Doing R&D and Importing Technology: an Empirical Investigation on Taiwan's manufacturing firms

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Abstract:

The objective of this paper is to identify the determinants of the decision to innovate in Taiwan. Three "innovation strategies" are considered: doing R&D only, importing technology only, and combining both. We estimate a Bivariate Probit on a panel of more than 27000 Taiwanese manufacturing firms observed from 1992 to 1995. Results suggest that the decision to do R&D over the period was influenced by the prior changes in exportations at the industry level, whereas the decision to import technology is affected by the current changes. We identify a non-linear relationship between firm size and innovation. Moreover, older firms tend to innovate less, whereas market structure doesn't affect the decision to innovate. These two results change when only high-tech industries are considered: the effect of firms' age becomes insignificant, whereas a more concentrated market structure is shown to increase the probability to innovate.

Keywords: R&D, importation of technology, market structure, technological opportunities, high-tech industries, panel data, bivariate Probit.

JEL Codes: L10, L20, O31, O33

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Several microeconomic studies have tried to identify the determinants of innovation. These studies typically represent the innovation process as an "internal R&D activity", and insist on the importance of industry-level factors, such as market structure. Another line of innovation research is dedicated to the existence of several modes of knowledge acquisition (which can occur, for instance, through the purchase of patents, through merger and acquisitions, and through the recruitment of scientists and high-skilled labour force). This line of research seeks to explain how firms operate choices among those different sources of knowledge; however, in doing so, it tends to focus on firm's characteristics only.

The present contribution integrates, in an empirical perspective, these two strands of the industrial organization literature. The objective of the empirical study is to identify the determinants of innovation at the microeconomic level in Taiwan, simultaneously considering several "innovation strategies": doing R&D, importing technologies, or combining both. This distinction is particularly relevant in the case of Taiwan, where the recorded history of innovation is shorter than in most Western countries, and where firms build on existing technologies in order to develop new products/processes. In the past decades, Taiwan's economy relied mainly on its relatively cheap labor force, to produce low valued-added, "labor-intensive" goods. At the end of the 1980s, as Taiwan began to face an increasing competition from other Asian countries (with an even cheaper labor force), it allegedly started to rely increasingly on innovation in order maintain the competitiveness of its industry.

Thus, changes in Taiwan's economic and industrial environment may have provided Taiwanese firms with a strong incentive to innovate. Our empirical analysis of firms' choice of innovation strategy will therefore take into account, besides firms'characteristics, broader economic factors such as market structure or the growth of exportations in each industry. The paper is organized as follows: our first section is dedicated to the theoretical background, enriched by some stylized facts. The data and econometric modelling are presented in Sections 2 and 3 respectively, while Section 4 is dedicated to the results of the estimations. Conclusions are given in a final section.

1. Theoretical background and stylized facts.

The economic literature about the determinants of innovation (for a survey, see e.g. Cohen & Levin, 1989) rarely pays attention to the "innovative strategy", i.e. to the way through which firms acquire new knowledge. Internal R&D is generally considered as the only source of knowledge, thus the terms "innovation" and "R&D activity" are often used as synonymous. Moreover, with few exceptions (Caves 1976; Bozeman & Link, 1983), studies paying attention to innovation strategies often focus on firm's characteristics and are generally not concerned with the effects of broader economic factors (such as market structure) on innovation activity. We intend to combine these two strands of literature, in order to identify the determinants of firm' choice of innovation strategy.

Although there exist several different types of technology sources[1], the present research will focus on the importation of disembodied technology by Taiwanese firms, as an alternative/complement to internal R&D. "Disembodied" technology or knowledge here refers to these knowledge and technology that are protected by intellectual property rights, but can be purchased by a firm and included in its production process. These include patented technologies, licensed technologies and royalties-inducing technologies.

The importation of technology generally involves not only disembodied, but also embodied, knowledge. The latter can be embodied in newly-acquired assets, such as intermediate inputs, new machines, or new technical personnel. However, the flow of embodied knowledge is difficult to follow with the data available in Taiwan. Moreover, there is some empirical evidence (e.g. Basant and Fikker, 1996) that, in newly industrialized countries, licensing agreements with foreign firms are at least as important a source of technology as R&D. For these reasons, we will consider the importation of disembodied technology as the main alternative (or complement) to internal R&D.

