Technology Acquisition Strategies in the Pharmaceutical Industry in Mexico

MARÍA PLUVIA ZUÑIGA, ALENKA GUZMÁN, and FLOR BROWN

ABSTRACT Firms in developing countries are characterized by weak technological capacities, insufficient human capital, and limited R&D. Consequently, these countries also produce fewer patents. Considering these disadvantages, companies in developing countries cannot rely on their in-house R&D efforts; they must import nonincorporated or soft technologies (license and technical-assistance agreements, and tacit knowledge transfer). In the pursuit of technological improvement, firms attempt to adopt an optimal technology acquisition strategy. This essay examines the use of in-house R&D and technology transfer in the Mexican pharmaceutical industry between 1994 and 2000 by using two econometric models. Unlike the pharmaceutical industries of other developing countries such as India and China, this study indicates that there is a low probability of complementarity between R&D and technology transfer in the Mexican pharmaceutical industry. This is a strategy that has been adopted only by some larger firms and multinationals.

Comparative Technology Transfer and Society, volume 5, number 3 (December 2007):274–96

INTRODUCTION

The pharmaceutical industry has always been a peculiar sector in which the division of labor exhibits well-defined international distribution of production (Gambardella, 1995). New molecules are traditionally developed in northern countries, despite differences of research and development (R&D) productivity and therapeutic specialties (Cockburn & Henderson, 2001; Grabowski & Vernon, 1994). In contrast, except for a reduced number of countries (for example, India, China, and Thailand), the pharmaceutical industry in the majority of the developing world relies largely on the strategy of imitation, especially in the production of generics (Subramanian, 1995). The efforts made by developing countries are particularly important in order to establish local generic-product industries and to deal with public health issues.

The importance of the technological development of the pharmaceutical industry has been shown in several studies. Lichtenberg (1998) analyzes the contribution of pharmaceutical innovation in terms of the decrease in mortality rates and its counterpart, the increase in longevity based on the income per capita.[1] Therefore, the performance and capacity to resolve health problems are tied to the capacity for innovation and follower companies' imitation strategy. Notwithstanding, the knowledge can be widely transmitted from the innovators to follower companies, particularly in the pharmaceutical and chemical industries (Arrow, 1962); where imitation is relatively easy (Levin, Klevorick, Nelson, & Winter, 1987; Mansfield, 1981), the passage from imitation to innovation sometimes requires a preliminary condition. It demands technological learning defined through the strategies of technological acquisition: to develop and/or acquire technology externally (Caves & Uekusa, 1976). Given the reduced level of R&D and the weak innovation productivity of their companies, developing countries cannot use their own technological efforts alone to reduce the technological gap (Basant & Fikkert, 1996).[2] The options for these companies are to acquire technology transfer (TT) nonincorporated, including tacit knowledge transfer, such as technological licenses of patented products and/or industrial processes; purchase consulting services

[1]The results of the econometric estimates of Lichtenberg's study reveal a highly positive relation, through diverse illnesses, between hope of life and rates of introduction of new drugs.

[2]The literature regarding innovative activity in developing countries has identified different factors that block the investment in R&D and halt the innovative efforts of the companies. These are: difficult access to financing and macroeconomic instability, the low level of human capital, institutional obstacles, and lack of intellectual-property protection, among others (Archibugi & Pietrobelli, 2003).

and training for the use of technologies, thus allowing the development of technical and technological skills; and subcontract R&D and services both for the improvement of products and industrial processes and for the adaptation of technologies (clinical trials). Innovation and/or imitation are essential to a firm's technology strategy. The decision to insource or outsource technology is conceived as a general strategy aiming to optimize innovative efforts and improve technological performance (Veugelers & Cassiman, 1999; Cockburn & Henderson, 2001; Grandstrand, Hakanson, & Sjolander, 1992; Henderson, Jaffe, & Trajtenberg, 1998).[3]

Weak technological development, insufficient human capital, and limited R&D have resulted in low patent production in developing countries. Considering this disadvantage, companies in developing countries cannot rely on internal R&D; these firms must import nonincorporated or soft technologies (license and technical-assistance agreements and tacit knowledge transfer).[4] In theory, the complement between internal R&D and the purchase of external technology transfer should generate a beneficial cycle for these companies: on the one hand, internal R&D capacity can favor absorption of external knowledge (Cohen & Levin, 1989; Kamien & Zang, 2000) and facilitate adoption of imported technologies in developing countries (Arora, 1995; Caves and Uekusa, 1976; Katrak, 1997); on the other, the purchase of external technologies can contribute to the optimization of a company's R&D efforts, thereby increasing its technological capabilities and eventually its endogenous innovation (Kaiser, 2002; Kamien & Zang, 2000). During a period of weak innovation, companies can purchase external technology in order to increase productivity. This acquisition substitutes for the lack of internal R&D, which can be expensive and, therefore, inaccessible. However, the substitution for R&D by technology transfer may produce an increase in technological dependence, eventually stunting companies' potential for innovation.

This essay has a twofold purpose: to study the factors used in determining the strategies for technology acquisition in the Mexican pharmaceutical industry, and to evaluate the complement between internal R&D and technology transfer. In industrialized countries and some emerging East Asian economies, the complement between internal R&D and technology transfer

[3]Regarding the formal sources of knowledge, companies combine different technology acquisition strategies such as the expense of in-house R&D and the purchase of technology and collaboration with other companies to create new technologies. Companies also acquire informal knowledge through patents, conferences, and industrial meetings.

[4]See Katrak (1989) and Lee (1996). In turn, the hard or incorporated technologies are those derived from use of the products (for example, machines, materials, and other production technologies) in which the technology can be transferred with the help of technical manuals.

clearly demonstrates an increase in technological development and innovation. This suggests that these strategies would not be successful in the case of the Mexican pharmaceutical industry, where the purchase of external technology fails to stimulate internal R&D and where expenditure in R&D fails to take advantage of lessons learned from external technology transfer.

