Artículos

Trade and Private R&D in Mexico

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Abstract: Using the National Survey on Employment, Wages, Technology and Training (Enestyc), this paper tries to find the relationship between increasing trade and the proportion of total income Mexican manufacturing firms invest on R&D. Based on two cross-sectional and a panel estimation procedures, the results confirm the idea that increasing the exposure to foreign markets affect the innovative efforts of Mexican firms. We also find that the firms engaging in some kind of R&D do not conform a random sample.

More specifically, our results show that, in 1992, the probability of finding a firm engaging resources in some kind of R&D increased with size, a market diversification measure, and a measure of industrial market power at a 2-digit level, while the intensity of the R&D effort depended, on market power and an industry concentration measure. For the 1999 estimation our results show that the probability of R&D investment at a firm level increased with size, a market diversification measure, and exposure to foreign competition, while the magnitude of the R&D effort of a firm was determined by the decrease in average import tariffs at the industry level and by the exporting efforts of the firm. We find strong complementarities between public and private innovation efforts in both years, but find that younger firms are doing stronger R&D efforts in 1999. The 1992-99 balanced panel results show that exporting firms invest more in R&D while import competing firms invest less, once size, market power and other control variables are taken into account.

Our estimation indicates that exporting give firms a great incentive to innovate, and that not only large, but also small firms contribute to the R&D efforts of a nation.

Keywords: R&D, trade liberalization, foreign direct investment, exposure to foreing markets.

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Resumen: Con datos de la Encuesta Nacional de Empleo, Salarios, Tecnología y Capacitación (Enestyc), este trabajo busca relacionar la apertura comercial con la proporción del ingreso que las empresas manufactureras privadas en México dedican a investigación y desarrollo (R&D por sus siglas en inglés). Con base en dos estimaciones de corte transversal y una de panel, los resultados sugieren que una mayor exposición a la competencia internacional promueve un mayor esfuerzo innovador en las empresas de la muestra y que las empresas que gastan en investigación y desarrollo no conforman una muestra aleatoria. Más específicamente, los resultados sugieren que en 1992 la probabilidad de que una empresa invirtiera en R&D estaba positivamente correlacionada con su tamaño, con la diversificación de sus mercados y con el poder de mercado en la industria (medido a 2 dígitos), mientras que la intensidad del esfuerzo innovador estaba positivamente correlacionada con el poder de mercado y con una medida de concentración de la industria. Las estimaciones de 1999 vuelven a sugerir que las empresas de mayor tamaño y las que diversifican mercados son las que tienen mayor probabilidad de gastar en R&D, pero sugieren que en esta probabilidad también influye positivamente la exposición a la competencia internacional. En cuanto a la intensidad en el esfuerzo innovador en 1999, el estudio sugiere que éste es mayor en empresas más pequeñas, en las empresas de aquellas industrias que enfrentan menores tarifas a las importaciones y en las que colocan parte de sus ventas en mercados internacionales. En ambos años del análisis, encontramos fuertes complementariedades entre el gasto público en R&D y el gasto privado. La estimación de panel balanceado vuelve a sugerir que las empresas exportadoras invierten más en investigación y desarrollo, pero que las empresas en industrias que enfrentan menores tarifas a las importaciones invierten menos, una vez que el tamaño, el poder de mercado y otras variables de control se incluyen en la regresión.

Nuestros resultados sugieren que las empresas exportadoras tienen fuertes incentivos para innovar y que no sólo las empresas grandes sino sobre todo las pequeñas están contribuyendo a los esfuerzos innovadores del país.

Palabras clave: investigación y desarrollo, liberalización comercial, inversión extranjera directa, exposición a mercados internacionales.

Introduction

The first attempt to theoretically establish what determines the R&D efforts within a firm can be tracked back to 1954, when Dorfman and Steiner (1954) concluded that the optimal (*i.e. profit maximizing*) research and development (R&D) intensity of a firm can be represented by the ratio of the quality elasticity of demand to the price elasticity of demand. In 1991, Grossman and Helpman (1991) used an economics approach to analyze the linkages between innovation and trade, and although many scholars have advanced the theoretical facet of this relationship, the empirical literature remains limited.

Theoretically, firms' R&D efforts are jointly determined by demand-side and technology-side factors (also called "demand-pull" and "technology-push" factors). The former includes firm sales and consumer preferences over quality and price, while the latter includes the R&D cost structure —or the production-cost effect of R&D—, and the firm technological competence. Empirical studies have tended to emphasize either demand-side variables or technology-related variables, but to correctly asses the impact of trade and foreign investment in the R&D efforts, we must take both into account (see Chang-Yang Lee, 2003).

As both demand-side and technology-side factors can be altered by the firm´s exposure to international trade, this paper tries to find out if increases in the exposure to foreign markets have changed the private R&D efforts of Mexican manufacturing firms. Using Mexican data to analyze the liaison between innovation and trade has several advantages. First, trade has become an important source of economic growth in Mexico, and a very important number of firms are now exposed to foreign competition. Second, private innovation has increased considerably since trade was liberalized, and this has not been related to an increase in public investment in R&D, and finally, innovation policies are almost non existent in Mexico, but they can be correctly designed and evaluated if the phenomenon is properly understood. These policies can be then adapted to other developing countries.

The theoretical literature provides no definitive answer on how trade affects research efforts, especially in the presence of informational asymmetries and strategic considerations common in both international trade and profit-seeking research efforts. According to Grossman and Helpman (1991), international trade affects firms' research policies in several possible ways. For import competing firms, monitoring research projects of foreign firms may be more difficult than monitoring domestic competitors, given the greater distance and potential language barriers. As a result, new products from abroad may be more likely to catch domestic firms by surprise. With a strong first-mover advantage, domestic firms may find it hard to compete technologically with foreign firms and may respond to import competition by reducing research efforts. On the export side, increases in the market size should raise the reward to research and therefore the private R&D efforts of firms (Funk, 2002). These responses, however, might differ in developing countries where imports are a basic source of technology. This means that a greater volume of imports, within a firm or an industry, might be related to improved technological knowledge and to increased R&D efforts, given that the technology accessible to the firm increases, at least in the short-run.

