00
Openness*ln(R&D)			0.02 **	0.02 *	0.01	0.00	0.02 ***	0.00	0.02 ***	0.03 ***
Trade Resiudal*ln(R&D)										
ICT*ln(R&D)										0.00
Time Trend	0.05 ***	0.04 ***	0.03 ***	0.03 ***	0.03 ***	-0.01	-0.03 **	0.00	-0.01	-0.02
Pseudo R-squared	0.17	0.19	0.18	0.21	0.20	0.21	0.23	0.22	0.24	0.25
Log likelihood	-2889.4	-2828.5	-2946.6	-2766.2	-2770.7	-2731.7	-1722.0	-2700.3	-1686.5	-1529.6

Levels of significance: *** 1%, ** 5%

A partial explanation for this pattern throughout the Latin American region, including Mexico, is found in the proliferation of state-owned public agencies during the ISI period that developed R&D capacity in order to better exploit the available natural resources and to jump start industries to supply local demand in the postwar period. For some reason, universities played the dominant role throughout the region in both government funding for innovation and attracting most of the skilled researchers. In part, insulated from competition, the research institutes had little incentive to coordinate with the productive sector, and the minor efforts in adapting imported technologies to the local environment were undertaken by subsidiaries of large multinational corporations, and many fewer by privately owned small and medium enterprises. The previously mentioned preliminary evidence on the determinants of R&D spending by private firms in Mexico provided by Meza and Mora (2002) indicates that prior to NAFTA, manufacturing-sector R&D was mainly a function of the domestic market share held by the company. It was until after NAFTA (the sample corresponds to 1999) when trade-related variables became positively correlated with R&D effort in the private sector. Yet it seems that the slight overall increase in productive sector R&D after NAFTA was not necessarily accompanied by improvements in the efficiency of total expenditures, thus indicating that the lack of coordination among the key elements of the NIS remains an important obstacle for Mexican innovation.

[15] The ICT index used in this analysis is the one provided by Lederman and Xu (2001), which is the result of the first principal component from factor analysis using four indicators of ICT: telephone lines per capita, cellular phones per capita, personal computers per capita, and internet hosts per capita.

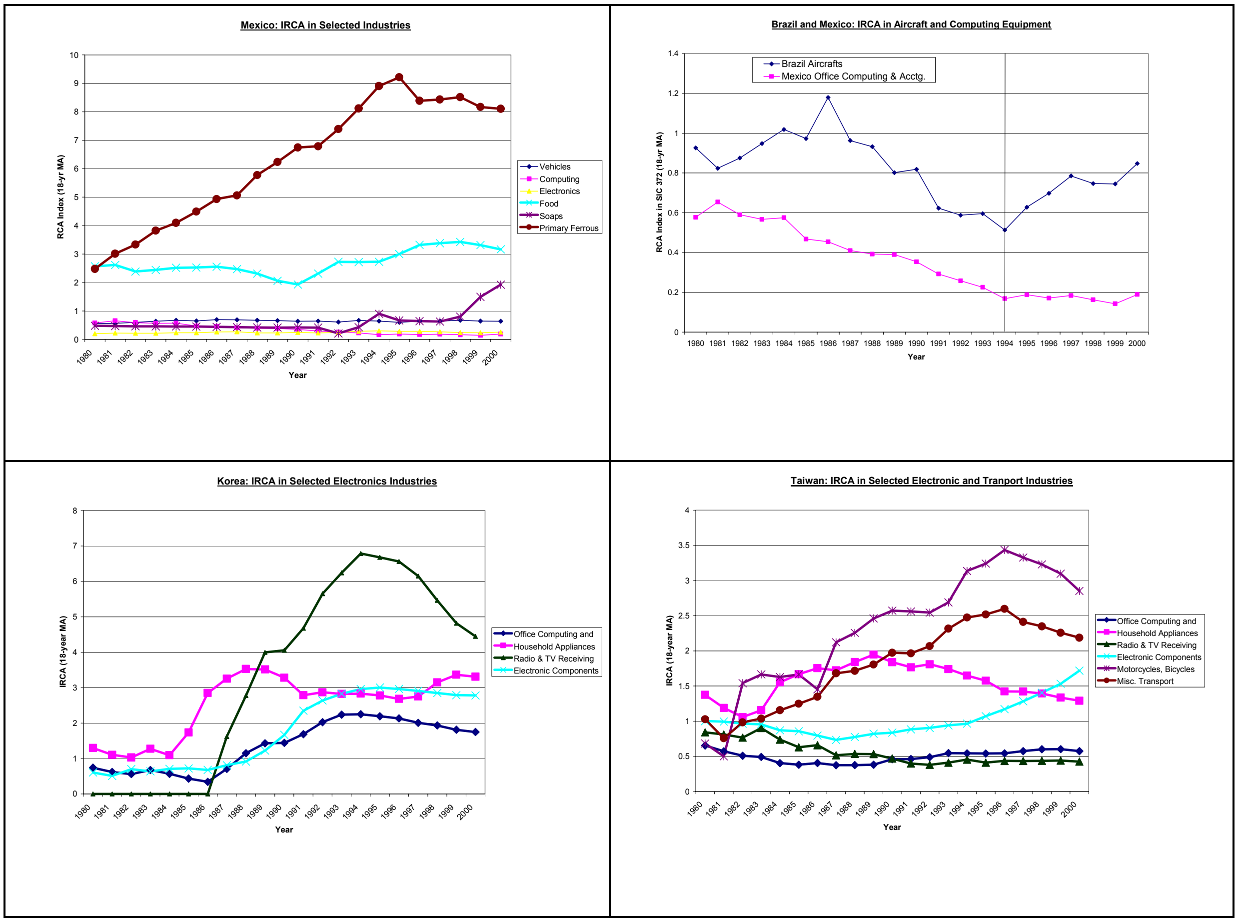
This pattern appears in sharp divergence with some of the Asian newly industrial countries (NICs), who very early on made dramatic investments in education, and who also recognized the importance of a well-coordinated NIS to support the private sector in the context of an export-oriented trade policy (De Ferranti et al. 2003). Unlike Latin America, where R&D activities were concentrated in public research institutions, these countries emphasized science and technology in the productive sector by providing financial and tax incentives, and the productive sector became the main user of R&D funds. Korea and Taiwan, in addition to making large investments in R&D, coordinated technology importation, diffusion, and development. At the same time, the large investment in education in these countries resulted in a highly schooled labor force able to adapt to constant industrial upgrading and economic restructuring. We return to these policy issues in the final section of this chapter.