The essay's second section presents the theoretical debate between companies' technological strategies and the results of empirical work cited later. The third section explores the profiles of international and Mexican pharmaceutical industries and their technological strategies. The fourth presents the results of econometric models, and the last section explores recommendations for policies that stimulate innovation.

THEORETICAL DEBATE ON TECHNOLOGICAL STRATEGIES AND THE EMPIRICAL EVIDENCE

Although the choice between internal R&D and external technology has yet to be subjected to comprehensive theoretical analysis, some theoretical approaches contribute important elements to this discussion. These approaches indicate the characteristics of the technological strategies followed by companies to incorporate, assimilate, and eventually generate the best new technologies in order to improve their competitive market edge. The literature on this topic suggests that the choices between internal and external technology are, first, substitution strategies. According to Williamson (1975, 1985), Teece (1988), and Pisano (1990), the election of internal and external technological sources depends on transaction costs. These costs are determined by the agents, the degree of specificity of the assets, and the frequency of the transactions; however, transactions related to R&D contracts present problems (for example, uncertainty, asymmetry of the information, and moral risk) due to the capacity to appropriate the tacit, and even the codified, knowledge that is regulated through copyright protection.

Second, the cooperation inherent in internal R&D favors a company's development to the degree that technological knowledge is spread, followed by decreased production costs. This cooperation also contributes to the reduction of internal R&D due to weak returns on innovation (de Bondt, 1996; Kamien & Schwartz, 1982; Katz, 1986; Spence, 1984).

Third, the importance is recognized for a complement between internal R&D and external technology transfer through the purchase of nonincorporated technologies (Cohen & Levin, 1989; Kamien & Zang, 2000). On the one hand, the investment in R&D is associated with a company's

innovative capacity that allows it to better absorb and assimilate external knowledge, thereby elevating its productivity; on the other, the purchase of technology supports the investment in R&D (Johnson, 2002; Katrak, 1997). Incoming and outgoing technological spillovers are generated in this process. These factors encourage a company's decision to pursue external technology to complement its internal R&D. The evidence presented here illustrates the diversity of technological strategies that exists among developing countries.

Finally, the nature of technological knowledge also influences a company's decision to acquire not only technological knowledge, but also the capabilities to produce and use this knowledge—and therefore, their orientation toward the internalization of R&D (Dosi, 1988).

the empirical studies

In the early 1990s, some developing countries such as India, Thailand, and Taiwan chose to deregulate international technology transfer (Katrak, 1997). The strategies followed in each country were different. In India, the substitution of internal and external technology sources explains the growth of productivity in the manufacturing sector, especially in science-related industries. At the same time, Taiwan established a complementary relationship between internal and external technological sources in these same industries (Chang & Robin, 2003).

Numerous empirical studies on industrialized countries agree regarding the complementary relationship among sources of knowledge, in particular in the largest and most innovative companies (Arora, 1995; Arora & Gambardella, 1990; Cassiman & Veugelers, 2002). Katrak's (1985) work on India and Braga and Willmore's (1991) and Johnson's (2002) on Brazil demonstrate the existence of a positive relationship between internal R&D and the purchase of nonincorporated technology. Braga and Willmore demonstrate that importation of technology, together with foreign ownership, the intensity of exportation, and the size of the company, increases the probability of exercising R&D-related activity.[5] Other studies reveal the lack of a significant relationship between R&D and technology transfer costs. Among Korean companies, Lee (1996) found that the probability of an internal R&D department increased with the purchase of foreign technologies. However, for those firms with an internal R&D department, the intensity in R&D is not affected.

[5]The technological activities evaluated include the probability of committing to R&D, the purchase of imported technology, and the adoption of quality-control measures.

In 1980, Katrak (1997) found an inverse relationship between investment intensity in R&D and imported technologies in India's electric and electronics industry. Katrak's work also illustrates that the factors of these technological strategies may differ. In contrast to the probability of exercising R&D, technology transfer is unaffected by firm size and the level of technological competencies.

In summary, the empirical literature concerning internal R&D and technology transfer presents diverging results. These studies suggest that only certain firms have the technological capabilities to adopt strategies using complementary sources of innovation. The firms that innovate are those that can benefit from technology transfer. These studies do agree in that the determinant factors that drive firms to invest in R&D and technology transfer can sometimes differ; therefore, decisions on one technological strategy do not necessarily work with another. The analyses of technological strategies regarding substitution or complementarity of technological sources will show the strengths and weaknesses on which firms build their competitive edge. These diverse results corroborate the importance of specifically analyzing the case of the Mexican pharmaceutical industry and its technology acquisition strategies.

TECHNOLOGICAL STRATEGIES IN THE GLOBAL AND MEXICAN PHARMACEUTICAL INDUSTRIES

During the past three decades, the world's pharmaceutical industries have experienced major transformations that have changed the nature of their competitive environment. First, the developments of science and technology, particularly in the fields of biotechnology and genetic medicine (Landau, Achilladelis, & Scriabine, 1999; Morange, 2003). Second, the process of fusions, acquisitions, and strategic alliances among pharmaceutical firms, particularly among transnational firms that have favored a concentrated production and distribution of medicines (Weinmann, 2002). And third, the tendency to globalize different steps of the process, such as marketing and production management, with the objective of introducing pharmaceuticals to major markets. Medicine and drug production is essentially based in industrialized countries; however, other emerging countries like India, China, and Brazil are gaining importance.

During the postwar era, some developing countries developed their local industries based initially on imitation, establishing themselves as important producers of generics. These countries include Korea, India, Tai-

wan, Argentina, Mexico, Brazil, and, more recently, China. However, some of these countries followed a passive strategy regarding technological progress while others simultaneously strengthened their production of generics and oriented themselves toward an active strategy based on R&D and innovation.