To analyze the link between trade and private investment in R&D, we use plant data from the 1992 and 1999 National Survey of Employment, Wages, Technology and Training (Enestyc from its acronym in Spanish). As we only have data for these two years, we do two cross-sectional analysis and then use a balanced panel data base. The analysis can be useful to understand the short and the long-run effect of trade on the private R&D efforts.

The R&D effort of firms is measured in this paper as the expenditure in R&D aimed to generate new products, prevent contamination and pollution, or to improve existing products and production processes, relative to total income, and not only to sales.[1] This because a firm can sell its innovations and, therefore, investment in R&D might not only increase sales of their own production goods. Besides, as Funk (2002) put it: "the R&D to sales ratio can lead to erroneous conclusions when analyzing the effect of trade on R&D efforts, because increases in import competition can reduce firms' sales more than it reduces R&D, leading to the inference that import competition increases research efforts". Our measure of R&D effort tries to avoid this problem, but when sales represent a very large proportion of the firm's income, the problem mentioned is hard to avoid.

This article is an extension of an investigation done for the World Bank and it is organized as follows. In the next chapter, we include a theoretical background based on a literature review. The theory presented here implies that R&D intensity is independent of firm size, unless firm size affects consumer preference or technological competence. In the second chapter, we describe the data set and the variables used to find the relationship between trade and the expenditure in R&D. In the third chapter, we present some descriptive statistics. In the fourth chapter, we make the estimations: two cross-sectional

[1] We are excluding from the numerator the purchase of long-lived equipment and the expenditure in technology transfer. Our exclusions are explained by our interest in expenses aimed to generate some kind of innovation.

and one panel regression. The estimations are done considering that the firms engaged in R&D do not conform a random group; therefore, to better understand the role our independent variables have played in the R&D efforts of Mexican manufacturing firms, we try to correct the selection bias we might have encountered by analyzing only the sample that report positive R&D expenditures. In the last chapter we conclude.

I. Literature Review

For many years, technological change was largely considered a result of the efforts made by governments[2] or a consequence of technical opportunities some firms faced. In 1950, Joseph Schumpeter stated that technological innovation was basically a product of large firms. This idea leaded to the concept of scale economies in R&D. In 1965, Frank Scherer suggested that the relationship between size of the firm and innovation was not linear —either if innovation was measured as an output or as an input—, and that the effort to innovate grew at a decreasing rate with the firm size (Scherer, 1965). Later in 1987, Cohen, Levin and Mowery (1987) showed that R&D contributes to firm survival. In a study about R&D and firm performance, these authors suggest an endogeneity problem if innovation has an effect on firm size.

In the late 1990s, and based on a sample of manufacturing firms in France, Crepon, Duget and Mairesse (1998) showed that the probability of engaging in R&D increases with the firm's size (number of employees), its market share and diversification, and with a demand-pull and a technology-push indicators. They also found that the research effort of a firm engaged in research increases with the same variables, except for size, and that the innovation output of a firm, measured by patent numbers or innovative sales, rises with its research effort and with the demand-pull and technology-indicators. This study takes into account the selectivity bias generated by the fact that only a few firms engage in R&D. In this study, industry characteristics that might affect the firm expenditure in R&D are included by using industry dummies that control for industry differences.

[2] Much of the new technology at that time was developed in war periods, and firms used to adopt that new technology to their purposes.

In general, studies that try to estimate the factors influencing the R&D efforts of firms agree on the fact that not only firm specific effects are important. In their survey of studies of R&D and patents, Cohen and Levin (1989) discuss the importance of demand, technological opportunity and appropriability as determinants of the research and innovative activities of firms. In their article, Cohen and Levin also investigate the effects of firm size and market concentration on innovation. With respect to market concentration, they mention that the causality might go from innovation to market structure: innovation can affect market concentration by increasing or decreasing the efficient scale of production. With respect to size effects, they explain that capital market imperfections give larger firms an advantage as they are more likely to get the finance for risky R&D projects due to the positive correlation of size with "the availability and stability of internally generated funds". Another claim is that the returns to R&D investment are higher when the firm has a big volume of sales "over which spread the fixed cost of innovation".

Cohen and Levin make great emphasis on the problems coming from measurement errors and on the sample selection bias, as most of the samples are highly non-random. They also claim that most of the empirical work regarding the determinants of R&D intensity of a firm has been focused on the effects of size and concentration, omitting important explanatory variables and consequently biasing the estimates of these effects and misleading inferences.

Regarding innovation and trade, Scherer (1982) examined the R&D investment response of high-tech firms to increased import competition in the US. He found considerable heterogeneity in firm level responses to increased import competition: some firms reacted aggressively and fought back (they invested more in R&D) and some firms reacted submissively and folded (they invested less). While he found different reactions, he also noticed that the short-run reaction to imports was on average submissive, but that large, diversified firms and those in concentrated markets reacted more aggressively than other firms. In 1992, Scherer and Huh (1992) deepened the analysis of the short-run and long-run effects of trade on private R&D. Using US data from the Census Bureau for the 1971-87 period they found that firms' R&D efforts do not respond to changes in import penetration rates in the short-run. They concluded that firms do not react to temporary events, but that when they react, they do it slowly.

