16 de diciembre de 2002

NÚMERO 249

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KNOWLEDGE, SCALE AND INNOVATION: LESSONS FROM VETERINARY PHARMACEUTICS AND POULTRY IN MEXICO

Abstract

I use two case studies on the veterinary pharmaceutical and poultry sectors in Mexico to discuss technological change in relation to liberalization in trade and investment. Most of the observed technological change takes the form of implementation rather than R&D. Taking as context a Schumpeterian model that shows that implementation is subject to disadvantages that can lead to a low technology trap, I discuss and compare technological change in Mexico to that occurring in developed countries. Since technological levels are determinants of comparative advantage, and the social returns of technological change are often higher than the private returns, public support of the demand and supply of innovation could produce important benefits. Well designed policies, along lines practiced in developed countries, need not prejudice efficiency and competition.

Resumen

Utilizo dos estudios de caso en los sectores farmacéutico veterinario y avícola mexicanos para discutir el cambio tecnológico en relación a la liberalización del comercio y la inversión en México. Gran parte del cambio tecnológico observado toma la forma de implementación, en contraste con la investigación y desarrollo. Comparo el cambio tecnológico mexicano con el que ocurre en países desarrollados, tomando como contexto un modelo Schumpeteriano que muestra que la implementación esta sujeta a desventajas que pueden llevar a trampas de baja tecnología. Dado que los cambios tecnológicos son factores determinantes de las ventajas comparativas, y que sus retornos sociales son a menudo mayores que los privados, el apoyo gubernamental de la innovación tanto por el lado de la demanda como por el de la oferta podría implicar importantes beneficios. Es posible, como se practica en los países desarrollados, diseñar políticas que cumplan estos objetivos sin perjudicar la eficiencia y la competencia.

Acknowledgement

This project emerged from conversations with David Sarfati, Sales Manager at Avimex, who then enthusiastically put me in touch with the people involved. The collaboration of Sergio Chávez González, General Director of the Unión Nacional de Avicultores, and Maria Antonieta Yánez Cervantes, Humberto Arenas Reyes and Carlos Sánchez Widmann, economic analysts of the same organization, is greatly appreciated. Bernardo Lozano, General Director of Avimex, was particularly forthcoming and also emphasized the need for innovation by firms in LDC's. The project also received unreserved encouragement from Bill Maloney at the World Bank, as part of the NAFTA Evaluation Project.

Introduction

How does technological change occur in practice in developing countries? How do trade liberalization and direct foreign investment, whose purpose is to increase economic growth and technological transfer, contribute to this process? These two policies are supposed to promote not only the capital accumulation that is viewed by neoclassical theory as the essence of economic growth (Harrod, 1939; Domar, 1946; Solow, 1956; Swan, 1956), but also technological change, the focus of more recent empirical work (Knight, Loayza and Villanueva, 1993; Islam, 1995; Caselli, Esquivel and Lefort, 1996; Klenow and Rodriguez Clare, 1997; Hall and Jones, 1999; Easterly and Levine, 2000). Specialists in economic growth argue that achievements in total factor productivity may result in amplified increases in income (Parente and Prescott, 2000), and that technological convergence rather than factor accumulation, was behind the catch up of the OECD countries to the US (Dollar and Wolff, 1994). Martin and Mitra (2001) show for the period 1967-1992 that TFP in both agriculture and manufacturing grew more rapidly in developed than in less developed countries. Maloney (2002) compares the development of Latin America with countries such as Australia, Sweden and Finland, finding that deficient human capital accumulation determining technological capabilities may have played in its failure to develop. Theoretical work also emphasizes the complementary between capital accumulation and technological change through research and development (R&D) (Aghion and Howitt, 1992; Howitt and Aghion, 1998), and shows that the diffusion and spillover of ideas can drive convergence and growth (Howitt, 2000).

The increasing pace of technological change has made innovation increasingly important. This is reflected, for example in the theory of international trade, which now considers technological levels as one of the determinants of comparative advantage (Krugman, 1995). Promotion of technological change has shifted from science policies to technology policies supporting innovation and adoption in various ways. These include "supply policies" linking research and development and "demand policies" through subsidies and tax breaks (Mowery, 1995). Such policies have been put in place in most industrial countries during the last two decades and in Japan since before World War II.

The economics of innovation and technological change have been studied mainly for developed countries. For example, the Handbook on this subject (Stoneman, 1995) includes chapters on measurement issues, appropriability, strategy issues, difussion, finance, employment, trade and policy. Of these, only Krugman's chapter on trade treats underdevelopment specifically, in a model that assumes that the South can only produce older products, while the North concentrates on the new, implying a permanent income gap.

The empirical study of innovation first concentrated on evaluating the Schumpeter's concerns with firm size and then moved to a broader concern with the determinants of technical change. Schumpeter (1934) argued that larger firms operating in a concentrated market were the engine of technological progress. Empirical studies have found that large firms are much more likely to be involved in R&D. However, when the intensity of R&D is considered, it has mostly been found to be proportional to size. Nevertheless, large firms are considered to have advantages arising not only from size per se but from appropriability conditions that are correlated to firm size through its output possibilities and through practical limits to firms' possible growth. In fact, the endogenous, dynamic, relation between firm size and innovation is not well understood (Stoneman, 1995). A whole new dimension has been introduced by the study of the strategic aspects of innovation, which are now considered essential to understanding industrial organization (e.g. Audretsch, Baumol, and Burke, 2001).

Another important consideration is the product cycle. New product markets are characterized by market share instability and a relatively competitive market structure, while mature products tend to have stable market shares and a more concentrated market structure (Mazzucato, 2000).

In practice, R&D is limited to just a few countries MENCIONAR DATOS and developing countries raise productivity by *implementing* technology. The dynamics of technological implementation in underdeveloped countries are quite different from those of technological innovation in developed countries, especially when they are opening up to trade and investment. Howitt and Mayer (2001) extend the Schumpeterian approach to distinguish between R&D and implementation. They note that human capital accumulation must reach a certain level, defined with respect to leading edge technologies, before countries can innovate through R&D. It turns out that if the productivity growth through implementation (a less productive innovation technology than R&D) is not fast enough, and the necessary savings in human capital cannot be generated, the threshold necessary for R&D may not be reached. Convergence clubs of countries characterized by *R&D*, or trapped in *implementation* or in *stagnation*, may arise even in an open economy. In their model, productivity levels can be quite different across countries and may be influenced by a series of country-specific and policy parameters. The model explains the divergence in per-capita income that took place between countries during the 20th Century (Pritchett, 1997), as well as the convergence that took place between the richest countries during the second half of the century. The low technology traps give a characterization of underdevelopment.

How is technological change in less developed countries different? Is there evidence for a low technology trap? How do these possible barriers to technological development work out in practice? Is it possible that these barriers are somewhat porous and that ways can be found to dissolve them so as to produce faster productivity growth? Tremendous examples exist where simple knowledge breakthroughs have resulted in multibillion dollar industries, as in the case of the

garment industry in Bangladesh (Easterly, 2000, p.146).[1] Recent studies on productivity and wage trends in Mexico after NAFTA find little evidence for convergence of Mexican to US levels (Hanson, 2002; Chiquiar and Hanson, 2002; Robertson, 2002), suggesting that there are barriers to technological change. The purpose of this paper is to throw some light on these issues by performing case studies on the poultry industry in Mexico (the 4th largest in the world), and one of its technological suppliers, the veterinary pharmaceutical industry. This sector is mainly a technological implementator, although some of the large enterprises have integrated vertically with firms providing technological services that border on R&D. In the case of the veterinary pharmaceutical sector, we focus on Avimex, a medium-size firm dedicated to innovative technological services including the development of new product lines, that has achieved world-level innovation. The firm's sales amount to 3.2% of the domestic market. It is the largest Mexican firm not belonging to a vertically integrated group of firms in the poultry or pork industries. Since 1986, Mexico has taken a series of steps to open trade, so the study of these two industries also throws light on the impact of liberalization of trade and investment.[2] The case studies allow us to examine the economic forces shaping innovation for technological implementators and for their technological service providers, as they actually occur in a less developed country.