Our objective is to test empirically the impact of three types of factors: (1) the industry-level factors (such as market structure) traditionally emphasized in microeconomic theory; (2) firms' characteristics and (3) broader economic factors associated with international trade, which may constraint the activity of Taiwanese firms.

1.1. Market structure and technological opportunities

According to classical industrial organization theory, innovations in product industries are largely determined by market structure. Following Schumpeter (1942), several studies have stressed the role of monopoly power in innovation activity. In principle, a monopolistic firm should be worried about the entry of potential rivals on its market, as this would cause a decrease of its monopolistic profit. This very threat thus gives the monopoly a strong incentive to remain alert and to innovative. While Arrow (1962) has contested the existence of a quasi causal-relationship between market structure and innovation, Dasgupta and Stiglitz (1980) have provided an alternative explanation for Schumpeter (1942)'s hypothesis: innovation and market structure would be codetermined by basic factors such as demand

[1] Bozeman and Link (1983) have established a list of alternative technology sources according to their relative importance: internal (or indigenous) R&D, purchase of new capital equipment, mergers and acquisitions, licensing from domestic & international firms, and government-sponsored R&D.

conditions, laws on property rights, and technological opportunities. In the short run, however, a causal relationship may exist.

The debate around Schumpeter's conjecture has led to a substantial amount of empirical research. Early studies (e.g. Hamberg, 1964; Scherer, 1967; Mansfield, 1968) often concluded that some degree of market power (measured by an index of industry concentration) tends to increase innovation (generally captured by R&D expenditures or R&D intensity). However, several authors (e.g. Scherer, 1967; Scott, 1984; Levin et al., 1985) have suggested that this relationship may be more appropriately represented by an inverted U-curve, which implies that a minimal amount of competition in an industry is necessary to foster innovation.

Later studies (e.g., Kamien and Schwartz, 1982) distinguish between *actual* and *anticipated* monopoly power, the latter referring to an innovator's ability to enjoy the full benefits of its research by preventing imitation. As Geroski (2001) underlines, the assertion that firms do R&D only if they expect that, by preventing imitation, they will be able to achieve some degree of market power and at least cover their costs is rather uncontroversial. However, Schumpeter's hypothesis is more questionable, as it states that an *actual* monopoly power will give a firm a direct and an indirect incentive to conduct R&D. The direct incentive occurs through the monetary returns to innovation, while the indirect incentive occurs via the control that the monopolistic firm can exert over the size of the returns to innovation. To test Schumpeter's hypothesis, Geroski (2001) develops an empirical model which control for both types of incentives. He finds that an actual monopoly power is likely to have a *negative* direct effect and a *positive* indirect effect on the decision to do research. Which one of these effects will prevail is uncertain, and thus the "net" effect of an actual monopoly power on the decision to conduct R&D remains uncertain.

According to the theoretical literature, the decision to innovate may also be influenced by firms' access to different *technological opportunities*, i.e. to different sets of technological knowledge. Microeconomic theory defines technological opportunities as the set of production possibilities which allows to translate research resources into new techniques of production employing conventional inputs. Dasgupta and Stigliz (1980), and Spence (1984), define technological opportunity as the elasticity of the unit cost with respect to R&D expenditures. Regardless of the definition, considering that firms face different "technological opportunities" allows to take into account the fact that firms' ability to innovate may vary across industries.

However, there is no consensus on how to make the concept of 'technological opportunity' empirically operational. To control for technological opportunity in the analysis of R&D activities, most studies use either conventional 2-digit industry dummies, or a set of dummy representing the degree of "closeness to science" of each industry (Scherer, 1965a; Link and Long, 1981; Levin et al., 1987; Lunn and Martin, 1986; Cohen et al., 1987; Cohen and Levinthal, 1989). Most studies conclude that the proxy variables representing "closeness to science" significantly contribute to explain inter-firm (or inter-industry) differences in R&D intensity. Other proxies used include the stock of knowledge (Griliches, 1979) and capital intensity at the industry level (Waterson and Lopez, 1983). The latter successfully explain inter-industry differences in R&D intensity in the United Kingdom. Finally, some authors (e.g. Braga and Willmore, 1991) suggest that export market generate more rigorous requirements of new technologies than domestic markets. Similarly, it has been suggested (Lall, 1983) that firms oriented towards foreign markets will be more aware of new technologies, and will strive to update their technological level.