Now, trade can also influence concentration and market power (Aghion and Howitt, 1998), and therefore the private R&D efforts. First, in domestic markets dominated by a monopoly or an oligopoly, import competition causes a reduction in the price-making ability of firms. To the extent that this loss in price-making power reduces the profitability of research investment, domestic firms may respond to increased import competition by reducing research efforts. Nevertheless, import competition may motivate firms with important monopoly power to increase research investments in order to protect their monopoly position (Funk, 2002). On the other hand, capital imports can increase technological competence of firms within an industry, causing also a reduction in the long-run R&D efforts of firms. Then, the impact of increased import competition on firm level R&D is uncertain. On the export side, increases in market size should raise the reward to research, so an expansion of exports markets should clearly increase research efforts.

There are not many empirical studies, at a firm level, that analyze the decisions of technological innovation in Mexico. In 1999, Brown and Domínguez (1999) tried to find the profile of innovative firms in Mexico. Based on the 1997 Annual Industrial Survey (EIA for its acronym in Spanish), the authors used a cross-sectional logit model to find, at a firm level, the variables affecting the likelihood of investing in R&D. The authors, following Pavitt, suggest that the composition of the industry defines the path and direction of the technological change of the whole economy. They conclude that the variable size losses its predictive power once the technological opportunity of the firm is taken into account. Their results confirm the importance of foreign exposure, and specifically exporting, to the probability of investing in R&D.

In 2001, Robertson and Álvarez (2001) compared the determinants of technological innovation of Mexican and Chilean manufacturing firms. Their article analyzes the relationship between exposure to foreign markets and specific innovations, such as investment in new tools, product design, R&D, and innovation in products and process. In their study, there are three links between foreign exposure and technological change: exporting to markets that demand higher technology, foreign direct investment, and trade in intermediate inputs. They jointly estimate the relationship between each of these factors and the firm decision to innovate by estimating a series of probit models for the year 1995. According to their results, exporting seems to play a large role in innovation. They consider Mexico and Chile as small developing countries, so they conclude that it is through external absorption that these countries get their source of technical progress. According to this, plants that export to developed countries are more likely to innovate in new products and in usage of new tools. In contrast, plants exporting to developing countries are more likely to invest in product design.

According to the literature presented, the factors influencing expenditure in R&D within a manufacturing firm can be firm-specific —like size, market diversification or age—, or sector-specific —like degree of concentration—, or even geographic-specific —like number of universities or local characteristics—. Other variables at a national level, like protection of property rights, patent laws, fiscal incentives, public finance to R&D, and tax incentives, can also be important, but they would have to be used in an international comparative study.

II. The Data

To estimate the efect of trade liberalization on investment in R&D as a proportion of total income in the Mexican manufacturing sector, we use data from the National Survey of Employment, Salaries, Technology, and Training (Enestyc) for 1992 and 1999, combined with other sources of information. The Enestyc is gathered by INEGI (Instituto Nacional de Estadística, Geografía e Informática). In 1992, Enestyc asked firms to give the proportion of total income they dedicated to research and development, excluding technology transfer and equipment acquisition. We use this percentage directly as our measure of R&D intensity in 1992. In 1999, firms are asked to give the money amount they dedicated to R&D excluding equipment acquisition and technology transfer. This amount is then divided by the total income firms report, and compared to the proportion firms gave in 1992. We are aware of the measurement error problems the question in 1992 can cause, but we found it more convenient to follow this procedure instead of trying to get the amount firms dedicated to R&D from a different source. We could have combined the Enestyc data with data from the EIA, where firms are asked to give the amount of pesos devoted to R&D in 1999 and several years before. The problem is that EIA does not include this question in 1992, and that by combining the data sets we would have lost a good number of firms, mainly from the micro- and small-enterprises groups.

INEGI has compiled the Enestyc at a plant level in four different years: 1992, 1995, 1999 and 2001.[3] The Ministry of Labor co-designed the questionnaire, which gathered information on training, technology, wages, employment, forms of labor contracting, and internal plant organization of Mexican manufacturing firms. Data from the 1992 survey includes 5 071 firms, and from the 1999 survey includes 7 429 firms. The panel data includes information of 1 148 firms for 1992 and 1999; therefore, we have a balanced panel to study the dynamic relationship between private R&D and exposure to foreign markets. Using the panel data, we solve the ommited variable problem. The data from the 1995 Enestyc is not included in our study because the values of our R&D intensity variable greatly differ from those reported in 1992 and 1999, and we were not sure this was a result of the economic and financial crisis Mexico suffered that year, or a result of measurement error.

Our sample is, in both years, 100% representative of the larger firms in the Mexican manufacturing sector, and includes a random sample of micro- and small-firms. The firms that reported no R&D are not excluded from our sample. As Cohen and Levin (1989) point out, the firms doing R&D do not make up a random sample. This means that the estimation of the determinants of the R&D effort of firms has to take into account the sample selection bias problem and try to correct it in order to better understand the reasons behind investment in R&D at a firm level. Our explanatory variables can be classified as firm, industry and region specific. Our firm specific variables include exports and foreign direct investment. In the cross-sectional estimations, we use a dummy variable equal to 1 to classify firms as exporters if they export more than 50% of their product. In the panel estimation we use the proportion of sales firms export. Our FDI variable is the proportion of foreign ownership the firm reports. In the cross-sectional estimations we also include a measure of market diversification of the firm as a proxy for demand, to test Schmookler's idea that demand plays a leading role in determining both the direction and the magnitude of inventive activity (Schmookler, en bibliografía 1966). This variable is equal to 1 if the firm sells its product in more than one country. The age of the firm in years is also included as right-hand-side variable in all the estimations. All the firm specific information comes directly from Enestyc.

[3] Enestyc 2001 was not ready at the time this study was conducted.