One approach to understand innovation and interactive learning, has been to study national systems of innovation. (Lundavall, 1995). These systems include universities, research institutes, R&D firms, and other industries. Blomström &Kokko (2001) recount recent technological policy successes in Sweden and Finland in these terms. To understand the low technology traps that may exist, we think of these systems as the knowledge and innovation sector, and seek to analyze its functions as well as the incentives and public policies that conform it in the case of a developing country. The knowledge and innovation sector acts in relation to a diversity of other productive sectors. Some may only implement technology while others may develop it, approaching the world-level leading edge. The human capital requirements of technological implementators involve production input skills that can be provided by technicians, engineers and so on. Technological implementators also require certain technological services that may be produced in house or purchased from specialized providers. These services include: 1) understanding and setting up the new technologies and 2) generating the knowledge necessary to adapt new technologies to local conditions and prices. Technological services providers may also perform R&D, generating new technologies at the world-level leading edge. The provision of these technological services requires a spectrum of skills ranging from technical specialists to scientific and technological researchers. Thus

[1] This could be considered an example of achieving implementation in a context of stagnation.

[2] In the period 1994-2002, Mexico established free trade agreements with the US, Canada, Chile, Bolivia, Colombia, Venezuela, Costa Rica, Nicaragua, Israel, and the European Union, and it has recently signed a treaty with...

the functions of the knowledge and innovation sector can be described as follows. The sector:

1. Trains people in the skills needed for production and for the provision of technological services (including technological implementation) and R&D.
2. Acquires knowledge from the global knowledge network, using it to provide technological services and for R&D.
3. Is the depository of the knowledge assets of the economy: public and private knowledge needed for the functions mentioned above, including the industrial secrets involved in production and in new technologies.

Effective human capital policy promoting technological change must take these functions of the knowledge and innovation sector into account.

As we noted above, technological implementation, the characteristic mode of technological change in developing countries, is associated with low technology traps. These traps results from advantages held by the leading countries, specifically a higher level of human capital allowing them to reach the threshold level needed for R&D (Howitt and Mayer 2001). This threshold advances with the technological leading edge and therefore the traps persist as economic growth occurs. In the case studies we pursue, several other economic forces due to trade and to the scale of operation, as well as knowledge assets yielding advantages for the leading countries, become apparent. Their impact is not well-covered by economic theory, particularly as it applies to less developed countries. We outline now 1) what the model implies about the knowledge and innovation sector and 2) how these additional advantages reinforce the multiple equilibria giving rise to convergence clubs in the Howitt & Mayer (2001) model.

Knowledge assets provide an important component of income, by making production and technological innovation possible and reducing its costs. Thus they constitute an element compounding any possible low development traps. For example, investment from abroad may increase employment and productivity. While there may be some knowledge spillovers, it is likely that the main knowledge gains will remain within the investing firms, that the transfer of knowledge assets will be small, and therefore that existing low technology traps will be preserved.

Another phenomenon interacting with technological change is the scale of operation. Scale has been one of the quintessential features of manufacturing since its origins. As soon as Solow (1957) established the importance of technological change, Stigler (1961) pointed out that scale is a related phenomenon of similar magnitude, something which Solow (1961) accepted. In spite of its importance, there is no well-accepted theory of the endogenous relation between scale and technological change.

The following point of view emerges from our studies. As industries grow, some of the opportunities for cost reduction involve increases in the scale of operation. To achieve these increases, it is first of all necessary to have a sufficiently

large demand for the product, or an opportunity for the consolidation of production. Next, it will usually be necessary to either develop a new technology or to implement one from the available pool. This may require, in turn, the availability of human capital, either for carrying out the new investment or as input for the new process. Thus, as the scale of operation rises, industries move from one production function to another with higher technology, rather than benefiting directly from returns to scale within the same production function or technology.

Many technologies are tied to scale for their operation and/or viability. Thus scale is a parameter that may dictate the available total factor productivity and give and additional advantage to R&D leaders. This in turn is a determinant of the demand and consequently of investment in human capital, which also depend on the total level of production per capita. Scale offers other advantages including trademark recognition and other commercial benefits, obtained when buying inputs or selling outputs.

Finally, technological change interacts with trade. Technological R&D leaders acquire monopoly rents on the world market that tend to be much larger than those that can be obtained from implementation, even when the implementation can be transplanted to other, perhaps less developed, economies. This gives R&D leaders and additional advantage. From this point of view, an important characterization of development is the ability to produce world-level innovations that can access world markets. In the case of smaller closed economies, technologies involving large scale of operation may be unviable, making technological change more difficult, and thus a low technology trap more likely. In the case of open economies, R&D leaders operating at large levels of scale will enjoy monopoly rents on the world market, thus compounding the income difference with less developed countries. Local industry in less developed countries will clearly have a hard time competing with their developed counterparts.

Competition has an ambiguous relation with innovation, which way be inhibited if there is to little or too much competition (Aghion et al, 2002). Thus without free trade, market size limitations and too little competition may inhibit technological growth (and therefore human capital formation), while with free trade competition may be too high, leading to the disappearance of whole domestic industries. In the more positive case in which competition enhances productivity growth under free trade, it is quite likely that whole industrial sectors will go through a process of consolidation and integration – meaning that some proportion of the firms in each productive sector will fail, in a process of creative destruction (Schumpeter, 1934). In addition, income distribution problems will tend to arise, since successful market concentration will have several effects. A higher scale of operation will tend to produce more wealth and demand skilled and unskilled labor. On the other hand, wealth will concentrate towards the ownership of the firms achieving market power.

The extreme case in which all manufacturing in a developing country were carried out by foreign firms doing their R&D in developing countries is consistent

with a low-technology trap. All technological rents from present and future enterprises would accrue to developed countries, and incentives for human capital investment in developing countries would be limited to production input skills, while innovation input knowledge and skills would concentrate in developed countries. The level of well-being entailed by this poverty trap may or may not lie above what the same country could achieve by liberalizing less radically, but will certainly be less than the well-being that can be obtained if well-targeted government support ensures the survival of all viable industries.

The following sections 1) describe the development of the poultry industry in Mexico and the economic forces that have shaped it, and 2) a) briefly outline the characteristics of the veterinary pharmaceutical sector in Mexico, (composed of multinational and Mexican firms), and the qualitative changes undergone in 15 years of liberalization, and b) describe the strategies, product lines and organization of Avimex, a medium size innovative Mexican firm in this sector as well as its contextual economic forces. The following sections discuss the findings from a theoretical economic point of view, addressing the dynamics of technological implementation and of the possible existence of low technology traps. The final section concludes.

The poultry sector in Mexico

Mexico was the fourth largest chicken producer and sixth egg producer in the world in the year 2000. It was also the third per capita egg consumer, after Japan and Taiwan, the seventh chicken consumer and the tenth turkey consumer. The poultry sector was amongst the most dynamic both in Mexico and in other countries. The average growth rate of per capita chicken consumption in Mexico grew at 4.7% between 1978 and 2000, while egg consumption grew at 3.1%.[3] In the US, chicken consumption grew at 4.2% between 1975 and 1990, and productivity grew at 2.9% over the period 1963-1984 (Ahmed, Z. and Sieling, M., 1987) for the US. Technological changes in production and commercialization have reduced real costs in poultry in relation to other animal products. These technological changes are relatively easy to implement in less developed countries and have led to a worldwide rise in the consumption of poultry products (Farrelly 1996). Changes in preferences away from red meats for health reasons have also contributed to the rise in consumption.[4]

In this section we give a short history of the poultry sector in Mexico. It is characterized by a series of crisis which will allow us to glean the main economic characteristics of the sector.

[3] All growth rates are average annual rates.

[4] The estimate of the relative role of changes in demand is beyond the scope of this work. We shall describe the trajectory of the industry in general terms.