B. Structural change in trade, but not in innovation

A World Bank report (De Ferranti et al. 2002, chapter 4) documented how Mexico's trade structure had changed during the post-NAFTA period. In a nutshell, NAFTA stimulated a structural change whereby Mexico became a net exporter of machinery, including telecommunications equipment, road vehicles and parts, and office and data processing equipment (i.e. computers). In addition, the incidence of intra-industry trade rose remarkably fast after 1994. If this transformation of trade flows was accompanied by a transformation of the patterns of innovative activity, then we could be certain that Mexico's innovation system has accompanied the productive sector, thus indicating that the emerging sectors are driven by innovation rather than simple maquila-type processes. Based on sector-level patent data from the USPTO collected by Lederman and Sáenz (2003), Figures 13 a-d show an index of Innovative Revealed Comparative Advantage (IRCA) that captures how patenting in various sectors in Mexico, Brazil, Korea, and Taiwan, relative to each country's total patenting compares to the world's share of total patenting in that sector. A value above unity suggests that a country has an innovative comparative advantage in that sector. This index of innovation comparative advantage has been used in the scientific literature (Patel and Pavitt 1995).

Strikingly, the principal sectors where Mexico shows a comparative advantage is in more traditional sectors, such as processed foods, soaps and paints, and primary ferrous products. Somewhat surprisingly, the emerging sectors of computers and automobiles are not above 1 and have not shown an upward trend. In contrast, Figure 13b shows Brazil's IRCA in aircrafts and indicates that since the privatization of EMBRAER (Brazil's small airplane and parts producer) in 1994, there has been an upward trend in this index.

Figures 13a-d. Mexico's IRCA in Innovation: Not in the "New" Sectors



If we compare these trends with Taiwan's and Korea's IRCA in electronic equipment and appliances, we see that both of these countries experienced substantial movement in the IRCA of these industries, as shown in Figures 13c and 13d. Korea in particular has demonstrated substantial increases in its innovative comparative advantage in these sectors relative to what it had in the 1980s, just prior to its big take-off in R&D effort. By 2000 Korea maintained a clear comparative advantage in innovation in the four sectors shown in the graph. Taiwan also experienced substantial changes in its innovative structure, and now has a clear comparative advantage in transport industries (motorcycles and bicycles, miscellaneous transport equipment) and various electronics products (radio and TV receiving equipment, household appliances). Thus, in stark contrast to these other developing countries with comparative advantage in net exports of electronics and transport equipment, Mexico seems not be experiencing a favorable change in its innovative activity. On the contrary, Mexico seems to have an innovative comparative advantage in traditional sectors, but not in the emerging machinery sectors. We interpret this as evidence that Mexico suffers from poor linkages in its national innovation system. To the degree that Mexico is simply relying on temporarily low labor costs to assemble computers, rather than developing depth in supporting a knowledge base, then these sectors may lose steam in the near future.

C. Are there linkages in Mexico's R&D effort?

In this subsection we "follow the money" by looking at how much of the R&D performed by the productive sector is financed by the public sector, how much of the R&D performed by universities is financed by the productive sector, and so on. Table 4 shows that in 1999, less than 20% of the productive sector's R & D is financed from foreign sources. Neither the government nor universities contribute significant amounts to the productive sector's efforts. In turn, all of the government's R&D is self-financed, and less thane 8% of the R&D performed by universities is financed by the productive sector. The three sectors function more or less autarkically, a recipe that is unlikely to produce economically meaningful innovation in the future.

Table 4. R&D in Mexico: Who does it and who pays for it? Expenditures in 1999 (millions of USD)

	Performed	Financed	Share of Financing
1. Productive Sector	**$588.70**		
Financed by:			
Productive Sector		$473.20	80.2%
Government		$7.30	*
Other		*	*
External		109.2	18.5%
2. Government	**$1,037.3**		
Financed by:			
Productive Sector		n/a	
Government		$1,037.30	100%
Other		n/a	
External		n/a	
3. Universities	**$607.3**		
Financed by:			
Productive Sector		$47.3	7.8%
Government		$332.20	54.7%
Higher Education		$223.50	36.8%
Higher Education and Government		$555.70	91.5%
4. Private/Non Profit	**$71.9**		
Total	**$2,304.2**		

Source: Carlos Bazdresch, CIDE, based on data from CONACYT.