In today's globalization, the domination of multinationals based in the United States and other industrialized countries has been strengthened through processes such as joint ventures and mergers and acquisitions, which have sought to make R&D investment more profitable and to reduce the time needed to introduce new molecules into the market. More than half of international joint ventures in the pharmaceutical sector have been concentrated in R&D, thus opening new opportunities for the production of medications in East Asian countries such as China and in some Eastern European countries. Of the 1,137 international agreements registered between 1990 and 1999 that were oriented toward cooperation in R&D, 54% involved the United States, 22% the European Union, and 13% Japan (Organization for Economic Co-operation and Development, 2001). The large corporations, with R&D centers in different countries spread around the world, globalize their research by making use of work in networks, benefiting from the existence of scientific communities and hence the reduced salaries of researchers. Different phases of the process are globalized, including marketing and production, with the purpose of introducing them in all the principal markets (for example, the United States, Japan, and Europe). The delocalization of activities with greater scientific or technological intensity is highly associated with the human-capital levels and capabilities in different countries. However, even while technology flows in the pharmaceutical industry occur essentially among industrialized countries, some developing countries participate as clinical-trial centers and as important producers of generics. In this context, countries such as India and China are significant as pharmaceutical exporters to other Asian and African countries and to Mexico and Brazil in the case of Latin American countries.

According to INEGI (Instituto Nacional de Estadística, Geografía e Informática), in 2003, the Mexican pharmaceutical industry consisted of 224 laboratories owned by 200 companies generating 47,000 direct and 45,000 indirect jobs. One fifth of the companies were dominated by multinationals, and the rest were majority owned by Mexicans. Among the 42 largest multinationals, 20 were companies from the United States, 13 were based in the European Union, and nine were Japanese. These companies were characterized by their high degree of vertical integration, their competitive advantage being obtained by offering new products, differentiation, tech-

nological prestige, and quality. In contrast, the Mexican companies produced for the local market and were only marginally innovative. They held a limited number of patents and competed in generic medications where competition in the market is based on cost, quality, and price. Some of these firms have attained a certain level of innovative research; for example, Probiomed, Silanes, Senosian, and Sophia.

In Mexico, there is a significant market for patented products because the production of generic products is limited. Private pharmacies have 80% of the share of medications produced, with government and public hospitals controlling the remaining 20%. Even though the government favors the production of generics, patented products control a large proportion of the market and therefore innovation, adaptation, and imitation are still very important.

Information from Mexico's annual industrial survey, *Encuesta industrial anual* (*EIA*) (1994, 2000), was used for the analysis of internal R&D and technology transfer strategies of Mexican pharmaceutical companies. The survey includes variables such as exports, gross production, aggregated value, investment, and employment. A total of 95 pharmaceuticals are included in the EIA, employing 40,000 people and representing 85% of the total pharmaceutical industry employment. The EIA notes the differences between Mexican and multinational pharmaceutical companies regarding their strategies in investing in technology. As illustrated in Table 1, 23 Mexican pharmaceutical companies invested in internal R&D in 2000, while a little more than one third purchased external technology. The number of Mexican pharmaceuticals investing in internal R&D increased from 11 to 23, while those investing in technology transfer increased from 13 to 16, and from 15 to 16 for hard technologies purchased between 1994 and 2000.[6]

In contrast, the number of multinational companies that carried out R&D investment only increased by one. A more significant number decreased their investment in technology transfer (33 to 24), and the num-

[6]Economic growth since 1996 and a more adequate infrastructure possibly contributed to an increase in technological investment (CEPAL, 1999); for example, better protection of intellectual-property rights can stimulate local companies to invest in innovative activities (Kanwar & Evenson, 2003). Two main factors may explain such an upward trend in the number of firms engaged in technological activities. First, a more beneficial macro-economic environment and institutional framework (i.e., stronger intellectual-property protection—mainly patent and trademark protection) may have stimulated local firms toward innovation and R&D investment. There are also many local producers of generic products investing in R&D to test branded products. Second, firms may more confidently commercialize technology and develop licensing partnerships after implementing product trials, thus facilitating a more active market for technology (Arora, Fosfuri, & Gambardella, 2001).

Table 1
TECHNOLOGICAL STRATEGIES IN THE PHARMACEUTICAL INDUSTRY

	1994				2000			
	Yes	*Percentage*	*No*	*Total*	*Yes*	*Percentage*	*No*	*Total*
R&D investment								
Domestic firms	11	23.91%	35	46	23	50.00%	23	46
Transnational firms	21	41.18%	30	51	22	42.31%	30	52
	32	32.99%	65	97	45	45.92%	53	98
Technology transfer								
Domestic firms	13	28.26%	33	46	16	34.78%	30	46
Multinational firms	33	64.71%	18	51	24	46.15%	28	52
	46	47.42%	51	97	40	40.82%	58	98
Hard technology								
Domestic firms	15	32.61%	31	46	16	34.78%	30	46
Multinational firms	33	64.71%	18	51	22	42.31%	30	52
	48	49.48%	49	97	38	38.78%	60	98

Source: Elaborated by the authors based on data from EIA, INEGI.

ber of firms with expenditures in machinery and equipment decreased from 33 to 22. These numbers are probably associated with the concentration of R&D in corporate headquarters in originating countries.

Although the changes in the transnational companies and local statistics are small, they indicate different strategies. The strategy of the transnational companies in developing countries is focused on the specialization of production plants in order to export products to other countries, or to subcontract with local companies to carry out part of the production in their facilities instead of investing in new plants (Kumar & Agarwal, 2000).[7] The R&D effort of national companies focuses on the adaptation of generic products based on the bioequivalence and -availability that are required. Only a few cases show that local industries focus their expenditures on R&D for the development of innovative products. In summary, according to the information obtained from the EIA, significant discrepancies exist in performance and investment in technology among firms of different sizes, and particularly between Mexican and foreign companies. Differences regarding the impact of technology transfer on internal R&D

[7]The fact that multinational firms are less active in technology transfer could indicate that they simply have not introduced new technologies—implying new technology transfer contracts—and that they therefore continue production of technologies that are obsolete, or almost obsolete.

investment may be expected; these characteristics are analyzed in the following section by using econometric models.