Commercial poultry began in Mexico in 1920. The Escuela Nacional de Avicultura (National Poultry School) was founded by the government in 1928. Bachoco, one of the largest present day egg producers, was also founded during these years. In 1945, the first incubator and balanced food plants were installed. The first large scale, mostly multinational, poultry farms using these technologies were installed, competing with the family farm. In 1957 the national poultry flock was reduced by 80% due to a Newcastle epizooty. This provoked a growing dependence of poultry consumption on foreign sources, causing a sectoral commercial deficit. A National Poultry Recuperation Campaign was launched, establishing a guarantee fund and guarantee prices, soft credits, tariff-free entry for newborn chicks, and technical and publicity support. The associations that were to evolve to the present day Unión Nacional Avícola (UNA, National Poultry Union) were founded. By the end of the 50's, these policies had achieved their aim of domestic self-sufficiency in poultry.

By 1960, UNA's main concerns were the size of the rents accruing to balanced food producers, intermediaries, incubator and reproduction plants, poultry food producers, and pharmaceutical and biological laboratories, mostly multinational firms. These concerns reflect three main features of the industry that, as we shall see, have characterized it for half a century: the importance of technological inputs, the importance of commercialization, climatic and pathological risk, and price fluctuations. These have give rise to a sequence of public policies to help solve some of the problems in the industry. Between 1961 and 1971 a credit and subsidies policy was applied with huge success. Chicken production grew at rate of 20% and egg at 18.4% during this period.[5]

The industry faced a crisis between 1970 and 1972. According to UNA, the main detonators were overproduction, the contraband of poultry products, prices below production costs, epizooties, transnational firms displacing their domestic counterparts through the control of technological inputs, the lack of a poultry census to plan production, and an excessive intermediarism. The price volatility faced by the industry originates, as in other agricultural sectors, from the length of the production process, that does not allow supply to adjust rapidly enough to price changes and provokes "overproduction", price levels below costs, and thus the need to solve a coordination problem in the industry through its associations. The presence of climate and pathological risk, and profit margins reduced by technological suppliers, intensify the problem. Egg production, the sector most supported by the state, faced the strongest crisis during this time.

The crisis at the beginning of the 70's favored concentration in the industry, because only the big producers had the financial and productive resources to survive it. UNA proposed the need for planning and for vertical integration, and collaborated with the Secretaría de Ganadería (Ministry for Livestock) to elaborate the National Poultry Plan for 1975-1980, including the following elements: 1) To organize

[5] We shall concentrate on the statistics for chicken and egg production. Turkey, which is also part of the poultry industry, plays a minor role.

production so as to achieve equilibrium between supply and demand. 2) To form production and marketing cooperatives to develop national genetic lines. 3) To promote the production of raw materials, and the production of balanced food by the poultry farmers. 4) The elimination of unnecessary intermediaries, an endemic problem in Mexican agriculture: the power of intermediaries has long been reinforced by extra economic means. 5) The coordination of sanitary campaigns. The outcome was that chicken and egg production grew at 6.9% and 6.8% respectively between 1971 and 1979.

By the 80's a good part of the poultry industry was highly technified. Production was based, as it is today, on the use of pure breeds obtained by means of a highly expensive selection process. This genetic material is obtained from abroad in the form of fertilized egg, and only exist in the US, England and a couple of other countries. The imported egg is incubated to produce reproductive birds, from which are generated hens for laying eggs or chickens for fattening. Genetic improvement has reduced the conversion index of food needed to produce a kilogram of chicken meat from 4.5 kilograms in 1950 to 2.7 in 1980 and 2.5 in 1990 (respectively from 4.5 to 2.5 and 2.3 in the case of egg). Egg production continued growing at 7.8% between 1980 and 1984, and chicken at 3%. However, with the 1982 Mexican macroeconomic crisis, the system of controlled prices collapsed. The industry consequently stagnated between 1984 and 1990. In 1985 the shortfall in the sale price of egg with respect to the concerted price was 39.1%. UNA now again pointed out as its main problems, besides inflation and tardy price regulation, the issues we have already mentioned: seasonal and cyclical price variations, climatic and pathological risk, uncontrolled illnesses, the lack of insurance, the consequent lack of commercial credit, scarce and expensive inputs (between 40 and 50% of sorghum and soy grains used for feed was imported), and the contraband of chicken legg, which has a lower price in the US due to preference differences.

In 1986 Mexico jointed GATT, and soon began planning for NAFTA. During the years 1990-1994 chicken production grew at 10%, and egg production at 6.9%, in spite of the fact that in 1991 there was a 39.9% drop in egg prices, followed by a drop in chicken prices in 1992. Amongst the factors generating this crisis, UNA lists massive imports of chicken in 1988 and egg in 1991 following the opening of trade; inflation, which resulted in a lag in consumer prices with respect to producer prices, deficient commercialization structures, a lack of technical and administrative assistance; the characteristic sectoral risk limiting financing and a typical egg overproduction scenario including demand and supply factors. The poultry sector participated in the NAFTA negotiations through UNA. The government gave this food production sector priority and negotiated a long protection period ending in 2003. It was expected that the prices of some of the main inputs including feed grains, birds for reproduction and fertile egg would fall. However, in 1994, as soon as Mexico entered NAFTA, a major macroeconomic crisis emerged featuring strong devaluation, inflation, slower economic growth, and high interest rates. Costs increased by 200%, with 65% of the rise linked to the exchange rate. Due to the

productive inertia, egg production grew by 9% in 1995, then diminishing by 2.3% in 1996. The unemployment generated by the crisis reduced the demand for poultry products. A good number of firms had become indebted in dollars, having invested in anticipation of the trade agreement. Thus the sector entered a crisis which provoked, as in previous crisis, its further concentration, since larger enterprises have several advantages including a higher access to credit and larger profit margins due to technological and commercial advantages and to the diversification of climatic and pathological risk.

The poultry sector recuperated in 1997, and chicken production grew at 5.7% between 1994 and 2000, while egg production grew at 5.2%. Meanwhile, employment in the sector grew at 4.5%. Real prices for the consumer have been volatile but have shown a marked tendency to decrease. Between 1989 and 1999 the average annual rate of decrease was 6.7% for chicken, and 2.25% for egg. The industry has followed a strong process of consolidation and concentration after NAFTA. In 1996 two firms accounted for 33% of production of broiler chicken. By 2001, three firms (Bachoco, Pilgrim's Pride and Tyson) produced 52%. It is interesting to note that Pilgrim's Pride entered the Mexican market in 1987-1988 (after GATT) using swaps to purchase Mexican currency at a reduced rate. Today 70% of the poultry industry is highly technified, 20% is semi-technified, and 10% is still the backyard, family type. For comparison, in the US with a chicken meat industry about 13 times bigger than Mexico's the three most important broiler chicken firms (Tyson, Gold Kist and Pilgrim's Pride) account for 37.5% of production, while 92% is produced by the 42 largest firms.

Stratification of Broiler Chicken Farms

Classification	Millions of birds per cycle	Number of Firms 1996	Market Share 1996	Number of Firms 2000	Market Share 2000	Number of Firms 2001	Market Share 2000
Big	16 – 60	2	33%	2	42%	3	52%
Medium	1 - 15.9	27	40%	36	47%	33	34%
Small	0 - .99	181	27%	162	11%	161	14%
Total		200	100%	200	100%	197	100%

Stratification of Egg Production Farms

Classific a-tion	Millions of birds per cycle	Number of Firms 1996	Market Share 1996	Number of Firms 2000	Market Share 2000	Number of Firms 2001	Market Share 2000
Big	2.5 – 7	6	29%	9	33%	9	35%
Medium	.7 - 2.49	34	50%	39	40%	33	36%
Small	0 - .69	170	23%	162	27%	168	29%
Total		210	100%	210	100%	210	100%

Besides the technological and risk factors accounting for concentration, commercial reasons have also been important. For example, Bachoco has based its growth on marketing, publicity and trade mark recognition, beginning its expansion in the central region of Mexico. This strategy was developed as a response to the presence of large US producers after GATT also using this strategy.

Now a days the minimum scale for production egg is 100,000 chickens. 71% of production is carried out in farms with more than 700,000 birds.