Most studies generally expect a positive relationship between technological opportunities and R&D expenditures; at the very least, it is generally observed that controlling for technological opportunities generally affect the results regarding concentration and market power. When controlling for technological opportunities, some authors (e.g. Geroski, 2001) find that a high concentration is more likely to retard (rather than stimulate) innovation, while others (e.g. Lunn and Martin, 1986) go as far as to say that the effect of concentration is significant in "low opportunity" industries only.

1.2. Firms' characteristics and the decision to innovate

While, according to microeconomic theory, industry-level factors such as market structure and technological opportunities may influence firms' decision to innovate, the characteristics of individual firms may also be expected to have an impact. Many empirical studies have thus examined another hypothesis originally formulated by Schumpeter (1942): innovation activity is supposed to increase with firm size. Since innovation is generally quite costly, large firms are more likely to get both the financial resources required for risky R&D projects and the ability to spread risk by undertaking a "portfolio" of R&D projects. Moreover, economies of scale may arise from this large scale R&D activity. However, as firms grow large, research may become over-organized and efficiency may be undermined by bureaucracy and red tape. The underlying question here is that of optimal firm size.

The early empirical literature suggests that there exists a continuous and positive relation between firm size and innovation activity (generally measured by R&D intensity only). This positive, linear relationship has been observed in both industry-specific studies and in studies covering several industries (Mansfield, 1964; Grabowski, 1968; Soete, 1979;

Link, 1980; Meisel and Lin, 1983). It has been suggested, however, that the size-R&D relationship depends on the type of industry (Acs and Audretsch, 1987): large enterprises may be more innovative in hihjly concentrated sectors, while small firms may be more innovative sectors where the concentration is low (such as emerging technologies).

A more subtle, non-linear relationship, has been identified by a number of other researchers. Scherer (1965a, 1965b) suggested that R&D intensity increases more than proportionally with firm size; however, after reaching a certain threshold, the effect of firm size becomes either weakly negative or insignificant. This finding was widely accepted as a tentative consensus in the early 1980s (Malecki, 1980; Link, 1981; Scherer and Ross, 1990), and a non-linear relationship has also been found in other investigations. For instance, Bound *et al.* (1984), using U.S. data, found that very small and very large firms have a higher R&D intensity than average-sized firms.

Regarding the impact of firm size on innovation strategy, it has been suggested that, due to their higher internal R&D capabilities, larger firms may be able to absorb more effectively external technologies. They may be actively involved both in internal R&D and in the pursuit of external knowledge (Cohen & Levinthal, 1990; Aurora and Gambardella, 1990; Veugelers and Cassiman, 1999). Reciprocally, small firms may lack of R&D capacity, and may be forced to rely only on the adoption of simple technologies that can be integrated in the innovation process at a reasonably low cost (Caves, 1976). Although theoretical works do not offer clear predictions on that respect, some empirical evidence can be found in Bozeman and Link (1983), and in Veugelers and Cassiman (1999).

Apart from size, firms' age may also affect their decision regarding innovation. It has often been claimed that young firms, due to limited resources and/or experience, have a relatively low R&D capacity, and thus are more likely to rely exclusively on the purchase of technology when they innovate. Shan (1989) has shown that new biotechnology firms in the U.S. manage to innovate by acquiring external technology through cooperative agreements. A possible exception to this rule are the start-ups, which rely on highly specialized human capital in order to develop specific internal R&D. As will be explained in Section 2, our data does not allow to identify start-ups, but there were assumedly very few of those in Taiwan during the period we focus on in this study (the early 1990s).

Conversely, older firms, which have acquired a significant amount of experience in doing R&D, may be more reluctant to purchase knowledge when the technological context changes. Pisano (1990) has found some empirical evidence of such a behaviour in the case of U.S. biotechnology firms, and interpret this result as a 'proof' that firms tend to follow routines in their technology sourcing activity, a behavioural model which may contrast with that of forward-looking, profit-maximizing firms[2].