COMPLEMENTARITY OF TECHNOLOGICAL SOURCES IN THE MEXICAN PHARMACEUTICAL INDUSTRY

The purpose of this section is to analyze the extent to which a complementary relationship exists between different technological sources in the Mexican pharmaceutical industry by using econometric models. Given the ongoing and discrete nature of technological decisions, Tobit- and Probit-type econometric models were proposed and subsequently estimated. The first method takes into account the probability of expenditure for R&D and technology transfer; the second estimates the probability of executing technological strategies by considering the simultaneous implementation of two types of investments. The independent variables included in these models are:

1. *Firm size:* Braga and Willmore (1991), Katrak (1989), Kumar and Saqib (1996), and Scherer (1965, 1967) find a positive impact of size on the probability of investing in internal R&D and, in addition, on the intensity of R&D expenditure in the industrial sectors. In the case of the pharmaceutical industry, we expect a positive relationship between size and R&D.
2. *Scale economies:* Spreading risk across a larger production base increases the technological investment and performance of larger companies (Cohen & Klepper, 1996). For this reason, a positive relationship between size and R&D is also expected.
3. *Firm exports:* Kumar and Agarwal (2000) demonstrate that firms which export their goods often participate in more technologically competitive markets, which often reinforces innovation of and upgrades to industrial procedure. Other authors, such as Álvarez (2001) and Braga and Willmore (1991), reveal that Brazilian and Chilean exporting companies invest more in R&D and technology transfer, therefore the sign anticipated for this variable is positive.
4. *Multinational firms:* These firms have a more sophisticated technological and productive structure that facilitates technology transfer from headquarters to subsidiaries. However, centralization of R&D activity at corporate headquarters explains the weak technological

activity of subsidiary companies, as demonstrated by Kumar and Agarwal (2000) in a case study of India, and Álvarez (2001) in a case study for Chile. In other words, either a positive or a negative relationship can exist regarding R&D and innovation for a multinational company's subsidiaries.

5. *Expenditure in hard or incorporated technologies (machinery and equipment):* Companies that import hard technologies for production need a minimum of internal technological effort to integrate them adequately into the production process (Cassiman & Veugelers, 2002; Cohen & Levin 1989). We therefore anticipate a positive sign for this variable.
6. *Capital intensity:* According to some studies, a positive relationship exists between technological imports and capital intensity (Kumar, 1998). The decision to import nonincorporated technology is associated with codified technology and, in particular, designs and models that require the technical assistance of the supplier. Consequently, we suggest that variations in interfirm technology purchases are likely to be linked to capital intensity.

results of the Tobit econometric model

The Tobit model is a combination of a probabilistic estimation with one of maximum likelihood (Wooldridge, 2002).[8] The information was organized in panel form for the two years of the study; therefore, for estimation purposes, the number of observations is 190. Three models were used to explain the relationship between R&D and technology transfer: ordinary least squares, Tobit in panel form with random effects, and Tobit on pooled data.

Table 2 summarizes the results obtained for R&D and technology acquisition investments. Several results are particularly significant. First, according to the Smith and Blundell exogeneity test, both R&D expenditure and technology transfer are exogenous in relation to each other in the case of the Mexican pharmaceutical industry; in other words, R&D does not correlate with investment and technology transfer. We estimated two models with R&D expenditure (column 1) and expenditure on technology transfer (column 2) as dependent variables. In the first example, purchas-

[8]Estimation by the ordinary least-squares method is not convenient due to the bias in the estimation of parameters because of the fact that the term of error includes the anticipation of zero investment.

Table 2

R&D AND TT INVESTMENTS IN THE MEXICAN PHARMACEUTICAL INDUSTRY (1994–2000)

	Tobit R&D expenditure	*Tobit TT expenditure*
Size	0.251 (0.086)[2]	0.382 (0.134)[2]
Exports	1.423 (0.518)[2]	0.938 (0.579)
Multinational	–0.234 (0.511)	1.39 (0.713)[1]
Technology transfer	0.033 (0.073)	
Hard technology	0.501 (0.331)[1]	–0.891 (0.343)[2]
Capital intensity	–0.424 (0.266)[1]	1.85 (0.267)[2]
Year 2000	0.584 (0.453)	–0.606 (0.418)
R&D expenditure		0.039 (0.090)
Constant	–0.809 (0.656)	–3.17 (1.161)[2]
Observations	190	190
MPL[a]	–290.59	–330.00
Exogeneity test[b]	5.82	7.54
Wald χ^2	34.18[2]	34.02[2]
% Censure	0.56	0.45

Notes: [a]Pseudo-probability estimation of maximum likelihood (MPL); [b]Smith-Blundell exogeneity test F (1.186). Standard errors are reported in parentheses (Huber/White/Sándwich). [1]5% significance; [2]1% significance.

ing technology transfer does not affect investment in R&D, given that the coefficient of the technology-transfer variable is not significant,[9] and in the second example, the coefficient of the R&D variable is also not significant.

[9]The Wald test is carried out to verify the validity of the model (the null hypothesis is that all the coefficients except the intercept are equal to zero. The null hypothesis is rejected for the two models, R&D and TT), which justifies the relevance of the explicative variables. The Tobit models use the Huber/White variance estimator instead of the conventional estimator. The standard errors, with their corresponding level of statistical significance, are reported in parentheses. Finally, the logarithmic statistic of pseudo-probability of maximum likelihood (MPL) facilitates a comparison of the different models; a decrease of MPL indicates better specification.

These results support the conclusion that external acquisition of non-incorporated technologies does not influence a firm's innovation. This conclusion is due, in our opinion, to the fact that R&D and technology transfer investment decisions are executed for different reasons and purposes that are unconnected to each other. For example, technological acquisitions are made with the objective of improving productivity (by reducing production costs), while R&D investments are intended to develop new products or improve those already existing, as in the case of high-quality generic medications produced by Mexican pharmaceutical firms. A similar conclusion is found in studies carried out in industries that are considered to be R&D intensive (Katrak, 1997; Kumar & Saqib, 1996).