The concentration of the industry has included vertical integration. In some parts of the country, such as Tepatitlán and Tehuacán, producers have grouped together for purchases and sales. The groups include pharmaceutical laboratories providing at least generic products. In Monterrey, the integration strategy has included the purchase of feed producing farms in the US, which have lower costs.

Since 1994, is spite of the protection of the poultry market, chicken imports have grown 2.7% per year, additionally jumping 23.5% in the year 2000. Total imports amount to 5.8% of national production. Egg import have grown 3.1% during the same period, representing only 0.6% of national production. Most of these are fertile eggs, due to Mexico's technological dependence for this input. The situation is completely different for turkey meat. Imports grew at 13% annually and amount to 7 times the national production, which is very small.

As part of the NAFTA negotiations, UNA carried out comparative economic studies with the US poultry industry in 1991. Egg production was 3.6 times bigger than Mexico's, and chicken and turkey production was 12.9 and 280 times as big. There were also production cost asymmetries between the two countries. In 1991 it cost 19% more to produce egg in Mexico than in the US, mainly due to animal feed costs, which are 10.7% higher in Mexico and represent 60% of total costs. The cost differential for chicken was 27%, while for turkey it was 30.5%. By 1998 the differentials had increased to 28%, 84% and 51.1% for egg, chicken and turkey respectively. The differential in total production increased for chicken but diminished for egg. UNA's present concerns focus on the forthcoming end of the period of protection under NAFTA in 2003. Besides the production asymmetries, there are consumption asymmetries. Chicken leg in the US has a much lower price than chicken breast, so large quantities may be exported to Mexico when the markets open. On the other hand in Mexico chicken pigmentation is considered essential. Also, Mexico is not self-sufficient in animal feed inputs, particularly sorghum, yellow maize and soy. Due to these limitations, the use of maize for animal feed is prohibited in Mexico, where it is destined exclusively for human consumption. Mexico is also behind in value-added processing such as the production of chicken nuggets, which is common in the US and almost non-existent in Mexico. Besides these factors of demand and supply, UNA is concerned with technological, commercial and phitosanitary improvements of the sector. Refrigeration during transportation can be pooled between firms. Attaining the necessary phitosanitary standards is quite complex and represents important export barriers. It is necessary to eradicate a series of illness from many localities and, as

far as possible, from transportation routes. This has begun, and help from the government has been requested.

Economic Forces Molding the Poultry Sector

The main economic forces that have shaped the development of the poultry sector are:

1. The successive acquisition of technologies from abroad. These have greatly raised the minimum scale of viable production plants for chicken meat and eggs, and have led to vertical integration through the in-house production of balanced animal food and some pharmaceutical inputs, as well as reproductive units, and also through the links to commercialization.
2. Climatic and pathological risk.
3. Price uncertainty due to rigidities in supply, which cannot adjust rapidly to changing prices.
4. The industry faces advantages to scale in the purchase of inputs and in the commercialization of its output, both because of the technological requirements for transportation, including refrigeration and to meet phyto-sanitary requirements, and thorough the effects of trademark recognition.

The risk that characterizes the sector, compounded with other risk sources such as macroeconomic crises, has meant that the sector has faced a series of crises during its history, every five or ten years. Each of these crises has resulted in a further bout of concentration. This has been due not only to the higher resilience of larger firms, because of their access to credit, but because of their higher profit margins resulting from better technologies that are viable only at higher levels of scale, input and output market advantages of scale, risk management through larger portfolios of assets, easier implementation of the appropriate organization of production from the veterinary point of view, and to treatment of pathological conditions. The crises have offered the opportunities of consolidation need for implementing production at a higher level of scale.

The poultry sector is considered strategic and has therefore been protected up to now throughout the liberalization of trade. It has also received a special tax treatment making all investments deductible, a policy which has promoted its growth quite effectively. Liberalization policies have impacted the industry in the following ways. First, there has been improved access to cheaper inputs, in particular sorghum and soybean pastes, the main ingredients of animal feed, and to fertilized eggs bearing the genetically pure and more productive chicken species used in production that are imported from abroad. Second, there has been a higher level of foreign investment in the poultry industry.. Their presence has brought a new level of competition and consolidation that has mainly been survived by firms that have achieved large enough levels of scale, such as Bachoco, or that have

formed commercial associations for the purchase of inputs and outputs. These consortiums have developed a high degree of vertical integration including, for example, veterinary pharmaceutical laboratories and even, in the case of the Monterrey group, ownership of firms producing animal feed in the US, where it is cheaper. Although the process of concentration has been going on for years, it has been accelerated by the opening up to foreign investment. This has led to increases in productivity that have even so been slower than in the US. The cost of liberalization, though has been that two of the three largest firms are now in foreign hands. Due to technological and other asymmetries in production costs, and in consumer tastes (chicken leg is not a US favorite so a lot of it is left over for export), the industry still fears the full opening to trade that will occur in 2003. Throughout this process, the industry has remained dependent on technology acquired abroad and has increased productivity mainly through technological implementation. Even though its growth has been fast, it is nowhere near the frontier of technological innovation.

Even though there has continued to be rapid technological change in the poultry industry both in Mexico and at the international level, it can be considered to be a mature industry. Market share is highly concentrated. Productivity levels depend on a large scale of operation and on a high level of vertical integration of production and commercialization. The diffusion or implementation of the new technologies in Mexico has taken the form of buying up of smaller enterprises, mainly by two foreign and one domestic large conglomerates.

The Veterinary Pharmaceutical Sector in Mexico

Multinationals and the industry in Mexico

Veterinary pharmaceutics is a high technology industry based on knowledge and research. It began operations in Mexico in the 40's, when the import substitution policy forced a large number of multinational firms to manufacture their products domestically in order to access the Mexican market. This made pharmaceutics available to the incipient livestock industry pharmaceutical knowhow and provided an important school for entrepreneurs, executives and technicians, who have applied their knowledge in domestic pharmaceutical firms. The trade liberalization that began in Mexico with GATT in 1986 and the signature of several free trade agreements since 1994 (see footnote 3) has induced the arrival of foreign firms in several modalities, many only as importers and distributors of products manufactured abroad. This has decreased the number and the market participation of domestic enterprises and placed their medium- and long-term viability at risk.

The present day veterinary pharmaceutical market in Mexico has sales of about 400 million dollars a year (Figure 1). Only one third corresponds to national

producers. Avimex, the firm on which we concentrate our study of the Mexican pharmaceutical industry is the 12th producer in Mexico, with 3.2% of the market. It is the third Mexican producer and the first amongst independent producers not associated to the big livestock producers (Figure 2).

Avimex: an innovative Mexican firm

Avimex was founded in 1952 by a medical veterinarian, who focused exclusively on the poultry sector. It took on a new life in 1986, when it was acquired by a team of four medical veterinary graduates from UNAM. The new partners met while working at one of the multinational veterinary pharmaceutical firms, where they acquired their first knowledge of the industry. They developed a firm with the mission to "provide animal health for productivity and for client development, through safe and efficient products, with high standards of service and personalized attention". Initially, the firm focused its attention on the poultry sector, to which it dedicates 70% of its sales. In recent years it has expanded to the hog and dairy sectors (25% and 5%), and is beginning to develop products for shrimp farms. Its product lines include biologicals, pharmaceutics, disinfectants and specialized balanced food additives. The biological products are mainly active, deactived, emulsified, adsorbed, single, bi-, tri- and polyvalent vaccines. The production process for vaccines, characterized by industrial secrecy, has experience a series of innovations in recent years that have been implemented in Avimex. Pharmaceuticals include oral presentations, soluble presentations, antibiotic mixes to be added to balanced foods, and injectable solutions. The additive and disinfectant products include "green" product lines of recent innovation.

Competitive context

Firms in the pharmaceutical industry can be classified according to their foreign or domestic ownership and according to their strategy regarding technological, price and service levels. We describe the types of firms that exist in the industry in the chronological order of their appearance.