Our industry specific variables include a measure of industry concentration at a 4-digit level, that was calculated from Enestyc data as the sales of the 6 largest firms as a proportion of total sales of the industry. We also include a measure of the industry mark-up at a 2-digit level. This measure was calculated by Castañeda (2000), and it reflects the market power of the industry. The author has a calculation of the market power of the Mexican manufacturing industries for a period before and a period after NAFTA, and they are both used in our study. To make sure these two variables were not highly correlated, we calculated the correlation between the two. This value was equal to –0.08, so we decided to include them both as independent variables. To measure import competition, we use the average weighted import tariffs at a 2-digit level industry that come from the Ministry of Economics. The lower is this variable, the more import competition the firms in the industry face.

Our state specific variable is an index of the availability of highly skilled workers in the state, combined with a measure of public expenditure in R&D in the state. For each state we have data on the number of individuals with a degree in science, the federal expenditure in R&D, the number of persons graduated from college, and the number of researchers registered. These variables are expressed in terms of the state population. We also have the proportion of the federal expenditure dedicated to R&D by state. These data come from Conacyt (Consejo Nacional de Ciencia y Tecnología), and are combined in an index to avoid multicolinearity problems. This combined index is called "state characteristics", and it does not change in time, therefore is not included in the panel estimation.

III. Descriptive Statistics

Table 1 shows that Mexico, like most developing countries, get most of the resources to finance its R&D from the government, while, in most developed countries, the funds come mainly from the private sector. On the other hand, Mexico invest significantly less in R&D than countries like Brazil, Argentina or Chile, as can be seen in Table 2. When compared to developed countries, like Sweden or Japan, the difference in resources devoted to R&D increases significantly. The creation of new knowledge, therefore, do not seem to be "at the core of Mexico's technological evolution", but rather the adoption and application of

Table 1. R&D Finance Structure by Country, 1999

		Finance sources	
Country	*Government %*	*Firms %*	*Other sources %*
Colombia*	70.0	13.0	17.0
Chile	64.3	21.5	14.2
Greece*	53.5	21.6	24.9
Mexico	*61.3*	*23.6*	*15.1*
Brazil	57.2	40.0	2.8
Turkey*	53.7	41.8	4.5
Canada	31.2	44.5	24.3
Spain	40.8	48.9	10.3
Germany	33.0	64.3	2.7
USA	29.2	66.8	4.0
Japan	19.5	72.2	8.3
Korea	24.9	70.0	5.1

* 1997 data.
Source: OECD, *Main Science and Technology Indicators*, vol. 1, 2001.
Conacyt, Encuesta sobre Investigación y Desarrollo Tecnológico, 2000.

Table 2. R&D per Capita, by Country (Dollars per Capita)

Country	*1993*	*1994*	*1995*	*1996*	*1997*	*1998*	*1999*
Japan	988.9	1064.5	1219.9	1033.9	969.2	916.2	1041.7
Sweden	722.2	–	941.7	–	990.9	–	1035.9
USA	643.5	649.5	698.3	742.0	791.7	837.7	892.1
Germany	566.7	579.7	679.5	656.4	589.1	605.2	627.0
France	520.0	534.1	603.9	598.7	521.4	525.1	514.9
UK	349.0	368.1	381.6	384.3	410.3	435.5	453.2
Canada	313.4	337.1	343.4	344.3	354.9	338.9	346.6
Korea	173.5	220.1	271.4	296.9	278.5	174.5	213.9
Italy	196.2	188.5	401.7	216.3	199.9	210.4	212.0
Spain	112.1	104.5	120.8	128.9	116.7	133.7	135.1
Brazil	25.8	32.8	39.5	41.7	–	–	–
Argentina	–	–	–	32.5	34.7	35.3	36.1
Chile	20.9	24.2	29.7	31.5	34.1	30.7	28.3
Mexico	*10.1*	*13.8*	*9.7*	*11.1*	*14.7*	*20.5*	*21.2*

Source: OECD, *Main Science and Technology Indicators*, 2001.

Table 3. R&D as Percentage of GDP, by Country (percentage)

Country	*1993*	*1994*	*1995*	*1996*	*1997*	*1998*	*1999*
Sweden	3.27	–	3.46	–	3.67	–	3.80
Japan	2.88	2.84	2.98	2.83	2.90	3.04	3.04
USA	2.52	2.42	2.50	2.54	2.57	2.60	2.64
Korea	2.22	2.44	2.50	2.60	2.69	2.55	2.46
Germany	2.35	2.26	2.26	2.26	2.29	2.31	2.44
France	2.40	2.34	2.31	2.30	2.22	2.18	2.17
UK	2.12	2.07	1.98	1.91	1.84	1.83	1.87
Canada	1.63	1.77	1.74	1.70	1.71	1.71	1.66
Italy	1.13	1.05	1.00	1.01	0.99	1.02	1.04
Spain	0.91	0.81	0.81	0.83	0.82	0.90	0.89
Chile	0.65	0.66	0.65	0.66	0.65	0.62	0.63
Brazil	0.61	0.74	0.87	0.91	–	–	–
Argentina	–	–	–	0.42	0.42	0.42	0.47
Mexico	*0.22*	*0.29*	*0.31*	*0.31*	*0.34*	*0.47*	*0.43*

Source: OECD, *Main Science and Technology Indicators*, 2000.

existing technological knowledge developed abroad (Bell and Pavitt, 1992). According to data in Table 3, in 1999, total investment in R&D as a proportion of GDP was only 0.43% in Mexico, while in Japan it was 3.04%; in Germany, 2.44%; and in the US it reached 2.64%. In countries like Spain, Chile and Italy the proportion of investment in R&D relative to GDP was relatively low (0.89, 0.63 and 1.04%, respectively), but not as low as in Mexico. For the same year, the investment in R&D of the productive sector relative to total investment in R&D was above 60% in Japan, Germany and the US. In contrast, in Mexico it was below 20%. In Spain and Italy, this proportion was above 40% (Conacyt, 2000).