In sum, beyond making a stronger effort to increase the stock of factors of innovation, Mexico needs to reexamine the package of incentives, explicit and implicit, in the innovation system. These include those affecting the research effort within each institution in the system—private firms, universities, and think tanks—and also the interactions among them. Below we deal with three elements of the NIS, namely government-financed research institutes, universities, and capital markets. These policy issues are discussed in more detail in the following and concluding section of this chapter.

1.6 Policies to Increase R&D Effort and to Improve Its Efficiency

As shown by the previous empirical analyses, the efficiency of the national R&D effort depends on the incentives for the productive sector to be linked and to help finance such effort. For the specific cases of Latin America and Mexico, the most important factor affecting the efficiency of NIS is the quality of university research, the lack of linkages between universities and the productive sector, and enrollment in tertiary education. Also, the low efficiency of the NIS itself might limit the productive sector's interest in raising its R&D investment, in spite of the potential high returns to R&D. Although there are numerous ways of improving the efficiency of the NIS and to raise the overall R&D effort, but improving the links between research organizations and the productive sector should be at the center of the reform effort in Mexico and more generally in Latin America.

The following paragraphs qualitatively evaluate existing evidence regarding policies to support technology transfer among private-sector firms (inter- and intra-national), Public Research Centers (PRCs), universities (both public and private), and capital markets. The main focus is on various country experiences that might be worth emulating by Mexico. In particular, whenever possible we describe policies and outcomes in several of the innovation leaders in the world, including the United States, Japan, Korea, Finland and others, and we also compare some of Mexico's policies to those observed abroad. This approach is consistent with the view that countries with relatively lagging innovation policies should attempt to "converge" towards policy models that have been tested elsewhere. Imitating policies and institutions and quantitatively monitoring the outcomes of these policies has been the guiding principle for the strengthening, for example, of Finland's science and technology policies since the early 1960s (Lemola 2002).

A. State-owned enterprises

A crude way of ensuring links between productive activities and R&D efforts is through public management of important economic sectors. This is the case in countries like Chile (CODELCO), Venezuela (PEDEVESA), Taiwan (Telecommunications), Costa Rica (Telecommunications, utilities), Brazil (Embraer prior to 1994), and Mexico (PEMEX). The evidence on the efficiency of total R&D expenditures in several of these countries is quite high, thus indicating that public firm management does not necessarily condemn a NIS to failure. In the case of Mexico, further research should assess the efficiency of PEMEX's R&D effort or existing analyses should be scrutinized. But even if PEMEX's efforts have prevented Mexico's NIS efficiency to be higher than it would otherwise be, they have not been sufficient to push Mexico towards the "average" OECD standard. In any case, there are various other government interventions, besides public management, that can help improve Mexico's R&D efficiency.

B. Promoting firm-firm linkages – how should the government intervene?

One of the most famous policy initiatives to promote inter-firm linkages in the U.S. is SEMATECH, a research consortium of semiconductor manufacturers set up in 1987 by 14 U.S. semiconductor firms with the financial assistance of the U.S. government, which has been given credit for reviving the industry in the face of Japanese competition (Irwin and Klenow 1999).

Firm collaboration exists in Mexico, for instance, in the Mexican *Unión Nacional Avícola* which partly concerns itself with raising the quality of technological inputs into the production process—again, with important interest in importing foreign technologies (Mayer 2002). There are other examples of international firm-firm interactions in Mexico, including TELMEX's technology transfer contract with its main technological supplier, ALCATEL, a U.S. company. In the latter case, the Mexican telecom concern implemented this firm-firm agreement as a "lateral" agreement to complement the work of its Long Distance Supervision National Centre located in Querétaro, which was created after the company's privatization to centralize "… the functions of supervision, maintenance, and negotiation to acquire long-distance technology for the firm" (Casas, De Gortari, and Santos 2000, p. 228). In both cases, the dominant private sector presence ensures relevance of R&D. Yet these efforts have developed without the involvement of the public sector, and have arisen out the firms' own concerns about their competitiveness.

In theory, it is unlikely that market forces alone will lead to the establishment of strong knowledge sharing and technology diffusion agreements among private firms, primarily because firms are naturally concerned about allowing potential competitors to profit from their own R&D investments and know-how. This is the so-called "limited appropriability" problem discussed earlier in this chapter. But there are other potential market failures related to capital markets that affect the financing of R&D efforts, especially for small and medium enterprises that wish to supply inputs of production to larger, often multinational corporations. In addition, in some sectors that rely on high-science technologies, markets are often non-existent for scientific applications due to lack of scientific knowledge in the private sector and lack of productive knowledge on the part of research scientists. Martin and Scott (2000) summarized the relevant market failures that are likely to limit the extent of private sector knowledge and innovation linkages among firms. The market imperfections, the productive sectors in which they might arise and the potential policy instruments that can help to resolve these failures are listed in Table 5. To Martin and Scott's original table, we have added the fourth column that lists the countries in which those policies have been applied.