The large multinational firms, which arrived since the 40's, usually provide high technology products originated in developed countries, at high prices and with low levels of service. This strategy is complemented with marketing publicity. In recent years multinationals have become more flexible. They now adapt their products to local markets and take local decisions faster. Trade liberalization has meant that an important part of multinational production has been shifted away from Mexico to reduce costs. In recent years, the degree of Mexican openness has promoted the presence of a new type of medium-sized multinational, similar to Avimex, from countries such as Spain, Belgium and Holland, offering products developed in their home countries.

The first domestic industries were founded in the 40's and 50's. Characteristically, they are family enterprises of medium and advanced technology producing for specific market niches, on occasion subcontracting for international laboratories. They seldom display a vocation for autonomous technological development.

The laboratories of the big poultry and hog producers appear in the 60's and 70's. As we saw, the poultry sector has concentrated. Its quest for vertical integration has led it to establish its own laboratories, in addition to its balanced food production. Bachoco, the Tepatitlán group, and the Romero group in Tehuacán include laboratories Pecuarius, Avilab and IASA (Investigaciones Aplicadas). The hog producing group in La Piedad include the LAPISA labs. All of these labs mainly produce the simpler pharmaceutical and biological products required by their conglomerates, and also perform some technological innovation. The concentration and vertical integration of the poultry market has thus reduced the pharmaceutical market for firms not associated to the big conglomerates.

Several domestic laboratories whose strategy is to sell at low prices without providing customer service and whose products have variable quality have appeared since the 80's. One could say that these laboratories produce generic products. This sector does not always register its products with the Ministry of Agriculture. It therefore saves on some costs and acting as an informal sector, with risks for the purchaser. They often belong to specialists who used to work in the big firms and then fell into unemployment due to the cutting back of production by multinationals or to the process of consolidation in that sector, which has been intense both at the national level and international levels.

Recently another type of competitor has emerged, human pharmaceutical firms venturing into the veterinary market. They own the productive capacity, invest in marketing and compete by price, looking for product and distribution lines.

Avimex is situates itself in the veterinary pharmaceutical market as an intermediate price producer selling high technology products and offering and innovative packet of services at the industrial level. The services it offers consist mainly of personalized training, consulting and problem solving in relation to animal health and productivity. These services are free, and are provided mainly for medium and large-sized producers. Recall that the poultry industry is subject to climatic and pathological risks, so that services of this kind are very important for the productivity and sometimes even the survival of livestock firms.

Avimex's strategy

Avimex strategy is to provide a technological service consisting of integrated animal health and productivity programs with a high technological content and highly individualized service. Avimex innovates in its service and, as far as possible, in its products. To provide this service, it runs its own distribution network. Each of its sales persons is a medical veterinary, some of them specialized in poultry or in hog

production. Because innovations are subject to imitation, the success of this strategy depends on continual product improvement and on the introduction of new products with technological content. Following this strategy, Avimex's sales have grown 34.4% annually since 1986 (in nominal dollars) and expects a 20% annual growth rate over the next 5 years.

Production

Avimex uses high-technology, sophisticated equipment installed in specially built areas. It has areas for sterile procedures, emulsifying, ovoscopy, quality control, and an experimental farm. Out of its approximately 120 employees, it has 50 BA's, and also two masters and one doctoral degree dedicated exclusively to research and development. 24 of the BA's are in sales, while the remainder work in the production process and collaborate in innovation.

A fundamental aspect of production is finding appropriate sources for the material inputs, which originate both in Mexico and abroad. This search is permanent and includes quality validation. After GATT, the price and quality of many inputs has improved, since products produced in Mexico do not enjoy such a high level of protection anymore.

It is interesting to point out that an important part of the highly specialized knowledge involved in production falls into the category of industrial secrets. This holds, for example, for vaccines. 70% of this knowledge has been acquired learning by doing, and by consulting scientific sources, and 30% by consulting international experts for different areas of activity in Avimex.

Research and development

The firm has an R&D department dedicated mainly to biological products. Its expenditure amounts to 10% to 15% of its biological sales. Between 1991 and 2000 Avimex introduced 39 new products. Avimex has developed world-level innovations in joint projects with Mexican and U.S research institutes, whose location of production is in the process of definition. Attainment of this rank of innovation represents an access to markets several orders of magnitude larger than the domestic market. Amongst its developments are the first deactivated vaccines with inclusion bodies against hepatitis in the world, the first bactrine against infectious coriza in Mexico in the three serotypes A, B, C; the first concentrated, inactivated vaccines against Newcastle in the Mexican market; the first oral and injectable magnacine solution for chicken, hog and cattle; and 100% natural disinfectants.

It is also the exclusive producer and distributor of several foreign innovations. Avimex's level of innovation allows it to export its products to Latin America, the Middle East and South East Asia.

Avimex obtains ideas for R&D from several sources. Specific needs are detected by the sales department in the field, and some of the research is directed to specific client's problems. Ideas also originate from technical and scientific publications. They also come from external consultants on the production process and on technical development. On occasion suppliers make a proposal when promoting their products. International fairs and expositions are a further source. New product lines can also arise from a technological transfer contract to produce in Mexico. These transfers have had important spillovers, by introducing the firm to new production technologies.

Programs developed by the research and development department follow a process of selection by a multidisciplinary team that examines the scientific, technical, productive, commercial and marketing aspects of viability. Parts of the new products, including research, may be subcontracted. For example, contracts for collaborative research have been established with the Mexican and US research institutes.

Interaction with research institutes

Avimex has established contracts for research projects with several research institutes. Normally these contracts arise when both parties have knowledge to contribute to the project. Both parties agree to industrial secrecy clauses. If the research is successful, usually the industrial party has the first option for the product's license while the research institute receives royalties on sales.

CONACYT (the National Council for Science and Technology) has offered monetary and fiscal support for private research for some time. Recently Avimex has been listed in the National Registry of Scientific and Technological Institutes and Firms, and has received support for several projects.

Competitivity and country context

One of the factors affecting the veterinary pharmaceutical industry is its regulatory context. Its products must be registered with the Ministry of Agriculture and must comply with a normativity analogous to the one for human pharmaceutics. These norms are intended to guarantee product quality and to lower sanitary risks. They respond to an incomplete information problem since clients cannot analyze the product when they purchase it, and will not necessarily be able to verify its quality even after using it. However, the application of this normativity is deficient, bureaucratic and subject to discretionality. A good number of small labs fail to register their products and sell unauthorized generics, thus saving costs and competing disloyally. These normativity problems slow the development of the industry and generate client distrust, due to the diversity of prices and qualities and the lack of credibility of the government certification. Besides this problem, there

are regulatory problems related to product piracy, contraband, and a slow and bureaucratic patent system leading to a low rate of innovation registry.

An analysis of the differences in working conditions the firm would face if it were located in the US are informative on its technical choices for production and on the incentives that contextualize it. In general terms, production in the US is organized at a higher scale, and uses more sophisticated and expensive equipment operated by more qualified personnel. Thus lower skill levels in Mexico lead to less capital intensive production and to lower technological levels . Regarding R&D, the main advantages that the US context would imply are the following:

1. High-level academia is active and available to carry out joint research projects with industry. Poultry firms often finance university research on their animal health problems. The results of this research serve as a knowledge source that supports product development by the pharmaceutical industry.
2. The potential market for products is larger in scale at both the productive and commercial levels. The benefits of any innovation are larger.
3. Once engaged in production in the US, it is relatively simple to export on the world wide.
4. The input market is much richer.

In this context it is relevant to state that the non-tariff barriers imposed by the US to the imports of veterinary pharmaceutical products are very tight and have the effect of an intense protectionism. Avimex has a whole series of equivalent and more economic lines (vaccines, for example) that it cannot viably export to the US due to these entry barriers. These barriers create very strong incentive for firms interested in supplying the US market to install their productive plants inside the US. The results are that the spillovers and other technological benefits tend to be transferred to that country.

There are additional advantages of the US "country system" compared to Mexico's. These include information sources, qualified personnel, less bureaucracy, and the inexistence of an informal market. Transport costs are smaller for imports. The incentives for research and for industry are greater.[6] The economic crises that have taken place in Mexico, the recurring lack of growth of the economy, resulting in lower demand, and uncertain and prohibitive credit markets, all slow and reduce firms' growth and performance. The 1994 crisis, for example, kept production stagnant during the years 1995-1997, although there has been a recuperation since then.