According to our data, in 1992, 32.4% of the Mexican manufacturing firms invested part of their resources in R&D. These firms invested, on average, 0.054% of their total income in activities aimed to generate new products, prevent contamination and pollution, or to improve existing products and production processes. In 1999, the percentage of firms engaged in some R&D activities had increased to 49%, and the mean proportion of income they dedicated to R&D had increased to 0.068%. This means that in a 7 years span, the average expenditure in R&D as a proportion of total income of Mexican manufacturing firms increased 25.9% (see Table 4).

Table 4. Summary Statistics

	1992	*1999*
R&D as a % of total income (mean)	0.054	0.068
Standard deviation of R&D as a % of income	0.126	0.629
% of firms investing in R&D	32.4	49.0
Number of workers (mean)	322.51	236.31
Exports as a proportion of sales (mean)	5.7	8.08
Age of the firms (mean)	22.1	20.21
% of firms w/more than 50% of FDI	16.21	8.93
% of executives in total employment	4.15	12.89
Number of firms in sample	4 982	6 648

Source: INEGI, Enestyc 1992 and 1999.

Table 5 presents data on R&D by manufacturing division. In 1992, the manufacturing division with the largest proportion of firms doing some investment in R&D, and the one that devoted the largest proportion of its total income to R&D was Basic Metals. In that year, around 45% of the firms in the Basic Metal Industry made some investment in R&D and, on average, these firms invested 0.075% of their total income in this area. In 1999, the manufacturing industry with the largest proportion of firms doing some kind of R&D was the Machinery and Equipment, but the industry that, on average, invested more in R&D as a proportion of income was the division of Non-Metallic Mineral Products. In this industry, the importance of R&D in total income increased more than 100% between 1992 and 1999. Despite the important increase, the numbers are still quite below averages with respect to nations like the US, Germany or Japan, and even below nations like Brazil or Chile. The data in this table is presented in Figures 1 and 2.

IV. Trade Liberalization and Private Investment in R&D

To analyze the relationship between research and trade, we run two cross-sectional generalized tobit models (GTM), one for each of the years we have appropriate Enestyc data, and a panel regression. The panel estimation is run to cope with an omitted variable problem. The GTM take into account the bias generated by a self-selection process of the firms interested in some kind of R&D, something that has been ig-

Table 5. R&D as a % of Total Income and % of Firms with R&D in Manufacturing Industry, by Division

	R&D as a % of total income		*% of firms with R&D*	
Division	*1992*	*1999*	*1992*	*1999*
Food, beverages and tobacco	0.046	0.025	27.70	44.40
Textiles, clothing and leather	0.034	0.046	25.05	37.00
Wood and wood products	0.054	0.040	23.98	40.75
Paper and printing	0.042	0.072	30.81	48.95
Chemicals, oil derivatives and coal	0.066	0.080	41.92	60.51
Non-metallic mineral products	0.063	0.127	31.42	34.48
Basic metals	0.075	0.044	44.91	57.43
Machinery and equipment	0.064	0.118	36.50	65.17
Other manufacturing industries	0.041	0.008	28.00	34.43

Source: INEGI, Enestyc 1992 and 1999.

Figure 1. Means of R&D as a % of Total Income, by Division

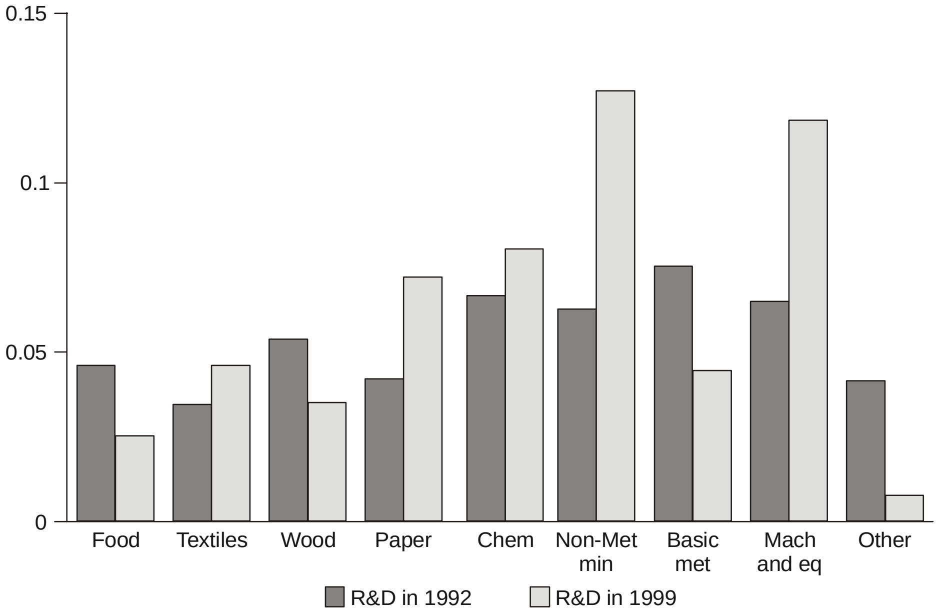
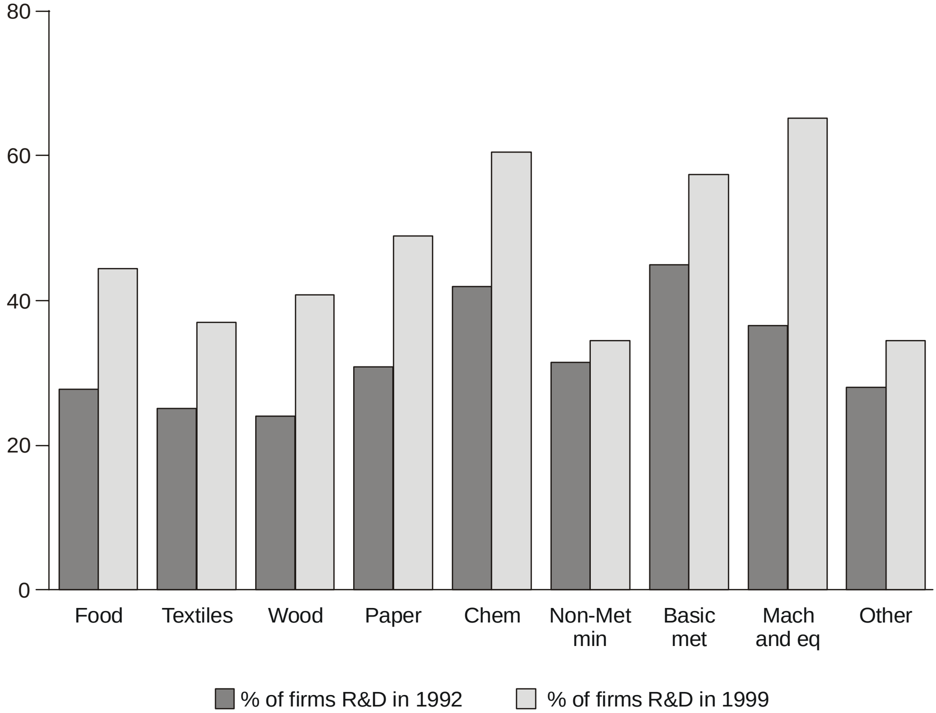