Another aspect of Table 2 that may be deduced from the estimations is the influence of exports. As observed in column 1, this variable was found to be statistically significant in the case of R&D, but not in the case of technology transfer (column 2). Agarwal (2000) and Braga and Willmore (1991) point out that firms oriented toward international markets are more motivated to increase their technological efforts, with the objective of conserving their participation in the world market.[10] With technology transfer, no significant difference exists between exporting firms and those focused on domestic markets.

Contrary to the results obtained by Agarwal (2000) and Kumar and Saqib (1996) regarding R&D for Indian companies, capital intensity negatively affects in-house technological effort, but positively affects the purchase of technology. This result suggests that firms better equipped in capital assets will dedicate progressively fewer efforts to innovation and more resources to technology transfer purchases. The size of firms was found to have more impact on external acquisition than internal R&D investment. As noted by Cohen and Klepper (1996) and Katrak (1997), this result demonstrates that increased size of a firm leads to less-than-proportional growth of internal R&D expenditure and external technology acquisition. The dummy variable that designates multinational firms does not contribute to the explanation of R&D expenditure, therefore it cannot be concluded that significant differences exist between these two types of firms in relation to internal technological investment. In contrast, it is implied that multinational companies have higher technology transfer expenditures.

Finally, complementarity is confirmed between internal investment in R&D and the acquisition of hard technologies (for example, machinery

[10]The U.S. Food and Drug Administration (FDA) demands, for example, that companies that export pharmaceutical products submit to bioequivalency tests for generic medications and the attribution of certificates of good production practices.

Table 3
R&D EXPENDITURES (TOBIT MODEL)

	1	*2*	*3*
Size	0.251 (0.086)[3]	0.212 (0.083)[2]	0.244 (0.086)[3]
Capital intensity	–0.424 (0.266)	–0.415 (0.267)[1]	–0.462 (0.258)[1]
Exports	1.42 (0.518)[3]	1.41 (0.520)[3]	1.44 (0.511)[3]
Hard technology	0.501 (0.331)	0.566 (0.316)[1]	0.625 (0.342)[1]
Technology transfer	0.033 (0.073)	0.242 (0.127)	0.127 (0.102)
Transfer*size		–0.093 (0.052)[1]	
Transfer*domestic			0.067 (0.506)
Technology transfer*multinational			–1.160 (0.613)[1]
Constant	–0.809 (0.656)	–0.576 (0.619)	–0.941 (0.658)
MPL[a]	–919.49	–915.27	–915.28
% Censure	0.56	0.56	0.56
Wald χ^2	34.18[3]	34.02[3]	34.02[3]

Notes: [a]Pseudo-probability estimation of maximum likelihood (MPL). Standard errors are reported in parentheses (Huber/White/Sándwich). [1]10% significance; [2]5% significance; [3]1% significance.

and equipment assets) (Cassiman & Veugelers, 2002), which demonstrates the need for a minimum of internal R&D capacity to identify, interpret, and integrate the hard technologies into the production process (Caves & Uekusa, 1976).

To evaluate the relationship between R&D and technology transfer expenditures associated with company size and with the substitution effect, three Tobit models were estimated with fixed effects; two models include the terms of interaction that link firm size and the two types of technological investment. They also link the interaction of the latter with the mute variables that designate multinational and Mexican firms. The first columns of Tables 3 and 4 present the results of the estimates without the interaction terms; they are presented here to compare the effects with the estimations that include them.

According to the results presented in column 2 of Table 3, the largest firms that purchase technology tend to substitute internal research efforts

Table 4

EXPENDITURE IN TECHNOLOGY TRANSFER (TOBIT MODEL)

	OVERALL		
	1	*2*	*3*
Size	0.382 (0.134)[3]	0.381 (0.134)[3]	0.363 (0.129)[3]
Capital intensity	0.853 (0.267)[3]	0.854 (0.266)[3]	0.892 (0.263)[3]
Exports	0.938 (0.579)	0.934 (0.580)	1.02 (0.583)
Transnational	1.39 (0.713)[1]	1.39 (0.713)[1]	1.98 (0.853)[2]
Hard technology	–0.891 (0.343)[3]	–0.889 (0.342)[3]	–1.02 (0.353)[3]
R&D	0.039 (0.090)	0.033 (0.123)	0.060 (0.109)
R&D*size		–0.001 (0.014)	
R&D*domestic			–0.189 (0.115)
R&D*transnational			0.227 (0.266)
Constant	–3.168 (1.161)[3]	–3.165 (1.164)[3]	–3.184 (1.145)[3]
MPL[a]	–1,135.68	–1,135.14	–1,135.68
% Censure	0.45	0.45	0.45
Wald χ^2	56.87[3]	57.55[3]	56.87[3]

Notes: [a]Pseudo-probability estimation of maximum likelihood (MPL). Standard errors are reported in parentheses (Huber/White/Sándwich). [1]10% significance; [2]5% significance; [3]1% significance.

as they increase their expenditure in external technology (see the coefficient [left column] "Transfer*size"). The distinction between multinational and Mexican firms in relation to the effects of external purchase (column 3) reveals the significant differences in the technology strategies of these two firms' types. This result confirms the fact that multinationals do very little research that can be adapted, and they depend on technologies developed by their corporate headquarters (Kumar & Saqib, 1996). The coefficient is not significant for Mexican firms.