[6] Technological policy in the US is addressed below.

Economic Forces Molding the Veterinary Pharmaceutical Sector

The veterinary pharmaceutical sector is a provider of technological intermediate products for other industries. It exists in two modes: as a separate industry providing other productive sectors or as a part of any of the "client" sectors, when these are highly vertically integrated. One of the reasons that it thrives in its independent mode at the international level is that its methods, product lines and innovations can be applied in several client industries specialized in different animal species (poultry, pork, and so on) and even in human pharmaceutics. The large multinational corporations supplying the world market have annual sales in the multi-billion dollar range.

Mexico's technological dependence in this field has implied that the multinational pharmaceutical corporations have been active domestically for a long time. During Mexico's period of import substitution the firms established productive plants in Mexico. These operated for many years and their presence had some spillovers in the form of learning on the part of Mexican entrepreneurs and technicians.

Trade and investment liberalization has led to substantial changes in the Mexican veterinary pharmaceutical market in the past 15 years. The larger multinational corporations have shifted production back to their home countries. Client industries have concentrated and some have now set up their own laboratories, which produce generic products, apply available technologies to local problems, and carry out some innovation in the process as well. Smaller multinationals now offer previously unavailable specialized products. Smaller Mexican laboratories now provide some of the domestic, easier to imitate products. Meanwhile, medium and large client firms that have not set up their own laboratories still require technological services. This is the niche that independent domestic medium innovative firms can address, so long as the large firms do not find this area of work profitable. In the case of Avimex, commitment to the best possible service, using the latest technologies and producing its own products have brought it ever closer to the technological frontier, producing innovations that adapt known technologies to local conditions and prices, and also actual, world-level innovations.

Within the knowledge and innovation sector, Avimex can be considered a provider of technological services. These services consist in adapting technologies developed mainly abroad to the needs of its clients, technological implementators. To provide these services, it is necessary to successively acquire knowledge belonging mostly to the realm of industrial secrets, by using a variety of sources, in a process that naturally leads from implementation to R&D. This process is spurred by competition, which includes multinational R&D leaders. The feasibility of providing these services depends on the availability of people with the appropriate skill levels, on access to the global knowledge network, and on the appropriate incentives, including product demand, research costs and the fiscal and institutional setting.

The pharmaceutical sector can be considered to be technologically fluid rather than mature. Even though the industry has existed for many years, it is still characterized by a high rate of innovation and market shares are still volatile, both at the domestic level in Mexico and on the international scale. Thus although there are very large firms dominating much of the market landscape, ongoing innovation creates an opportunity for creative domestic firms to act, as technological service providers, and even as R&D innovators.

Discussion

Our two case studies show clearly that technological change in Mexico takes mostly the form of implementation rather than R&D. The poultry industry falls neatly into the category of technological implementator. It is wholly dependent on technology from abroad in the form of the genetic lines of its chicken, which are sold with a complete, detailed instruction kit as to feeding, veterinary treatment, and so on. Its process of technological change is a series of technological implementations. Avimex is instead quite purposefully a technological service (or intermediate input) provider. Much of what it does plays the function of adapting technology developed globally to local conditions and prices, althought it also performs some R&D. Both the poultry industry and Avimex operate in a context where there are industry leaders with advantages in knowledge and scale with whom it is very hard to compete.

Even when their foreign competitors are also technological implementators, it is essential for domestic firms to be able to access the same sources of knowledge and technology, which will usually be abroad. The need to access technology may be one of the fixed costs giving advantage to larger firms. It also forms the basis for the demand for technological service firms, whose functions are to bring and adapt knowledge from the global knowledge and innovation system (sector network) and to accumulate the knowledge assets necessary for production, some of which take the form of industrial secrets. Technological service firms first work within the realm of technological implementation, collecting public and recreating private knowledge for production. But this process can lead, of itself and under the impact of competition, to bona fide world-level R&D with results yielding word-level innovations. Thus the provision of technological services by adapting global knowledge to local needs and conditions may under sufficiently propitious circumstances, lead to the beginning of R&D and to loosening the knowledge barriers that hold low technology traps in place.

The main activities of local technological service providers will often begin with those left out by the multinationals. These include:

1. The production of generic brands when the corresponding knowledge has become available.

2. The production and adaptation of inputs to local conditions and prices that the large multinationals are not providing or cannot provide cost-effectively.

The first line of activities performs only very limited innovations. The second line includes both providers associated to vertically integrated groups of production (or belonging to single corporations) and independent providers focused on medium and large firms that are not part of the vertically integrated consortiums, and who in effect demand full packets of technological services. Both of these types of innovative providers will need to acquire knowledge that is usually in the realm of industrial secrets just to be able to produce some of their product lines (as in the case of vaccines). Attentive to new needs and techniques as they are expressed by their clients, and as they become available through providers and technological and scientific publications, these innovative providers will produce successive innovations ranging from technological implementation that may obtain markets in other underdeveloped countries to, with success, much more valuable world-level innovations at the technological frontier with high potential world-wide sales. It is nevertheless likely that, at least at first, these new developments will be bought by the large multinationals, whose infrastructures make the final development, production and sale of new technologies easier, and which also offer the potential threat of imitation. Thus technological providers that begin to innovate act in the niches left over by international competitors, who have important advantages including scale. Implementing new technologies leads naturally to the technological frontier and therefore to true R&D with world-level innovation that has the potential of serving world-markets.

One of the main disadvantages faced by the industry in less developed countries is the reduced access to research institutions ready to join in the necessary research projects. In the case of Mexico, public science and technology institutions such as CONACYT are improving their targeted monetary and fiscal incentives supporting research and development. Nevertheless, much remains to be done to improve the connection between universities and the use of technology in Mexico and other less developed countries. Concretely, 1) human capital formation must accord more closely in quality and skills with the productive and technological service requirements, and 2) universities must be more closely connected with scientific and technological research related to production. Both aspects require a closer connection between industry and education, and academic institutions that must be designed to benefit all concerned, with special care given to appropriately serving both public and private objectives. A telling example of the disconnection that exists at present between public academic institutions and technological research for production in Mexico is that collaboration contracts often do not include monetary incentives for the scientists involved.

In the US, an active technology policy has been implemented since President Bush's 1990 *US Technology Policy*, followed by President Clintons's *Economic Report of the President* (1994), which articulated first principles about why government should be involved in the technological process (1994, p 191):

The goal of technology policy is not to substitute the government's, judgment for that of private industry in deciding which potential 'winners' to back. Rather, the point is to correct market failure...

The competition and efficiency problems raise by technological policies have been addressed. There is a tradeoff between multiple independent firms competing and coordination benefits that reduce risk and appropriability problems. One policy approach has been to ease antitrust treatment in relation to innovation through the passage of several Acts of Congress. Another has been partially-funded, privately-performed research in a 'public/private partnership competition policy'. This policy has the objective to select innovation projects with high social rates of return that would not be privately viable, and funding them through well-designed processes ensuring efficiency. An example of such a program is the Advanced Technology Program (ATP) established within the National Institute of Standards in a program originated in 1988. It has funded such research projects as the Technologies for the Integration of Manufacturing Applications involving factory-floor innovation systems. Link and Scott (2001) show that this is an example of a research project that would not have been undertaken privately but that has a substantial social rate of return. [7]

In a recent study, Meza (2002) shows that R&D in Mexican firms increased substantially between 1992 and 1999. She also shows that the determinants of R&D intensity changed from such factors as market concentration and competition to proportion of product exported in each firm. Although 1999 was also a time of economic expansion, it is likely that trade liberalization has led to higher returns to innovation and more R&D. Since private funding for R&D is on the rise, the time may also be ripe for public support for innovation. Bazdresch (2002) proposes a series of policies addressing this point, as well as other aspects of the Mexican innovation sector.