Table 5. Innovation, Sectoral Market Failures, Policies

Main mode of innovation	Sources of sectoral innovation failure	Typical sectors	Policy Instrument	Countries
Development of inputs for using industries	Financial market transactions costs facing SMEs; risk associated with standards for new technology; limited appropriability of generic technologies	Software, equipment, instruments	Support for venture capital markets; bridging institutions to facilitate standards adoption	Israel, Sweden, Finland
Application of inputs developed in supplying industries	Small firm size, large external benefits; limited appropriability	Agriculture, light industry	Bridging institutions (extension services) to facilitate technology transfer (e.g., PRCs)	USA, Chile
Development of complex systems	High cost, risk, limited appropriability (particularly for infrastructure technology)	Aerospace, electrical and electronics technology, telecom/computer technologies, semiconductors	R&D cooperation subsidies (e.g. research consortia)	Japan, USA
Applications of high-science-content technology	Knowledge base orginates outside commercial sector; creators may not recognize potential applications to effectively communicate new developments to potential users	Biotechnology, chemistry, materials science, pharmaceuticals	Bridging institutions to facilitate diffusion of advances in big research; incentives for knowledge appropriation	USA

Source: Adapted from Martin and Scott (2000).

In general terms, Table 5 indicates that the establishment of non-market "bridging" institutions can help solve key market failures. There is not magic recipe for designing these organizations, although PRCs and universities often fulfill this bridging role.

C. Public research centers (PRCs)

In Mexico, government financed institutes enjoy a disproportionate share of the national research budgets. The logic of the ISI period was that fledgling industries often lack the in-house capability to undertake the necessary research. Alternatively, the same problems of appropriability and lumpiness suggest that industry-level institutions can address an important market failure. However, as Rosenberg (2000) argues, in practice, government institutions established for these purposes are likely to have little positive impact for two reasons. First, in general, government researchers have relatively little understanding of the specific needs of the productive sector. Second, it is difficult to provide researchers at public institutes with strong incentives to be responsive to economic needs.

This problem of mismatched agendas appears in force in Mexico, where the situation of the roughly 150 PRCs reveals the perils of poor incentive design. These centers are dependent on the secretariat to which they belong and frequently oppose any efforts of the secretariat to contract firms or outside universities who might be more qualified to investigate a particular question.[16] If the private sector and universities perceive that PRCs that enjoy ample government subsidies will thus succeed in producing economically meaningful innovations, they might actually curtail their own R&D efforts

[16] Discussions with and presentations by Carlos Bazdresch, CIDE, who is a former head of CONACYT in Mexico, various dates during 2001 and 2002.

since they might consider themselves to be uncompetitive relative to the governments' PRCs. This is one of the reasons why theory indicates that publicly funded R&D might crowd-out private R&D. Most existing empirical studies at the micro- and national levels find that publicly financed R&D in the U.S. and European countries are not substitutes for private R&D, although most studies suffer from methodological and data problems that led David et al. (2000) to conclude that this evidence should still be treated with great caution. The extent to which public funding of R&D in Mexico, without firm links with the private sector, has led to a crowding out of private R&D needs to be investigated further, but it is likely that complementarities have been quite rare.

Further, the lack of competition has had the usual depressing effects on quality and created obvious disincentives to work with other institutions who might be potential rivals. Proposed reform laws foresee greater autonomy for the centers and further offer the possibility that research funds will be allocated by competition and not automatically to the particular center of investigation. These reform efforts should be supported.

Having said this, it is important to note that some PRCs in Mexico have successfully performed technology transfers to the private sector. On the other hand, low levels of human capital in the private sector itself, which is related to low tertiary and secondary schooling especially in rural areas, have also become obstacles to successful PRC-intermediated technology transfers. Three such cases are summarized in Box 2. An interesting aspect of the three cases is that they are related to areas of innovation where Mexico has a notable IRCA, as discussed in section VB above, namely primary ferrous metals (the relationships between CIATE-Querétaro and Altos Hornos) and food items (the case of CINVESTAV-Irapuato; and CIATEQ's relationship with sugar producers from Veracruz). Yet in both of the cases related to CIATEQ, its original relationship with Altos Hornos and the sugar industry dates back to prior to the privatization of both industries. Hence this experience reveals that successful technology transfer relationship between PRCs and firms might take time to develop, and government management of firms might be a useful stepping stone towards more effective R&D investments.

These examples cannot be used to support the nationalization of industries, because the interesting finding is precisely that the CIATEQ-Altos Hornos relationship has survived after privatization. This experience does suggest, however, that additional incentives, such as collaboration subsidies, might be necessary to instigate knowledge linkages between the PRCs and the private sector in current market economy. But competition among PRCs and universities will be required in order to raise the quality of the scientific institutions that are key for the efficiency of the NIS, as demonstrated by our econometric evidence discussed in section VA above.

In addition, the experience of CINVESTAV-Irapuato indicates that linkages with sources of innovation in the United States can be quite rewarding in terms of the helping to diffuse and adapt knowledge from abroad for practical uses in Mexico. This types of international linkages could also be supported by both the Mexican and the U.S. government.

D. Universities

There are several channels through which universities enrich the innovation network. First, they produce tertiary educated workers who are the lifeblood of the NIS. The overriding importance of this function cannot be overstated. Interviews with high-tech companies in Costa Rica highlight the issue of generation of quality human capital in a country as an order of magnitude more important than other factors including R&D incentives, or R&D suppliers, and so forth (see De Ferranti et. al. 2002, 100-104). Second, universities are well suited for large, long-term, basic research. Third, they are likely to maintain contacts with research centers in industrial countries and hence perform an important role as a link to worldwide scientific and technological know-how. In all cases, the degree to which they remedy the underlying market failures depends on the links to the productive sector.