1.3. The impact of international trade

Taiwan doesn't have a long history of innovation. Until recently, the lack of investment in R&D closely related Taiwan to those newly-industrialized countries which rely mainly on labor-intensive products. However, since the late 1980s, Taiwanese firms found it more and more difficult to compete with low-cost producers located in China and in other Asian industrializing countries. As a result, Taiwan's government felt an urgent need to upgrade the country's industrial structure toward a high value-added, technology-intensive production. In that perspective, it can be said that pressure coming from international competition and trade has provided Taiwanese firms with an important incentive to innovate.

This intuition can build on stylized facts: Table 1 gives the ratio of the value of exportations to total sales by industry ("exportations intensity") in Taiwan for the years 1986, 1991 and 1996 (columns I, II, and III respectively), as well as the change in this ratio between these dates (columns IV and V). Depending on the industry, exportations intensity varies from less than 5% to more than 70%. For the sake of clarity, the various Taiwanese industries are regrouped into four industrial categories: "Electronic", "Metal and Machinery", "Chemical", and "Food, Textile and Other". The most exportation-intensive of these four sectors are the "Food, Textile and Other" industry and the "Electronic" industry. The 'basic industries' ("Metal and Machinery" and "Chemical and Process"), have comparatively low ratios, and thus tend to be more oriented towards the domestic market.

INSERT TABLE 1 ABOUT HERE

Regarding the changes in the exportations intensity ratio, more than 4/5 of the 21 industries reported in Table 1 experienced a decrease in their exportation share between 1986 and 1991. Traditional industries regrouped in the "Food, Textile and Others" category have experienced the most substantial decreases in the ratio. However, the overall decrease in Taiwan's exportations intensity apparently stabilized in the first half of the 1990s: only a little bit more than half of the 21 industries experienced a decrease between 1991 and 1996, and the magnitude of the decrease is much lower than in the previous period. Overall, Taiwan's industry can be said to have been challenged on the exportation market since the early 1980s. This challenge is more apparent in traditional industries, where the process of production usually relies on comparatively low-skilled workers.

[2] The notion of routine has been proposed by Nelson and Winter, (1982), p. 134.

Over the same period (i.e. the 1980s and 1990s), Taiwanese firms seem to have invested hugely in innovation: Figure 1 shows a steady growth of R&D expenditures and technology importations (both measured in millions of New Taiwan Dollars) over the 1982-2000 period. This growth becomes even more important (for both items) in the 1990s, with the investment on R&D always remaining higher than the purchase of technology. It thus makes sense to assume that Taiwan's industry found in innovation an answer to the difficulties it encountere on the international market.

INSERT FIGURE 1 ABOUT HERE

2. Data and variables

2.1. The MOEA panel and the DBAS data

This research used census data gathered by the Statistic Bureau of Taiwan's Ministry of Economic Affairs (MOEA). The Statistical Bureau of MOEA conducts a yearly census survey, and collects data on every plant in operation that holds a registered certificate in the manufacturing sector. This data covers all manufacturing industries in the Taiwanese economy. In Taiwan, most manufacturing firms are single-plant producers, so the distinction between plant and firm is not as relevant as in Western industrialized countries. Thus, we will refer to the MOEA data as "firm-level data" hereafter.

As was said in the previous section, the history of innovation in Taiwan is not a long one, the most important event being the industrial restructuring which took place throughout the 1990s, with a strong support from the government. Thus, when studying innovation in Taiwan, it makes sense to focus on the 1990s. When the present research was started, post-1997 data was not available. Moreover, the MOEA census was not conducted in 1991 and 1996. For these reasons, our research will focus on the 1992-1995 period only (this period will be referred to as the "observation period").

Over this period, we observed a panel of more than 27,000 Taiwanese manufacturing firms. The MOEA census data provides reliable information on firms' total R&D expenditures, as well as on the monetary value of imported technologies (i.e. new/recent technologies purchased by the observed Taiwanese firms on the international market between 1992 and 1995). We use this information to build our dependent variables, as will be explained in Section 3. Additional information available in the MOEA data includes (among other variables) firms' sales and number of employees. This information is used to build our explanatory variables, as is explained below.