The two case studies show that the scale of operation is a fundamental axis in understanding technological change and competition, that can interact strongly with the low technology implementation trap (Howitt & Mayer, 2001). Scale has, for example, been a determinant factor shaping the technological possibilities of the domestic poultry and veterinary pharmaceutical sectors in Mexico. The multinational firms these domestic sectors compete with tend to be huge. This important role of scale is not the exception. In a study on technological change and human capital in Mexico carried out with a municipal database for the period 1988-1993, Mayer and Foster (2002b) show that average manufacturing scale (number of workers per firm) is a significant index of productivity and a correlate of technological change and social development in general. By estimating productivity change, they show that manufacturing scale and its rate of change are positively

[7] The information on the US in these paragraphs is paraphrased from Link and Scott, (2001)

correlated with technological change and are amongst the determinants of the returns and changes in the returns to physical and human capital. In particular, increases in the returns to human capital correlated to productivity change increase with scale. Conversely, they show that average municipal manufacturing scale, and its rate of change are significantly correlated with the main indices of development, including migration and education. They are also correlated with future urban schooling and school attendance of 12 to 18 year olds (as a proportion of time spent in school and at work).

Trade and competition also shape technological change. In the process of industrial maturation, domestic firms face a process of concentration and vertical integration that is likely to be intensified when foreign firms possessing large capital resources and high levels of technology invest in the home market. During this process they will be dependent for many basic technological inputs and will usually not be in a position to make any important innovation. However, they will need the expertise and trained personnel necessary to implement new technologies, and will usually succeed in competing only if differences in productivity are not initially too high and if they have enough capital available for investment. This can only happen if the industry has already reached some level of maturity and if the appropriate human capital for production and for the provision of technological services is available.

When trade and investment are liberalized, it is likely that the increased level of competition will tend to provoke a wave of creative destruction with uncertain productivity outcomes. A rational planner would design the liberalization to ensure the survival of *all viable sectors*. For example Mexico selected the poultry sector as strategic, protecting it through the trade liberalization, and giving it fiscal incentives for investment. Under these conditions the industry had access to cheaper inputs and went through a process of concentration that took time and raised its scale of operation, in this case spurred by the competition of large foreign firms that invested in Mexico, which, however, took over a large portion of the market, shifting rents and spillovers and destroying domestic capital and knowledge assets. The remaining industry has strengthened, continues to be viable and will probably face full liberalization successfully, especially if non-tariff barriers to the US are overcome. Even so, only 30% of the industry remains in domestic hands.

Both of the sectors we studied faced non-tariff barriers to trade in the form of US sanitary regulations. These have the effect of protecting the US market from competition and must be taken into account *thoroughly* when formulating trade agreements. One of the effects of these barriers is to locate industry, and its spillovers, in the protected countries. We saw several examples: multinational pharmaceuticals and American poultry producers located in Mexico when trade in the corresponding products was restricted. Conversely, some pharmaceutical production was shifted abroad from Mexico when these restrictions were relaxed. Similarly, multinational and other pharmaceutical firms have incentives to locate in the U.S because of the non-tariff barriers to trade. When developing countries open

to trade and investment, it is likely that only their more mature domestic manufacturing industries will survive. Under these conditions, which naturally work to the advantage of the developed countries, the non-tariff barriers must be fully included in treaty design amongst the barriers to be reciprocally reduced in a mutually agreed timetable. The necessary sanitary (and other) investments must be financed and the procedure for their success *waranteed.*

There are some additional factors that affect the development of firms that we have not touched. For example, smaller firms tend to be family enterprises which have a natural life cycle that is not necessarily compatible with embarking on sizeable technological change. Often, owners prefer instead for their enterprises to run their course, hoping to be bought out eventually by the larger firms to become productive units following a prescribed technological and commercial scheme. In the context of underdevelopment, choosing the strategy of innovation requires entrepreneurs with a high level of vocation and the pursuit of excellence.

Summarizing our discussion, technological change in underdeveloped countries, which takes the form mainly of implementation, adoption or diffusion, with the possible presence of some R&D, tends to occur in a context of disadvantage that characterizes the condition of underdevelopment. There are several advantages that developed R&D leaders have over less developed technological implementators, in addition to the human capital threshold level required for R&D that is presented in the Howitt and Mayer (2001) model. The first is a closer relation to the sources of public knowledge and private spillovers. These are accumulated as industrial secrets that diffuse relatively slowly, and that are usually kept even when investing abroad. Second, advantages of scale when these are required for the use of new technologies, or when these exist for commercial or other reasons. Third, the access to larger profits in world markets through trade and investment.

In our discussion above we have emphasized firm ownership (domestic versus foreign). It may be asked, what difference does the ownership of investments, and the resulting knowledge and profits make? The answer is clearly given by the theoretical model, and can be ascertained by asking the following questions: whose children will be educated, will work in the high-skilled jobs, and will enjoy the monopoly profits of innovation? Which firms will do R&D in the future?

If trade and investment liberalization should lead to a situation in which all production were carried out by foreign firms, this would be compatible with a poverty trap in which all domestic income accrues to low-skilled labor, any pre-existing domestic capital has been "creatively destroyed" and domestic knowledge and technology receive no rents.

Conclusions

Trade liberalization and foreign investment are intimately related to technological change. In fact, in the modern theory of trade, technological levels are considered fundamental determinants of comparative advantage. Technological change in less-

developed countries is just a complex as it is in the developed world, but faces a different set of circumstances characterized by a series of disadvantages. These call for a specific theoretical and empirical analysis. The main differences are the following 1) there is less likely to be R&D; instead most technologies are implemented. 2) The local knowledge sector is usually weak, and knowledge flows must be sought from abroad. 3) Rents for knowledge and technology thus usually flow abroad and do not result in any further domestic enrichment. 4) Domestic industry competes with developed counterparts having important advantages in knowledge, technology and scale, including manufacturing and commercial channels.

Our case studies show that the industrial organization of domestic production and the productivity capabilities of domestic firms in underdeveloped countries are deeply influenced by liberalization as firms compete more directly with their foreign, especially developed counterparts. In mature sectors such as poultry, a rapid concentration is likely to occur, with domestic producers mostly being integrated and bought up by foreign consortiums. Knowledge, innovation, and their rents will tend to remain in foreign hands. The need to implement technologies from abroad will give rise to a demand for technological service providers on the part of smaller producers. In more fluid sectors with high rates of innovation, these technological service providers may be able to learn enough to perform leading edge R&D.

It is well recognized that the private incentives for R&D are usually less than the social returns. For this reason developed countries support and subsidize R&D and other forms of technological change in various ways. It is quite clear that social returns are also higher than private returns for an important portion of the technological implementation that is potentially possible in less-developed countries. When trade and investment liberalization are recommended to less-developed countries, the full policy packet must include what the developed world itself applies: support (both domestic and international) for technological change. Technological capabilities lie behind competitive advantage and productivity. The specific reality of underdevelopment has to be addressed, by promoting the right mix of skills, implementation and knowledge transfer from abroad as well as local R&D when possible. Only nations achieving good rate of technological change will be able to benefit from trade and investment liberalization.

In more advanced countries the "national innovation systems" approach has been successful in promoting the development of the knowledge sector. These systems are 'national' for reasons of culture, law and public policy, but also because of the rents associated with knowledge. In less developed countries, the various components of the knowledge sector, must also be brought closer together. The right incentives to enhance the interaction between industry and educational and scientific institutes, as well as the knowledge flows from abroad, and the appropriate mechanism for efficiency and the promotion of projects with high social returns must be set up. These policies can be implemented without prejudice to efficiency and competition, as their recent counterparts are in developed countries.