Table 4 presents the estimates including the purchase of technology transfer as the dependent variable. Once the relationship between size and internal R&D is considered, the increase in R&D capacity of large companies ("R&D*size") discourages the purchase of technology transfer, given

Table 5

BIVARIATE PROBIT MODEL: R&D AND TT INVESTMENT DECISIONS

	OVERALL		MULTINATIONAL		DOMESTIC	
	RD=1	*TT=1*	*RD=1*	*TT=1*	*RD=1*	*TT=1*
Size	0.120 (0.05)[1]	0.460 (0.11)[3]	0.172 (0.071)[2]	0.610 (0.272)[2]	0.150 (0.08)[1]	0.560 (0.16)[3]
Capital intensity	–0.236 (0.110)[2]	0.254 (0.120)[2]	–0.170 (0.180)	0.370 (0.200)[1]	–0.390 (0.170)[2]	0.210 –0.180
Exports	0.530 (0.220)[2]	0.280 (0.220)	0.340 (0.450)	0.050 (0.470)	0.910 (0.520)[1]	0.510 (0.430)
Hard technology	0.040 (0.040)	–0.060 (0.040)	0.140 (0.060)[2]	–0.040 (0.070)[1]	-0.060 (0.060)	-0.080 (0.050)
Year 2000	0.230 (0.190)	–0.430 (0.210)[2]	0.480 (0.340)	–0.050 (0.370)	0.090 (0.280)	–0.630 (0.310)[2]
Constant	–1.49 (0.470)[3]	–5.55 (1.070)[3]	–1.77 (0.860)[2]	–5.48 (1.470)[3]	–1.33 (0.600)[2]	–6.61 (1.870)[3]
Observations	190	190	88	88	102	102
MPL[a]	–218.88		–91.37		–120.25	
Wald $\chi^2(5)$	59.41[3]		35.40[3]		31.41[3]	
ρ	0.260		0.0780		0.790	
Wald test $\rho = 0$	0.211		0.228		0.028	

Notes: [a]Pseudo-probability estimation of maximum likelihood (MPL). Standard errors are reported in parentheses (Huber/White/Sándwich). The estimated model is a Probit model (grouped). The coefficient of correlation of the remainders ρ resulting from the individual equations (*RD* probability and *TT* probability). [1]10% significance; [2]5% significance; [3]1% significance.

that the coefficient is not significant (column 2). On the other hand, the distinction of firm-type does not contribute to an explanation of the significant differences regarding the impact of internal R&D on technology transfer expenditures. The results reveal little evidence regarding a strategy of complementarity of internal technological effort and technology acquisition in the Mexican pharmaceutical industry (column 3).

the estimations of the bivariate Probit econometric model

The Probit model facilitates the consideration of both the technology investment decisions, and provides an alternative approach to compare the impact of the different factors previously obtained by the Tobit model. The dependent variables are *RD* and *TT*; both are dummy variables where *RD* = 1, *TT* = 1 when a company invests in R&D or technology transfer, and *RD* = 0, *TT* = 0 otherwise. The independent variables are the same as in the previous models. The results are presented in Table 5.

The positive coefficient between the terms of error (ρ), obtained from the results of columns 1 and 2 for the industry as a whole, suggests that there is some degree of complementarity of technological strategies. The Wald $\chi^2(1)$ statistic demonstrates that the independent variables are sufficient to explain the probability of the two types of technological acquisition.

The individual estimation of the group of multinational and Mexican firms demonstrates that the model behaves better statistically for the second case. The model for the industry as a whole predicts a complementarity probability of 0.14. For the multinational companies, this probability is 0.18; for the Mexican pharmaceuticals, it is only 0.089. In summary, these results show that there is little complementarity between technological sources in the Mexican pharmaceutical industry. A positive relationship does not appear to exist between internal R&D investment and technology transfer. More than complementation, though, the results indicate that the multinational and large firms tend to substitute internal research effort as they increase their expenditures in external technology.

In summary, the evidence provided by the bivariate Probit model indicates that the technological strategies of pharmaceutical firms have some degree of complementarity, but the probability of occurrence is very low. The results from the Tobit and Probit models show that the largest firms and the multinational firms tend to substitute internal research efforts as they increase their expenditures in external technology, but there is a probability that some of them increase their R&D and discourage the practice of technology transfer. This conclusion is confirmed also by the evidence from the Probit model.

The Tobit model results indicate that multinationals do very little research within their home countries, and that they depend on technologies developed outside their corporate headquarters. These results reveal little evidence regarding a strategy of complementarity of internal technological effort and technology acquisition for both multinational and Mexican pharmaceutical firms. The results of the model show the segmentation that exists among national companies: on the one hand, there are local companies that have based their development of generic drugs on a closed economy, with lax intellectual protection and a niche in the public sector that refuses to accept the necessity of change in order to face the growing competition; on the other, there is a group of companies that have created an innovation strategy focusing on the production of new products and technologies. According to these companies, the process of innovation has been limited mainly due to a lack of adequate financing and an absence of public policies that support the industry, as in India and Brazil.

CONCLUSIONS

This research proposed to evaluate the influence of external knowledge sources on internal corporate research efforts. Little evidence exists regarding the case of developing countries. The innovation strategies in the pharmaceutical industry are very complex. Through the use of two evaluation approaches, empirical analyses of companies' technological strategies were examined with the intention of discovering some of the factors determining them.

Our results are summarized in three points. Contrary to studies addressing industrialized countries and other industries, the purchase of technology exercises a marginal effect on corporate R&D investment decisions; moreover, R&D efforts do not affect the purchasing of technology. This conclusion casts doubt on the hypothesis concerning absorption capacity and the catalytic effect of technology on firms' long-term goals for innovation in the Mexican pharmaceutical industry.

The absence of a complementary relationship may be explained by the divergence of technological objectives of the firms. While R&D investment by companies is explained by participation in export markets, technology purchase is determined above all by capital intensity and company size. Our results confirm, nevertheless, the importance of international diversification (for example, participation in export markets) for a company regarding investment in complementary technology acquisition strategies: R&D, and technology transfer.

With reference to technology policy, this research offers little evidence of a significant effect of policies that promote technology transfer on innovative capacity in the pharmaceutical industry. An alternative to increasing innovative capacities and industrial productivity consists of increasing the connection between the industry and scientific activity developed in universities and public research centers. This technological co-operation should include not only collaboration in product innovation and development (for example, in biochemistry and biotechnology), but also in terms of industrial-process upgrading, such as higher-quality medications, and productive plant modernization. If it is true that when a firm licenses a patented drug it produces the same drug and sells it under the patented brand name, it is important that firms possess the technological capabilities linked to R&D investment in order to produce a generic version of the drug when the patent expires. Moreover, they must develop new technologies for the treatment of diseases common to developing countries.