Figure 2. Percentage of Firms Doing R&D, by Division



nored in all other studies about the determinants of private investment in R&D in Mexico. If the R&D decision is not random, and we look for the determinants of the intensity of this decision ignoring this, we might reach wrong conclusions.

To find the determinants of R&D investment of Mexican manufacturing firms, we estimate our generalized tobit models with two equations, the first equation accounting for the fact that the firm is engaged in research activities, and the second one for the magnitude or intensity of these activities (Heckman, 1979).

We assume that there exists a latent dependent variable g_i^* for the firm i given by the first equation:

$$g_i^* = x_{0i}\, b_0 + u_{0i}$$

where x_{0i} is a vector of explanatory variables, b_0 is the associated coefficient vector and u_{0i} an error term, and where g_i^* expresses some decision criterion, such as the expected present value of the firm profit associated to research investment. The firm invests in research if g_i^* is positive or larger than some constant threshold, overall or industry specific (provided x_0 contains a constant error term or industry dummies).

We then assume that a latent or true intensity of research k_i^* for firm i is determined by a second equation:

$$k_i^* = x_{1i} b_1 + u_{1i}$$

with $k_i^* = k_i$, the actual expenditure in R&D as a proportion of income this firm invests in R&D (that is, when g_i^* is larger than the industry threshold), where x_{1i} is the vector of explanatory variables, b_1 the corresponding coefficient vector, and u_{1i} is a disturbance term that summarizes omitted determinants and other sources of unobserved heterogeneity. Note that the explanatory variables in the two equations need not be the same.

Finally, because k_i^* is only observable when g_i^* is larger than the industry threshold, we also have to specify their joint distribution in order to get an estimable model. We then assume a joint normality of disturbances in the two equations (i.e., the generalized tobit model assumption):

$$\left| \begin{matrix} u_{0i} \\ \\ u_{1i} \end{matrix} \right| \sim_{\text{iid}} N \left| \left| \begin{matrix} 0 \\ \\ 0 \end{matrix} \right| , \left| \begin{matrix} \sigma_0^2 & \rho\sigma_0\sigma_1 \\ \\ \rho\sigma_0\sigma_1 & \sigma_1^2 \end{matrix} \right| \right|$$

where σ_0 and σ_1 are the standard errors of u_{0i} and u_{1i}, and ρ is their correlation coefficient. The first equation is in fact a probit equation which is not fully identifiable, and we can only estimate the parameter vector b_0/σ_0 which is equivalent to normalizing the standard error $\sigma_0 = 1$.

IV.1. Cross Section Estimates

The estimation of our generalized tobit models confirms that investing in R&D within a Mexican manufacturing firm did not consist in a random decision, neither in 1992 nor in 1999. The number of firms included in the sample is 4 982 in 1992 and 6 648 in 1999. The number of censored observations (observations with no investment in R&D) is 3 366 in 1992 and 3 388 in 1999. The value of the Wald chi-squared statistic in both years shows that our group of independent variables significantly explains the decision to invest part of the firm's income in R&D.

The results of the first equation of the generalized tobit estimation (called "non-selection hazard equation"), for 1992 and 1999, are presented in Table 6. Dummies for states and 2-digit level industries are included in both years to control for some of the omitted variables at those levels. Our results show that in both 1992 and 1999, the probability of finding a firm investing in R&D in the short-run was positively correlated with the market diversification measure, and with the size of the firm. The market diversification measure is equal to 1 if the firm sells its product in more than one country. The causality between these two variables, however, is not clear, because it could be the case that firms that invest in R&D can better sell in foreign markets. Regarding size, our results show that the probability of investing part of the income of the firm in R&D increase at a decreasing rate with size, confirming Scherer's idea. Nevertheless, it is likely that size is capturing other firm characteristics that facilitate R&D activities, like access to a formal capital market. In 1992, the probability of finding a firm doing some R&D effort was also positively correlated with our measure of the market power of the industry at a 2-digit level, but it was not correlated with any of our trade and exposure to foreign market variables (except for market diversification). This suggests that firms in concentrated industries had larger incentives to invest in R&D than competitive firms.