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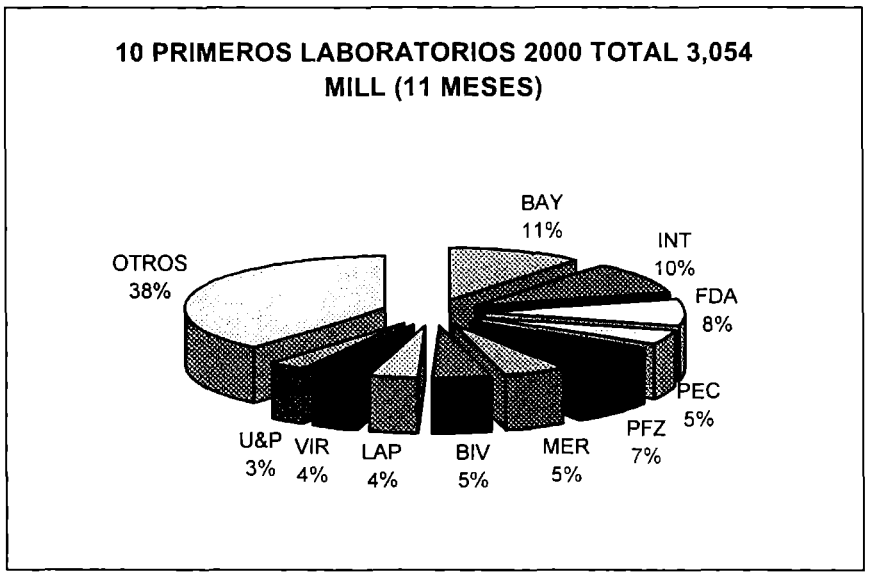
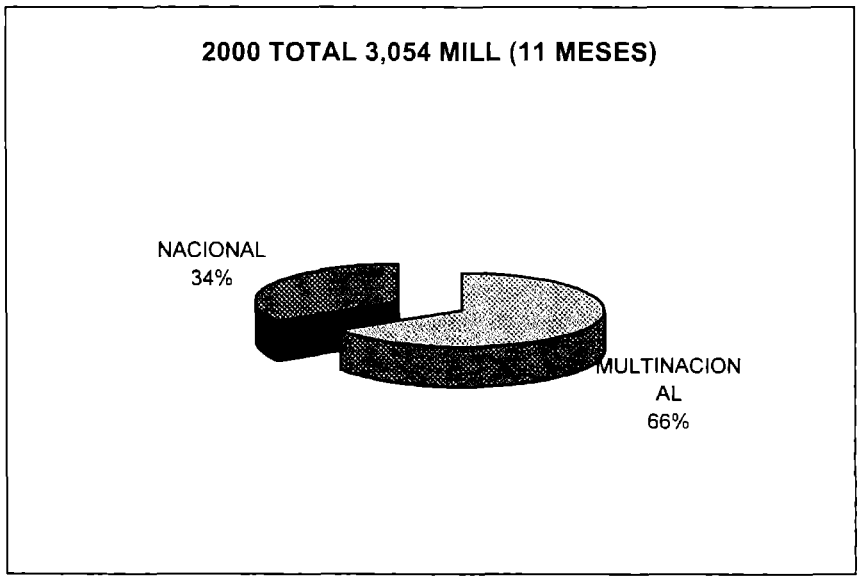
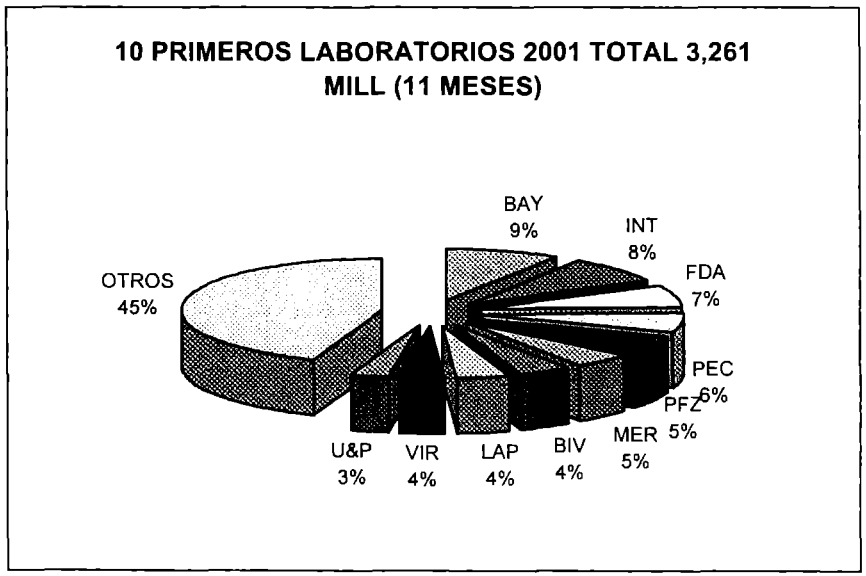
Figure 1. Sales in the Mexican Pharmaceutical Veterinary Market







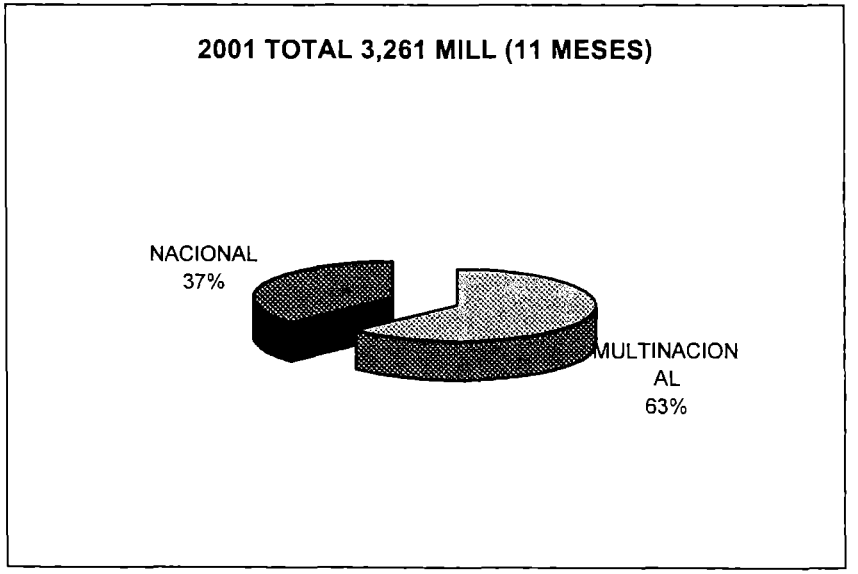
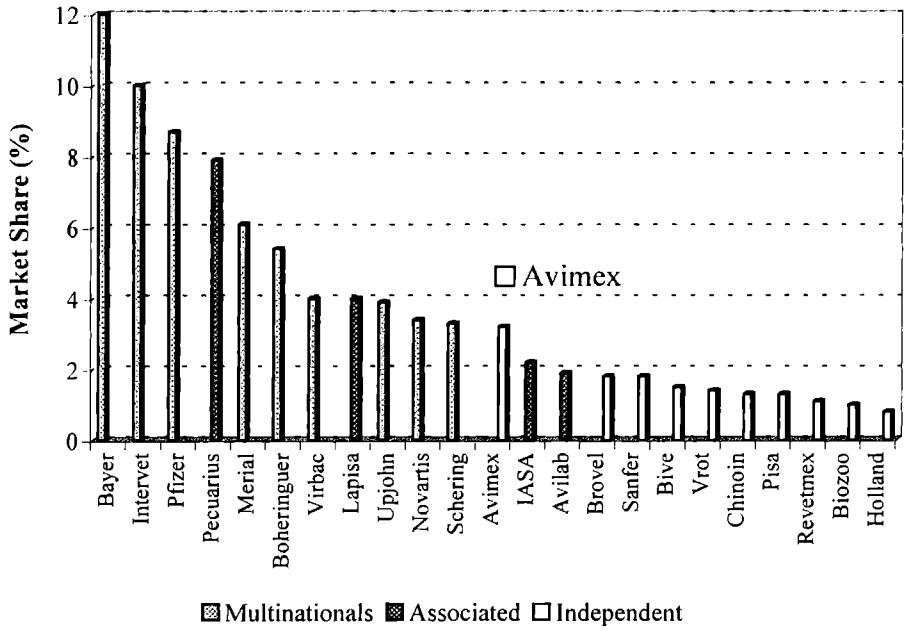


Figure 2. Market Share in Veterinary Pharmaceutics in Mexico



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