Finally, it must be noted that the decisions assumed by pharmaceutical

firms upon choosing internal R&D and technology transfer as a substitute or complement to improving the technological level of their productive activities respond not only to the microeconomic concerns of the company, but also to the macroeconomic context. The success of technology strategies pursued by firms, therefore, requires the design of industrial, fiscal, financial, and educational policies that will facilitate the development and accumulation of technological capabilities.

Even while a significant percentage of national companies presents insufficient technological progress and faces numerous obstacles to development, a certain foundation of technological and institutional capacities exists in Mexico that can be maximized to strengthen innovation in its pharmaceutical industry. For example, in accordance with its innovative strategy, the company Silanes Bio-clon has made an alliance with the Biotechnology Institute of the Universidad Nacional Autónoma de México (UNAM). This alliance has fostered the development of innovative treatments for spider-, scorpion-, and snakebites by taking advantage of the high specialization of researchers in the field of biotechnology. These new products are part of what is currently called "orphan illnesses," which are of interest to the large pharmaceutical corporations; therefore companies that have created paths of innovation understand the potential of close alliances with institutes and universities that implement scientific research. Hence policy actions could be designed to foster measures to stimulate a beneficial cycle in which the complementary strategies of internal R&D and technology transfer clearly favor technological development and innovative paths. These measures include recognizing the strategic character of the pharmaceutical industry within the country's industrial policies; creating high-level human resources, especially in biotechnology and genomics; and supporting the creation of R&D centers in universities, institutes, and companies.

Last, it is necessary to mention a limitation of this work. Since the calculations were based on data supplied by the pharmaceutical firms and not through direct surveys, the amount spent on R&D by small firms is underestimated because these firms often do not quantify the extent of their technological effort, especially in the case of Mexican firms. If a firm has no R&D department, it will usually respond that it has not spent any money on R&D, even if its staff members are innovating and adapting imported technologies for local use. Nevertheless, our econometric results are in agreement with the trend indicated in many of the studies of R&D behavior in the pharmaceutical industry in Mexico, due to the fact that it is an industry in which 65% of companies are large; therefore the underestimation of the R&D total is not statistically significant.

ACKNOWLEDGMENTS

This essay forms part of the ECOS-NORD MS031 research program sponsored by CONACYT-SEP-ANUIES and the French Ministry of Education. Earlier versions were presented at the September 2004 Congrès AFSE (Paris) with the title, "R&D and Technology-Purchasing Decisions in the Mexican Pharmaceutical Industry." It was also presented at the 11th Technological Management Seminar ALTEC 2005 with the title, "Technology Acquisition by Local Imitators and Foreign Subsidiaries: A Study of the Pharmaceutical Industry" (Salvador de Bahía, Brazil, October 2005).

REFERENCES

Agarwal, A. (2000). Deregulation, technology imports and in-house R&D efforts: An analysis of the Indian experience. *Research Policy, 21*(9), 1081–1093.

Álvarez, R. (2001). External sources of technological innovation in the Chilean manufacturing industry. *Estudios de Economía, 28*(1), 53–68.

Archibugi, D., & Pietrobelli, C. (2003). The globalization of technology and its implications for developing countries: Windows of opportunity or further burden? *Technological Forecasting & Social Change, 70*(9), 861–883.

Arora, A. (1995). Licensing tacit knowledge: Intellectual property rights and the market for know-how. *Economics of Innovation and New Technology, 4*, 41–49.

Arora, A., Fosfuri, A., & Gambardella, A. (2001). Specialized technology suppliers, international spillovers and investment: Evidence from the chemical industry. *Journal of Development Economics, 65*(1), 31–54.

Arora, A., & Gambardella, A. (1990). Complementarity and external linkages: The strategies of the large firms in biotechnology. *Journal of Industrial Economics, 38*, 361–379.

Arrow, K. J. (1962). Economic welfare and the allocation of resources for invention. In R. R. Nelson (Ed.), *The rate and direction of inventive activity* (pp. 609–625). Princeton, NJ: Princeton University Press.

Basant, R., & Fikkert, B. (1996). The effects of R&D, foreign technology purchase and international and domestic spillovers on productivity in Indian firms. *Review of Economics and Statistics, 78*(2), 187–199.

Braga, H., & Willmore, L. (1991). Technological imports and technological efforts: An analysis of the determinants in Brazilian firms. *Journal of Industrial Economics, 24*, 421–432.

Cassiman, B., & Veugelers, R. (2002, October). *Complementarity in the innovation strategy: Internal R&D, external technology acquisition and cooperation in R&D*. Working paper presented at the meeting of the IESE. Conference in Universidad Carlos III, Madrid, October, IESE Bussiness School, University of Navarra.

Caves, R., & Uekusa, M. (1976). *Industrial organization in Japan*. Washington, DC: Brookings Institution, 124–140.

CEPAL (1999). *Las industrias farmacéutica y farmoquímica en México y el Distrito Federal*. Gobierno del Distrito Federal, Secretaría de Desarrollo Económico, México.

Chang, C. L., & Robin, S. (2003). *Doing R&D and importing technology: An empirical investigation on Taiwan's manufacturing firms*. Paris: Université catholique de Louvain, Institut de Recherches Economiques et Sociales (IRES)

Cockburn, I., & Henderson, R. (2001). Scale and scope in drug development: Unpacking the advantages of size in pharmaceutical research. *Journal of Health Economics, 20*(6), 1033–1057.

Cohen, W., & Klepper, S. (1996). Firm size and the nature of innovation within industries: The case of process and product R&D. *Review of Economics and Statistics, 78*(2), 232–243.

Cohen, W., & Levin, R. (1989). Empirical studies of innovation and market structure. In R. Schmalensee & R. Willig (Eds.), *Handbook of Industrial Organization* (pp. 1060–1107). London: North Holland.

De Bondt, R. (1996). Spillovers and innovative activities. *International Journal of Industrial Organisation, 15*, 1–28.