Although the MOEA panel is a rich dataset, it does not keep track of the economic context of the 1990s. In order to get information on exportations, we had to combine the

MOEA data with industry-level data provided by the Directorate General of Budget, Accounting and Statistics (DGBAS) of Taiwan's Executive Yuan. The DABAS data comes from a large survey conducted every five years by the DGBAS, and available at the 4-digit industry level. This data records the monetary value of Taiwan's exportations (by 4-digit industry) in 1986, 1991 and 1996. The indicators computed with the DGBAS (growth rates of exportations) were added to the MOEA panel, where they can be used as industry-level control variables. The matching was made possible because the MOEA panel data precisely records the industry (4-digit) to which each firm belongs.

2.2. Explanatory variables

The explanatory variables that we will use in our econometric analysis have been defined in accordance with our theoretical background and stylized facts. Microeconomic theory often emphasizes market structure and technological opportunities as the most important determinants of the decision to innovate. The MOEA panel allowed us to build explanatory variables which directly refer to this classical theoretical framework. The most important of these variables, from a theoretical perspective, may be our indicator of market structure, the widely-used *Herfindahl index*, or *H index*:

(1) $$H_{jt} = \sum_{i=1}^{N} S_{ijt}^{2} ,$$

where S_{ijt} is the market share of firm i in industry j at year t[3]. The main advantage of the H index over more traditional measures (such as the *Concentration Ratio*) is that it takes all firms into account. Moreover, by squaring market shares, the *H* index weights more heavily the sales values of large firms, which allows for a more accurate measure of the largest sellers' shares (Scherer and Ross, 1990).

Our data didn't provide any measure of "closeness to science" by industry, so we will rely on classical 2-digit industry dummies to control for technological opportunities. As was said in Section 1, this is common practice in the literature. Regarding firms' characteristics, we were able to control for firm size ($Size_{it}$), which is represented by a 5-categories variable based on N_{it}, the number of employees of the i^{th} firm in year t:

(2) $$Size_{it} = \begin{cases} 1 \text{ if } N_{it} < 50 \\ 2 \text{ if } 50 \le N_{it} < 500 \\ 3 \text{ if } 500 \le N_{it} < 1000 \\ 4 \text{ if } 1000 \le N_{it} \end{cases}$$

[3] The market shares being expressed in percentage here, the H index would reach its maximum value of 10,000 in an industry with a single, purely monopolistic, firm.

By taking Category 2 as the reference, it is possible to control for the presence of non-linearity in the size-innovation relationship. We also include firms' age (Age_{it}), computed in years, among our explanatory variables. Finally, we include a dummy indicating, for each firm, whether it is a subsidiary, and a dummy indicating whether or not a given firm export technology. The rationale for including the later dummy is that firms exporting technology have better access to the international technology market, and as such have better information about which technologies are available for purchase, and about their potential application. This may affect their decision to import technology.

More generally, to represent the effect of changes on the export market on firms' decision to innovate, we calculate the growth of exportations in industry *j* over two subsequent periods (1986-1991 and 1991-1996), using information from the DGBAS:

(3) $$Grexp_{j91\text{-}86} = \frac{\exp_{j91} - \exp_{j86}}{\exp_{j86}}$$

(4) $$Grexp_{j96\text{-}91} = \frac{\exp_{j96} - \exp_{j91}}{\exp_{j91}}$$

where exp_{jt} is the export shipment in industry *j* at year t. These two indicators allow us to test for the possibility of both a simultaneous (growth of exportations between 1991 and 1996, which roughly correspond to the observation period of the MOEA panel) and lagged (growth of exportations between 1986 and 1991) impact of changes in exportations. Note that, while a decrease in exportations before 1992 may have provided Taiwanese firms with an incentive to innovate (in order to face harsher international competition), steady exportations over the observation period may (following the argument of Lall, 1983) have provided them with higher technological opportunities. By including a control for both the simultaneous and lagged effect of exportations, we hope to explore these hypotheses further. Finally, in order to control for the effect of exogenous economic fluctuations (business cycle, for instance) we include a time-specific effect (year dummies) in our list of covariates.