Higher education plays a dominant role in Mexican and Latin American R&D, as shown in Table 6.[17] The high concentration of R&D performed by the universities has an impact on the nature of the research done. Hansen et al. (2002) argue that there is a rough correlation between the dominance of the university sector and the proportion of R&D expenditures on basic research. Logic dictates that this slight bias is not necessarily a weakness, depending on the extent to which universities and their researchers have incentives to link their research efforts to the productive sector.

Table 6. Structure of R&D Effort in Selected Countries, 1995-2000
(percentages of total R&D expenditures, annual averages)

Country	Financed by the Productive Sector	Financed from Abroad	Performed by the Productive Sector	Performed by Higher Education	Performed by the Non-Productive Public Sector
BRA	39.14	0.00	44.04	44.27	11.69
CAN	44.56	12.69	57.69	28.67	13.64
CHL	19.37	5.75	9.62	47.11	43.27
CRI	n.a.	n.a.	32.58	48.72	18.70
FIN	62.72	4.12	66.95	19.12	13.93
IRL	66.46	8.79	71.58	20.46	7.96
KOR	73.02	0.08	72.53	10.42	17.05
MEX	19.06	5.22	22.66	39.82	37.52
SWE	64.37	3.47	75.73	21.57	2.70
TWN	60.03	0.10	61.00	12.20	26.80
USA	62.98	0.00	73.88	14.33	11.78
VEN	38.13	0.00	n.a.	n.a.	n.a.

Source: Authors' calculations based on annual data collected by Lederman and Sáenz (2003).

The economic value of this non-applied research to the economy can to some degree be measured by the degree of interaction with firms. For example, in Finland, 40 percent of firms have collaborative arrangements with universities (Brunner 2001), and as Blomström et al. document, these interactions have been vital to the continued dynamism of both the high-tech and more traditional forest industries. Comparable numbers are not

[17] The data in Table 4 for Mexico differs from that in Table 6 due to the different sources of the information and different time periods. The data in Table 6 are internationally comparable.

available for Mexico. However, Figure 14 reports survey results published by the latest issues of the Global Competitiveness Report (GCR) of business perceptions of university-private sector interactions (labeled "collaboration" in Figure 14). Mexico, as many Latin countries, appears with a very low ranking.

This is consistent with case studies by Mayer of Avimex, a veterinary pharmaceutical company in Mexico, who notes that despite a high 10–15 percent of sales spent on R&D and world-class innovations in joint projects with U.S. research institutes, the major disadvantage Avimex and Mexican firms in general face is the lack of research partners within the country, which has forced them to look for partners in the U.S. Returning to the patent regressions discussed in the previous section of this chapter, the roots of the Mexico's R&D inefficiency appear to be precisely these quality and collaboration factors.

The isolation of the Mexican university arises from both demand and supply sides. There are a number of factors—along the themes of poor design and faulty incentives—responsible for the dearth of effective linkages and collaboration between scientific institutions and the private sector in LAC. But there is also a lack of incentives for universities to link and address private sector knowledge needs. The incentives within the universities are generally biased away from collaboration with business. Arguably there is a more "liberal arts" as opposed to "technical" culture, with deep historical roots that resonate with Lazonik's analysis of the inadequate U.K. system.[18] Because researchers cannot appropriate the benefits of innovation, they have little incentive to undertake innovations and link with the private sector. Various developed countries allow ownership rights to government-funded R&D — often on a case-by-case basis — and in some instances, such as in the United States and Japan, explicitly in the national patent laws. In the United States, the Bayh-Dole Act of 1980 allows industry contractors of the government, national laboratories, and academic institutions to automatically retain title to the inventions that come out of their research work, even if it is funded by the government. In return, the government receives from the university or industry a royalty-free license for governmental purposes. There is convincing evidence that these laws have in fact helped speed the rate of patenting by research conducted in the U.S. public laboratories (Jaffe and Lerner 2001), and thus the lessons regarding incentives for patenting by researchers applies also to the Mexican PCRs as well as universities.