Dosi, G. (1988). Sources, procedures and microeconomic effects of innovation. *Journal of Economic Literature, 26*, 1120–1171.

Gambardella, A. (1995). *Science and innovation: The US pharmaceutical industry in the 1980s*. Cambridge: Cambridge University Press.

Grabowski, H., & Vernon, J. (1994). Innovation and structural change in pharmaceuticals and biotechnology. *Industrial and Corporate Change, 3*(2), 435–449.

Grandstrand, O., Hakanson, L., & Sjolander, S. (1992). *Technology management and international business*. London: Wiley.

Henderson, R., Jaffe, A., & Trajtenberg, M. (1998). Universities as a source of commercial technology: A detailed analysis of university patenting, 1965–1988. *Review of Economics and Statistics, 80*, 119–127.

INEGI. (1994, 2000). *Encuesta industrial anual* (*EIA*) (Annual industrial survey). Instituto Nacional de Estadística, Geografía e Informática, Mexico.

INEGI. (2004). *Monthly industrial survey, Mexico*. Instituto Nacional de Estadística, Geografía e Informática, Mexico.

Johnson, D. K. (2002). Learning by licensing: R&D and technology licensing in Brazilian invention. *Economics of Innovation and New Technology, 11*(3), 163–177.

Kaiser, U. (2002). An empirical test of models explaining research expenditures and research cooperation. *International Journal of Industrial Organisation, 20*(6), 747–774.

Kamien, M., & Zang, I. (2000). Meet me halfway: Research joint ventures and absorptive capacity. *International Journal of Industrial Organisation, 18*, 995–1012.

Kamien, M., & Schwartz, N. (1982). *Market structure and innovation*. Cambridge: Cambridge University Press.

Kanwar, S., & Evenson, R. (2003). Does intellectual property protection spur technological change? *Oxford Economic Papers, 55*, 235–264.

Katrak, H. (1985). Imported technology, enterprise size and R&D in a newly industrialising country: The Indian experience. *Oxford Bulletin of Economics and Statistics, 47*(3), 213–229.

Katrak, H. (1989). Imported technologies and R&D in a newly industrialising country: The experience of Indian enterprises. *Journal of Development Economics, 30*(1), 123–139.

Katrak, H. (1997). Developing countries' imports of technology, in-house technological capabilities and efforts: An analysis of the Indian experience. *Journal of Development Economics, 53*, 67–83.

Katz, M. (1986). An analysis of cooperative research and development. *RAND Journal of Economics, 17*, 527–543.

Kumar, N. (1998). Technology generation and transfers in the world economy: Recent trends and prospects for developing countries. In N. Kumar (Ed.), *Globalisation, foreign direct investment and technology transfer: Impacts on and the prospects for developing countries* (pp. 11–42). London: Routledge.

Kumar, N., & Agarwal, A. (2000). *Liberalization, outward orientation and in-house R&D activity of multinational and local firms: A quantitative exploration for Indian manufacturing.* Discussion paper no. 18, Institute of Economic Growth, Delhi, from http//www.ieg.nic.in.

Kumar, N., & Saqib, M. (1996). Firm size, opportunities for adaptation, and in-house R&D activity in developing countries: The case of Indian manufacturing. *Research Policy, 25*(5), 712–722.

Landau, R., Achilladelis, B., & Scriabine, A. (1999). *Pharmaceutical innovation: Revolutionizing health*. Philadelphia: Chemical Heritage Press.

Lee, J. (1996). Technology imports and R&D efforts of Korean manufacturing firms. *Journal of Development Economics, 50*(1), 197–210.

Levin, R., Klevorick, A., Nelson, R., & Winter, S. (1987). Appropriating the returns from industrial research and development. *Brookings Papers on Economic Activity, 3*, 783–831.

Lichtenberg, F. (1998). *Pharmaceutical innovation, mortality reduction, and economic growth*. Working paper, no. 5668. National Bureau of Economic Research, Cambridge, MA.

Mansfield, E. (1981). Composition of R&D expenditures, relationship to size of firm, concentration and innovative output. *Review of Economics and Statistics, 63*, 610–615.

Morange, M. (2003). *Histoire de la biologie moléculaire*. Paris: La Découverte.

Organization for Economic Co-operation and Development (OECD). (2001). *New patterns of industrial globalisation: Cross-border mergers and acquisitions and strategic alliances*. Paris: OECD.

Pisano, G. (1990). The R&D boundaries of the firm: An empirical analysis. *Administrative Science Quarterly, 35*, 153–176.

Scherer, F. (1965). Firm size, market structure, opportunity, and the output of patented innovations. *American Economic Review, 55*, 1097–1125.

Scherer, F. (1967). Market structure and the employment of scientists and engineers. *American Economic Review, 57*, 524–531.

Spence, M. (1984). Cost reduction, competition and industry performance. *Econometrica, 52*, 101–121.

Subramanian, A. (1995). Putting some numbers on the TRIPs agreement pharmaceutical debate. *International Journal of Technology Management, 10*(2), 252–267.

Teece, D. (1988). Technological change and the nature of the firm. In G. Dosi, G. C. Freeman, R. Nelson, & L. Silverberg y Soete, (Eds.), *Technological change and economic theory* (pp. 256–281). London: Printer Publishers.

Veugelers, R., & Cassiman, B. (1999). Make and buy in innovation strategies: Evidence from Belgian manufacturing firms. *Research Policy, 28*(10), 63–80.

Weinmann, N. (2002). Les acteurs mondiaux: Une redistribution des cartes. In A. Moreau, S. Rémont, & N. Weinmann (Eds.), *La industrie pharmaceutique en mutation*. Paris: Les études de la documentation Française.

Williamson, O. (1975). *Markets and hierarchies: Analysis and antitrust implications*. New York: Free Press.

Williamson, O. (1985). *The economic institutions of capitalism*. New York: Free Press.

Wooldridge, J. (2002). *Econometric analysis of cross-section and panel data*. Cambridge, MA: MIT Press.