Table 2 gives summary statistics for all our explanatory variables. Our econometric estimations were performed first on the whole panel, and second on two high-tech industries (electronic and precision instruments). For the later estimation, we used 3-digit (rather than inappropriate 2-digit) industry-dummies; appropriate summary statistics for these dummies (and for the other explanatory variables) are also included in Table 2.

INSERT TABLE 2 ABOUT HERE

3. Econometric modelling

To investigate the innovation decisions of Taiwanese firms, we estimate a bivariate Probit model, implemented for panel data. We now define two dichotomous variables, RD_{it} and IT_{it}, so that:

RD_{it} = 1 if firm *i* does some R&D in period *t*, 0 otherwise

IT_{it} = 1 if firm *i* imports technology in period *t*, 0 otherwise

These two variables describe events that are *not* independent: a firm may import technology while conducting R&D. If one considers RD_{it} and IT_{it} as random variables, then their joint distribution will cover the four situations described below:

		IT_{it}	
		1	0
RD_{it}	1	(1, 1)	(1, 0)
	0	(0, 1)	(0, 0)

where (1, 1) correspond to the situation in which a firm is both doing R&D *and* importing technology ("mixed" strategy), (1, 0) to the situation in which a firm innovates only by doing R&D ("R&D only" strategy), (0, 1) to the situation in which a firm innovates only by importing technology ("IT only" strategy) and (0, 0) to the situation in which a firm does not innovate. These four situations constitute the choice set of firm *i* at time *t*.

Now, let us define two latent variables y^*_{it1} and y^*_{it2} such that:

$RD_{it} = 1$ if $y^*_{it1} > 0$, and 0 otherwise

$IT_{it} = 1$ if $y^*_{it2} > 0$, and 0 otherwise.

This leads to the following bivariate Probit specification:

(5) $$\begin{cases} y^*_{it1} = X_{it1}.\beta_1 + u_{i1} \\ y^*_{it2} = X_{it2}.\beta_2 + u_{i2} \end{cases}$$

where X_{itj} (j = 1, 2) is a vector of explanatory variables, and β_j (j = 1, 2) its associated vector of parameters (to be estimated). The errors terms u_{i1} and u_{i2} are supposed to follow a joint normal distribution, with mean 0, variance 1. The correlation coefficient of the error terms is denoted by ρ. The correlation of the error terms stems from the possible presence of omitted variables in the determinants of the firms' choices of innovation strategy, which would affect each equation. In our empirical application, the vectors X_{it1} and X_{it2} will be identical. Our bivariate Probit model was estimated by the conventional Maximum Likelihood technique.

The model is estimated first on the whole panel of more than 27000 manufacturing firms, and then on a group of approximately 2500 firms operating in the "high-tech" industries ("electronic" and "precision instruments"). The results of these estimations are presented in the next section. An alternative set of explanatory variables, involving a 3-years lag of the Herfindhal index rather than the "contemporaneous" index has also been implemented for the year 1995, on both the whole dataset and the "high-tech" industries. The lagged index wasn't significant; the results of the estimation of this "lagged" model is nonetheless presented in the Appendix, to allow for comparisons.

4. Results of the estimations

4.1. Estimation on the whole population

Table 3 presents the results of the estimation conducted on the whole population of 27754 firms. Overall, the decisions to do R&D and to import technology seem to be affected in much the same way by the same factors. One exception concerns the exportations: an increase in the growth rate of exportations over the 1986-1991 period would significantly spur R&D, while the importations of technology would be stimulated by an increase in the growth rate of exportations over the 1991-1996 period. It thus seems that the decision to do R&D has been influenced by the pressure from the international competition, whereas the decision to import technology is affected by the higher "technological opportunities" Taiwanese firms acquire when they confront themselves to the international market.

INSERT TABLE 3 ABOUT HERE

Firm size influences both decisions in a non-linear way: large firms (500 to 1000 employees) have a significantly higher probability to innovate, but very large firms (more than 1000 employees) as well as very small ones (less than 50 employees) have a significantly lower probability to innovate. This result is somewhat surprising, as it is the exact opposite of the conclusions Bound *et al.* (1984) infer from their research on U.S. firms. It might be explained by the specificity of Taiwan's industrial development, but nonetheless calls for further investigations.