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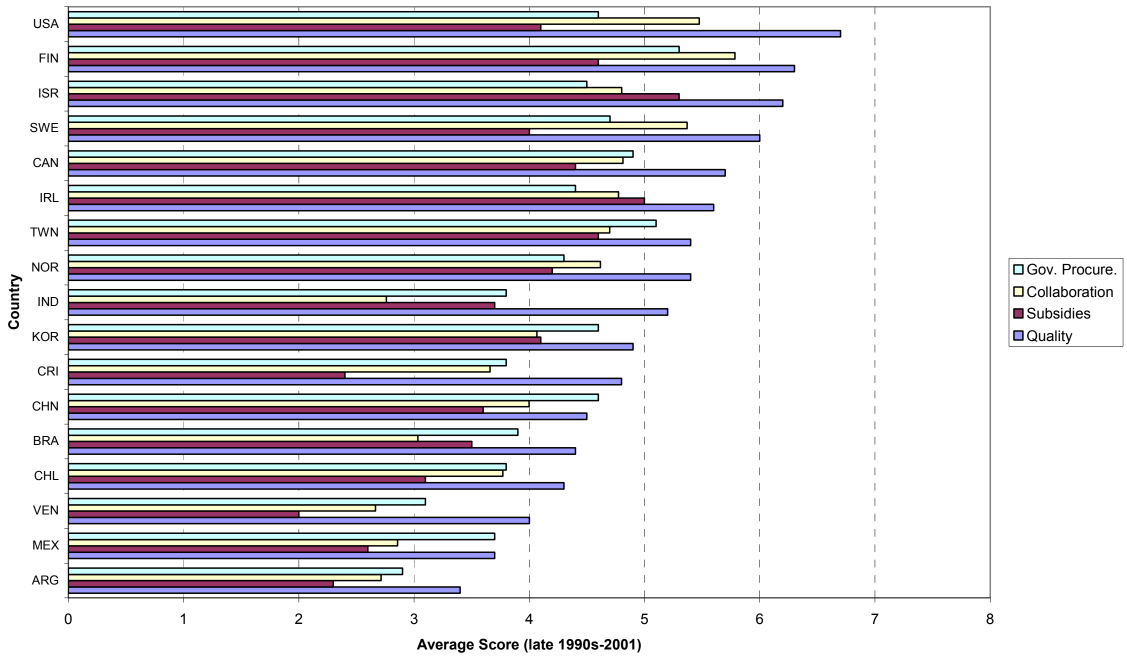
[18] This appears to be the case throughout the region. Agapitova and Holm-Nielsen (2002) argue that, overall, the university mentality in Chile is not geared to solving problems on a business time scale, and Mullin (2001) argues that overall academic interests tend to be narrow and unapplied. Observers of Costa Rica's two-star technical school stress not so much incentives, but the "foundational impulse"—a desire to be patterned more on the Massachusetts Institute of Technology (MIT) or other technical schools of excellence than on those with a liberal arts bias.

Figure 14. GCR Survey Results: Private-Sector Perceptions on Innovation-Related Factors, 1996-2001



Goldfarb, Henrekson, and Rosenberg (2001) cite differences in academic structures and their influence on researcher involvement with the commercialization of research ideas as an important reason for the much lower spillovers from academia to industry in Sweden as compared to the United States. In the United States, competition for researchers and scientists has reinforced the need for policies that are attractive to them. Universities have established technology transfer offices (TTOs) and have liberal policies on faculty leave of absence and consulting privileges that allow faculty to pursue commercial opportunities while keeping their position as a faculty member intact. In Sweden, however, universities do not gain from the commercialization, and hence offer resistance to faculty involvement with industry. For instance, it is difficult for Swedish professors to take temporary leave to organize firms, as is done in the United States. What matters is that property rights are allocated to the university or the researcher, and thus the innovation can be commercialized. However, how they are allocated also has a significant impact. If researchers get the property rights, they are likely to remain at the university; otherwise, they will likely move to the productive sector.

At a more mundane level, Mayer (2002) argues that, in Mexico, bureaucratic rigidities make it difficult to write contracts and get access to the use of laboratories and equipment from the university. The approval process is very centralized and bureaucratic and hence a disincentive to firms to attempt interactions with the universities.

E. Capital markets

By nature, innovation has long gestation periods and high risk. Hence, innovation policy is necessarily tightly linked to credit markets and failures in the latter can paralyze innovation. In particular, the absence of venture capital where the introduction of a new idea might get seed money is noted throughout the region as a barrier to technological progress. In Mexico there is presently no recognition of the venture capital firm as a legal entity. There are holding companies or "SIMCAS" that hold other firms' assets, but the legal structure does not encourage the association of several entrepreneurs to share risk. Further, the profits of the SIMCAs enjoy unfavorable fiscal treatment.

We showed earlier in this chapter that total R&D expenditures tend to be higher in high-income countries than in poor countries. It is possible that one reason why this occurs is that rich countries have more developed domestic capital markets that help finance risky R&D efforts. Lederman and Maloney (2003) analyzed the empirical determinants of R&D expenditures over GDP with data covering developed and developing countries during 1960-2000 using five-year averages of the available information from Lederman and Sáenz (2003). Their results are presented in Table 7. Regarding capital markets, the variable "private credit" stands for credit to the private sector as a share of GDP. It has a positive and significant effect on R&D effort. Moreover, combined with, the level of public expenditures, and the extent of protection of intellectual property rights, financial depth explains the lion's share of the positive correlation between GDP per capita and R&D effort.[19] Consequently, an important element of the Mexican NIS reform agenda for the future is inextricable from financial-sector policies aimed at deepening the domestic credit market and/or increasing the extent of financial integration with the U.S. (see chapter 3 of this report).

Table 7. Determinants of R&D/GDP

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Dependent Variable	**R&D/GDP**									
Estimation Method	**GMM System Estimator**									
Explanatory Variables:										
R&D/GDP at t-1	0.791***	0.760***	0.651***	0.826***	0.736***	0.787***	0.731***	0.834***	0.576***	0.643***
Log (GDP per capita)	0.004***	0.002***	0.004***	0.001*	0.002***	0.004***	0.001**	0.001***	0.000	0.000
GDP growth	0.028**	0.033***	0.035**	0.053***	0.023***	0.018	0.024**	0.035***	0.047***	0.044***
Fixed	-0.007	-.013***	-.016***	-0.012**	0.001	-0.007	-0.006*	-0.013**	-0.011**	-0.009*

[19] The IP index was provided by Park (2001).