Our cross section estimation for 1999 show that, in the late 1990s, the probability of finding a Mexican manufacturing firm investing in R&D was positively correlated with the firm being an exporter and having foreign direct investment, and negatively correlated with the industry concentration measure. Notice that import competition did not significantly affect the probability of doing some research, even after NAFTA was put into effect. This suggests that being in a concentrated industry was not an incentive to invest in R&D anymore, while being exposed to foreign markets as an exporter or as a recipient of foreign capital played an important role in the R&D decisions of firms. It is interesting to notice that the age of the firm is negatively and

Table 6. Non-Selection Hazard Equations. Dependent Variable: Dummy for R&D at Firm Level

Variables	*1992*	*1999*
Micro enterprise	–0.891**	–1.052**
	(–11.18)	(–19.75)
Small enterprise	–0.233**	–0.398**
	(–4.13)	(–7.66)
Medium enterprise	–0.141**	–0.248**
	(–2.95)	(–5.57)
Age of the firm in years	–0.002	–0.003**
	(–1.57)	(–2.78)
Exporter (= 1 if firm exports > 50%)	0.047	0.265**
	(0.53)	(4.13)
Market diversification	0.231**	0.437**
	(4.79)	(2.20)
Foreign direct investment	–0.001	0.001*
	(–0.75)	(1.72)
Average import tariff	–0.010	0.038
	(–0.12)	(0.66)
Concentration measure	–0.057	–0.225**
	(–0.48)	(–2.18)
Market power	0.649**	–0.065
	(2.27)	(–0.52)
Index of state characteristics	0.002	0.002
	(–1.19)	(0.51)
λ (inverse mills ratio)	0.109**	0.120*
	(5.20)	(1.87)

Numbers in parenthesis are z statistics.
** Significant at a 95% level.
* Significant at a 10% level.

significantly correlated with the dependent variable in 1999. This suggests that younger firms were, in the late 1990s, more likely to do a R&D effort than their older counterparts. Notice that the inverse mills ratio is significant at a 99% level in both years, confirming the presence of a sample selection bias.

In our results of the non-selection hazard equation, presented in Table 6, it is important to point out the robustness of the signs and significance of the firm size variables. They kept their explanatory power in every specification of the model. This result is consistent with all other studies in Mexico regarding the probability of finding larger firms investing in R&D. However, we do not include the size of the firm as explanatory variables of the R&D effort of the firm, i.e., in our second equation of the generalized tobit estimation.[4] This is justified by the Cohen and Levin statement that "capital market imperfections give larger firms an advantage as they are more likely to get the finance for risky R&D projects due to the positive correlation of size with the availability and stability of internally generated funds". Therefore, we can say that larger firms are more likely to engage in some kind of R&D activity, but it does not necessarily imply that they will make a larger R&D effort.

Table 7 presents the results of our second equation estimation, i.e. the estimation of the determinants of the R&D effort of firms, once the sample-selection bias is corrected. Table 7 suggests that the only factors that explained the R&D intensity of firms in 1999 were related to trade liberalization, while in 1992 the R&D efforts of the firms were more related to having some market power. In 1999, exporting firms seem to have invested significantly more in R&D activities than their non-exporting counterparts, while import competition seems to have positively affected the R&D efforts.[5] This result contradicts the theory and could be interpreted as a consequence of the short-run effect of import competition on income. As mentioned above, increasing competition from foreign products may motivate firms to do more research, but it can also negatively affect sales and income. The combination of the two effects, when the negative effect on sales more than compensates the negative effect on R&D, can be interpreted as a positive effect of increased import competition on the R&D efforts of firms. Table 7 also suggests that, in both 1992 and 1999, public R&D efforts complemented the private ones.

The problem with the cross-section estimation is that firm specific variables not included in the regressions might be affecting the R&D effort variable. For example, it is possible that, other things equal, more traditional firms, with vertical directing structures, invest less than modern firms. Or maybe more educated entrepreneurs invest more in R&D than other kind of entrepreneurs. To deal with this

[4] To test the relationship between size of the firm and R&D effort, we included the size variable in the second equation of the tobit estimation, but it was not significant.

[5] A decrease in average import tariffs represents increasing competition with foreign firms. If the coefficient is negative it means that a decrease in import tariffs increases R&D efforts, meaning that an increasing import competition positively affects the R&D efforts of firms.

Table 7. Generalized Tobit Model Second Equation (Corrected for Sample Selection Bias)
Dependent Variable: R&D as a % of income at firm level

Variables	*1992* *Wald chi-squared* *= 71.56* *Prob > chi2 = 0.000*	*1999* *Wald chi-squared* *= 66.54* *Prob > chi2 = 0.000*
Age of the firm in years	0.000	–0.002**
	(–1.51)	(–2.09)
Exporter (= 1 if firm exports > 50%)	0.015	0.087*
	(0.79)	(1.66)
Foreign direct investment	–0.000	–0.000
	(–1.33)	(–0.35)
Market diversification	0.020*	–0.011
	(1.78)	(–0.07)
Average import tariff	0.000	–0.023**
	(0.35)	(–2.47)
Concentration measure	0.079**	0.095
	(3.02)	(1.06)
Market power	0.024**	0.041
	(3.19)	(1.19
Index of state characteristics	0.000**	0.001**
	(2.95)	(2.25)
Constant	–0.050	0.009
	(–1.27)	(–0.11)

Numbers in parenthesis are *z* statistics.
** Signficant at a 95% level.
* Significant at a 10% level.

ommitted variable problem we estimate a fixed effects model with a balanced panel data.