Investment/GDP										
Log (IP Index)		0.003***							0.003***	0.003***
Private Credit/GDP			0.003***						0.004***	0.003***
Log (Educational Attainment)				0.004***						
Government Expenditure/GDP					0.032***				0.033***	0.024***
Openness						0.001***				
Quality of Research Institutions							0.009***			0.001
Collaboration between productive sector & universities								0.005***		
Sargan Test (p-value)	0.10	0.45	0.10	0.18	0.32	0.26	0.13	0.16	0.54	0.79
2nd Order Serial Correlation (p-value)	0.47	0.53	0.51	0.43	0.65	0.44	0.50	0.43	0.81	0.69
Observations	102	102	102	102	102	102	101	102	102	101
Countries	41	41	41	41	41	41	40	41	41	40

Notes: Period dummies were included in all regressions. Coefficients are significant at *** 1%, ** 5%, and * 10%.

In India, besides ample fiscal incentives for R&D, a development financial institution (namely the Industrial Credit and Investment Corporation of India – ICIC – and its subsidiaries) initiated venture capital in 1988 and subsequently private venture capital firms emerged, albeit at a smaller scale. In Israel, Trajtenberg (2001) reports that innovation policy is essentially credit policy. Hence Mexico might want to consider proposal to revamp the role of its development financial institutions with a narrower focus on innovation and R&D credit programs. This is the logical next step in moving away from the old-fashioned industrial policies in favor of focused innovation incentives. But clearly the NAFTA chapter on intellectual property rights had a substantial impact on Mexican R&D, which explains, together with the recovery of the Mexican economy after 1995, the resurgence of R&D especially after 1996, as shown in Figure 9 above.

G. Summary of policy recommendations and monitoring progress

The main policy implications can be summarized as follows.

First, NAFTA effects on innovation could have acted either through trade liberalization or through the improvement in the protection of intellectual property rights demanded by the agreement. While import competition was associated with improvements in manufacturing TFP as discussed in section III, it might also have helped indirectly by improving the efficiency of R&D in Mexico as shown in section VA. But Mexico still has an inefficient NIS. In addition, Mexico's improvements in intellectual property rights were probably associated with the moderate yet insufficient increase in R&D expenditures in the late 1990s. Finally, to the extent that NAFTA increased credit availability to Mexican firms (see Chapter 3), then this might have stimulated the modest recovery of R&D. Nevertheless, the main conclusion of this chapter is that NAFTA is not enough to ensure technological convergence in North America, since Mexico still suffers from inefficiencies and low levels of R&D.

Thus our second conclusion is that Mexico needs to address issues related to the inefficiency of its NIS. In particular, it needs to improve the quality of its research institutions (PRCs and universities). This is likely to be associated with incentive reforms and public subsidies to stimulate linkages between the existing research institutions and the productive sector. This applies not only to private firms, but also to strengthening the R&D effort of PEMEX. In this regard, we have proposed various policies that can provide incentives for researchers to get involved with the productive sector, in particular incentives for the appropriation of innovations emanating from technical research. In practice it is difficult to know before the fact what is the most effective institutional design for establishing contracts between firms and researchers so that the firm can be confident that the researcher will provide effective applied research services and not divulge corporate strategy secrets to other competitors. Besides regulatory changes affecting IPRs for university and PRC researchers, it is also likely that public subsidies will be needed to provide additional incentives for firms to establish such links, especially when there is little previous collaborative experience and thus little mutual trust. Hence we recommend that subsidy programs of this sort be implemented initially only with modest funding on a pilot basis. These are reforms that Mexico can implement on its own after more careful study.

Third, Mexico needs to keep working on the development of its domestic credit markets. Generally related policies are discussed in chapter 3 of this report. Policymakers should also consider revamping their development financial institutions to focus their efforts on providing credit for venture capital funds and more generally to help finance collaboration between PRCs, universities, and the productive sector. Together with the improvement of the quality of universities and further efforts to expand tertiary enrollment, in time these policies will stimulate increases in Mexico's total R&D effort as the productive sector finds more rewarding quality research partners.

Fourth, Mexico could negotiate with its NAFTA partners the co-financing of research exchange programs. While we have noted efforts that have produced fruitful collaboration between PRCs and innovative firms in the U.S., it is quite likely that not enough is being done. Given the fact that the U.S. government remains the world's leader in funding R&D, and given Canada's interest in promoting its own R&D, it is likely that Mexico can find receptive ears in these countries.

Finally, any such efforts will need to be evaluated over time in order to adjust and continuously improve them. To conduct such evaluations, it will be necessary to improve the quality and availability of innovation-related data. In fact, besides close monitoring the financial linkages between PRCs, universities, and firms, it might be useful to build an information-based monitoring facility that would play a similar role as the National Commission for the Evaluation of Research Activity (CNEAI) in Spain since 1989. This commission has improved the quality and quantity of basic research output in Spain, even in a period of time when public funding of research declined (Jiménez-Contreras et al. 2003). The main monitoring variable used by the CNEAI is the number of publications of government- and university-funded research, which are made public once or twice a year. Indeed, given the reputational rewards sought by researchers, it is likely that the mere publication of the performance index can by itself improve the quality of research. This principle could be used to improve the quality of applied research by, for example, maintaining an accurate count of patents granted by the U.S., Canadian, and Mexican governments to researchers residing in Mexico and financed by public funds, either via the PCRs or universities. Other important variables to monitor are discussed in De Ferranti et al. (2003, Chapter 8). The World Bank has already begun with the discussion and design of a innovation monitoring facility.

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Box 1: How Much Should Mexico Spend on R&D? Some Algebra.

Beginning with a simple production function

$$Y = K^{\alpha} L^{1-\alpha} S^{\lambda}$$

where S is the stock of accumulated R&D. This can be rewritten as

$$\Delta \ln Y = r_k \left(\frac{I}{Y}\right) + r_s \left(\frac{\dot{S}}{Y}\right) + (1-\alpha)\Delta \ln L$$

using the fact that $\beta_x \Delta \ln(X) = r_x \left(\frac{\dot{X}}{Y}\right) = r_x(x)$

where r_x is the rate of return on factor X and x is the share of investment in X over Y, and β_x is the output elasticity of this factor. If we remove the influence of physical factors to get TFP then the social rate of return to R&D is

$$r_s = \Delta \ln TFP / s$$

where s is the share of R&D spending in income. Following Jones and Williams (1998), the optimal level of R&D expenditure occurs where r_s= r, the real interest rate. So, the ratio of the optimal level of R&D investment to actual along a balanced growth path can expressed as the ratio of the social rate of return to R&D to the real interest rate.

$$\frac{s^*}{s} = \frac{r_s}{r}$$

Jones and Williams argue that for a very conservative estimate of 28% return to R&D in the US, a long run 7% rate of return on the stock market over the last century suggests that the US should be investing perhaps 4 times the present level.

Box 2. Knowledge flows from PRCs to the productive sector in Mexico

This text box uses the words and materials from Casas, de Gortari, and Santos (2000, 230-232).

Case 1. Since its establishment in the 1970s, the Center of Research and Technical Assistance based in Querétaro (CIATEQ) has interacted with industry. One of its first projects was on metal-mechanics, particularly metallurgy. This project involved long-term collaboration with the Altos Hornos de México company in Coahuila. CIATEQ's early specialization in metal-mechanics led to another long-term collaborative project mechanizing agriculture, first with industries producing capital goods for agriculture in general and later with the sugar mills. The latter has been maintained without interruption and has involved multidisciplinary projects in several areas, including materials technology. At first, this collaboration was with the sugar cane producers association from Veracruz. Due to privatization, collaboration now exists directly with sugar cane enterprises from other regions and countries, such as Guatemala. This example shows how knowledge and technological capabilities accumulated by CIATEQ on metal mechanics have gone through different learning stages, starting with state-owned companies prior to the mid-1980s. These efforts contributed to the development of material sciences, leading innovations in metal pieces and metal casts, and the design, development and operation of industrial plants and services. This network is interregional and international.

Case 2. In Mexico's Bajío region, farmers' associations[20] are becoming aware of the value of knowledge to solve their crop problems. This is the case of the strawberry, which is one of the main regional crops and has huge potential for the national market as well as the export market. The Center for Research and Advanced Studies based in Irapuato (CINVESTAV-Irapuato) has tried to help farmers acquire technology to make virus-resistant strawberries by applying a 20-year old technology. It is called in vitro micropropagation and is utilized to propagate virus-free strawberry plants. Since 1983, CINVESTAV has worked to establish contacts with peasants without success. In 1995, new contacts were made through state and municipal governments, establishing a bilateral relationship with farmers through governmental financial support. The goal of the project was to establish a laboratory to teach farmers how to micropropagate the plants. Despite CINVESTAV's on-site laboratory and extensive training, the peasants have not been able to assimilate the knowledge because of their lack of adequate education and interest in the strawberry species micropropagated by the research center. Nevertheless, farmers' associations in Mexico have begun to initiate interactions with PRCs and to convince local governments to support them.

Case 3. In 1991, CINVESTAV-Irapuato began collaborative interactions with a foreign company -- Monsanto. This company developed technology for the genetic modification of potatoes to make them virus resistant. CINVESTAV-Irapuato sought to apply this technology to Mexican potato varieties from different regions. The transfer of technology involved several knowledge flows and diverse knowledge networks, including: the transfer of genes modified by Monsanto; the training of researchers in the Monsanto Research Centre on the Science of Life located in St. Louis, MO; the field tests of the genetically modified Alpha potato, performed in the state of Washington by Monsanto; the acquisition of equipment by the center, and the rapid advancement in scientific capacities for developing new modified varieties. In this bilateral collaboration, other actors have participated as intermediaries or financing agencies.[21] This networking allowed CINVESTAV-Irapuato to make a breakthrough in applying modified genes to local agriculture, creating a knowledge capability that could, in the near future, lead to further innovation.

[20] These organizations are crop-specific, close to government agencies (particularly the Ministry of Agriculture) and play an important role in the diffusion of official policies related to technical aspects of crops. They participate in public/private organizations representing the interests of middle-man farmers. However, they also take independent positions with regard to government policies.

[21] On the international side, the project has been mediated by: (a) the International Service for Acquisition of Agri-Biotech Applications (ISAAA), which is a nonprofit organization, that has the role of easing the acquisition of technology from industrialized countries for developing countries; (b) the Rockefeller Foundation, which has financed the collaboration, mainly the salaries and travel expenses, of researchers going to the United States, as well as the purchase of reagents and equipment for CINVESTAV; and (c) the INIFAP, in charge of carrying out large scale field tests throughout Mexico on the modified potato variety.