IV.2. Panel Estimation

Although the cross-section models presented above included geographic and sectoral dummy variables to control for unobservables at those levels, it is very likely that the unobserved firm heterogeneity is biasing our results. To solve this problem, we also run a fixed effects model with firms included both in the 1992 and the 1999 Enestyc. The independent variables do not include dummies and they are: age of firm in years, size of firm measured as total number of workers, proportion of

Table 8. Balanced Panel Estimation
Dependent Variable: R&D as a % of Income at Firm Level

Variables	
Age of the firm in years	–0.028
	(–1.23)
Number of workers	0.000
	(0.61)
% of exports	0.076**
	(3.61)
% foreign capital	–0.010
	(–0.66)
Average import tariff	1.284**
	(13.85)
Concentration measure	–0.887
	(–0.19)
Market power	2.061**
	(3.34)
Constant	–7.579**
	(–2.61)

Numbers in parenthesis are *t* statistics.
** Signficant at a 95% level.
* Significant at a 10% level.

sales exported, proportion of capital provided by foreign investors, industrial average import tariff at a 2-digit level, industrial concentration maesure at a 4-digit, and industrial market power measured at a 2-digit level. Geographic variables included in the cross-section estimation do not vary in time, therefore, they are not included in the panel.

Table 8 shows the results of the balanced panel regression. The results suggest that once firm heterogeneity is taken into account, exporting a higher proportion of production increases the R&D efforts of the firms, while having a higher proportion of foreign investment do not. Age and size of the firm do not seem to matter. Surprisingly, increases in import competition seem to motivate firms to invest less in R&D in the long-run, as theory predicts, even after the effect on sales and income is taken into account. Finally, more market power at the industry level seems to be correlated with a higher R&D effort.

The panel results still show the importance of the exposure to foreign markets to explain the amount of resources firms devote to innovate.

However, the incresing competition firms face through this exposure may constitute a source of innovation as long as it does not eliminate monopolistic rents. Market concentration seems then to positively affect innovation, but the causality is not clear. Innovation may affect concentration by increasing or decreasing the efficient scale of production, but innovation may be motivated by an increasing competition.

V. Concluding Remarks

Investment in R&D constitutes an input to the R&D output of firms, and R&D output —usually measured as the number of patents registered— seems to have a significant role explaining TFP and, therefore, growth.

In most developed countries the resources devoted to R&D come mainly from the private sector, and specifically from firms. In Mexico, most of the resources engaged in R&D come from the government, but a very small part of the federal budget is devoted to it. However, as this work has shown, in the 1992-99 period, both the number of firms investing in R&D, and the average percentage of income firms dedicated to R&D experienced an important increase. In 1992, Mexican manufacturing firms invested on average 0.054% of their total income in R&D activities, and about a third of the firms made some R&D effort. In 1999, almost half of the firms in the manufacturing sector declared they had invested part of their income in R&D, and the average amount they dedicated to R&D had increased to 0.068% of their total income. Although the increase in the mean proportion of income aimed to R&D activities is not very dramatic (25.9%), the variance of the R&D effort of the firms increased from 0.126 in 1992 to 0.629 in 1999. This means that many firms started their R&D efforts with very small proportions of their income, but that many other Mexican manufacturing firms started investing very important amounts in R&D activities.

What drives the private investment in R&D in Mexico? Literature from the mid-20th century gave the firm size a very important role in the generation of new products and new production processes. Large firms were even considered a main source of growth, ignoring that size give firms some conditions that facilitate R&D activities, but that once size is controlled for, its effect on R&D intensity is practically null. Indeed, in our samples, the small firms are the ones engaging a larger proportion of income in innovative activities.

Another path of research leaded to the hypothesis that demand plays a leading role in determining both the direction and the magnitude of inventive activity. Market diversification is considered an important source of innovation, but our results only confirm the idea that market diversification determine the direction of the inventive activity but not the magnitude. In both years of our analysis, market diversification is an important determinant of the probability of finding firms engaging resources in R&D activities, but we find it not significantly explaining the intensity of the R&D effort of the firms. The importance of market diversification and demand conditions in the private R&D intensity creates a direct link between international trade and firm productivity, because we can easily assume that trade liberalization improves market conditions of items produced domestically, and facilitates market diversification.

The comparison of the results in 1992 and 1999 supports the theoretical prediction that, at the present time, exporting constitutes an important incentive to pursue R&D activities within manufacturing firms in Mexico. In 1992, being an exporter was not an incentive for firms to innovate. This was more a task for firms in more concentrated industries. It is important to notice, however, the possible liaison between a higher import tariff and a higher market power. It is likely that highly protected industries were also highly concentrated. These two variables then might be correlated, and a multicolenearity problem might be present in our estimations.

In 1999, the importance of foreign market exposure explaining R&D efforts within firms is evident. Market concentration no longer determine the R&D intensity of firms, while being an exporter positively and significantly determine the R&D effort of a firm. Regarding import competition, the 1999 cross-section estimation suggests that import competing firms invest more in R&D activities when the market for their product becomes more competitive (i.e. when the import tariffs decrease), than the other firms in the sample with similar observable characteristics. This might suggest that facing more competition encourage firms to innovate in order to protect their market share, at least in the short-run. It is important to point out that we did not find evidence of a relationship between foreign direct investment and R&D intensity, but that we found that foreign direct investment increased the probability of investing part of the firm resources in R&D.

In the panel estimation we find that the empirical evidence totally supports the theory and suggests that, in the long-run, exporting motivates research within firms, while import competition encourages less R&D efforts.

Our results suggest complementarities between the R&D efforts of the government and the R&D efforts of the firm, at least in the short-run. Engaging more public resources in R&D seems to positively affect the R&D efforts of the firms, both in 1992 and in 1999, although it is important to keep in mind that in more developed countries the private sector assume a major role in the R&D efforts of the nation.

According to the evidence presented in this study, policies aimed at increasing the private R&D efforts in the country have to emphasize the importance of exporting, especially in the small firms sector. Import competition seems to negatively affect R&D, but this is expected as it affects the price-making ability of firms. The public sector can participate directly in activities intended for innovation generation, but it might be advisable to analyze other kinds of public participation in the R&D efforts of the country. A relevant conclusion of our study is that long-run growth rates can be improved in Mexico if the low rates of investment in R&D start increasing in the short-run.

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