Age also affects both decisions in a similar way: older firms have significantly lower probabilities to do R&D *and* to import technologies. This is consistent with the "entrepreneur mentality" that now prevails in Taiwan: older firms are typically turned towards the national market, and long had import help and support from the government. Younger firms tend to be more innovative, and are not afraid to try and sell their output on the international market.

Subsidiaries have a significantly higher probability to innovate; these firms are often subcontractors with large international companies (generally Japanese and American), for which they produce intermediate materials (e.g. electronic parts & components). The perspective to loose their contracts if they don't provide regurlarly upgraded material gives these firms a strong incentive to innovate. Finally, as expected, firms which export technology have a higher probability to innovate, either trhough R&D or thrhough the importation of technology. This is consistent with the notion that internationally-oriented firms have higher technological opportunities.

4.2. Estimation on the high-technology industries

Looking at the 2-digit industry dummies in Table 3 reveals that only firms operating in the electronic (D13) and chemical & petrochemical (D5, D6) industries have a higher probability to innovate than those operating in the "precision instruments" industry (D15, our reference). It thus makes sense to estimate our econometric model a second time, on the high-technology (i.e. electronic and precision instruments) industries only. We could have considered chemical industries as well, but we feel that the aforementioned high-technology industries are more archetypal of Taiwan's recent economic development. The results of this estimation are presented in Table 4.

INSERT TABLE 4 ABOUT HERE

For the sake of concision, we will focus our comments on the results which set the high-tech industries apart from the rest of the population. A first difference is that, in the high-tech industries, the growth rate of exportations do not affect the decision to do R&D, while it significantly decrease the probability to import technology. The second important difference concerns firm size: while the results regarding very small firms and large firms remain similar to those observed in the whole population, *very large firms* now appear to have a significantly higher probability to import technology. This may be caused by the larger amount of financial resources available to large firms.

The effect of firm age becomes insignificant in the high-tech industries; this may be because most high-technology firms are comparatively young, or, in other words, because age differences are less important among the population of high-technology firms. The most important result probably concerns market structure: while it didn't affect the decision to innovate in the whole population, the Herfindhal index now significantly increases both the probability to do R&D and the probability to import technology. Thus, in Taiwan high-tech industries, the assumption according to which a more concentrated market structure is correlated with a higher probability to innovate seems to hold.

4.3. Estimated probabilities

An interesting feature of the Bivariate Probit model is that it provides several types of estimated probabilities that are particularly relevant for our purpose. Table 5 presents these (averaged) probabilities for both the whole population and the high-tech industries. Due to the large proportion of firms that don't innovate (approximately 80% in the population and in the high-tech industries alike), it is not surprising to see that among the four probabilities described in Section 3, Prob(RD=0, IT=0) is the highest. Among the three possible innovation strategies ("R&D only", "IT only" and "mixed"), the probability to do R&D only is the highest in both the whole population and the high-tech industries. This probability is, however, twice as high in the high-tech industries as in the whole population.

INSERT TABLE 5 ABOUT HERE

The most interesting results in Table 5 are perhaps those regarding conditional probabilities: indeed, the probability to do R&D (conditional on importing technology) is rather high in both the whole population (0.43) and the high-tech industries (0.57). This result suggests that importing technology may be a necessary (but not sufficient) condition to do R&D in Taiwan. In other words, there might be some complementarity relationship between R&D and the importation of technology in Taiwan. Moreover, the probability to import technology (conditional on doing R&D) is close to zero in both groups; according to this result, it seems that Taiwanese firms do not generally conduct "adaptive" or "absorptive" R&D. This type of R&D, which is often needed in developng countries when it comes down to adapting advanced foreign technologies, does not seem to be required in a newly-industrialized country as Taiwan.

5. Conclusion

The objective of this paper was to identify the determinants of the decision to innovate in Taiwan, bringing together two strands of the economic literature on innovation: on the one hand, microeconomic research focusing on the (industry-level) determinants of R&D and, on the other hand, studies insisting on the existence of a plurality of modes of knowledge acquisition at the firm level. We distinguished three strategies (doig R&D only, importing technology only, and combining both) and estimated a Bivariate Probit on a panel of more than 27000 Taiwanese manufacturing firms observed from 1992 to 1995.

Results suggest that the decision to do R&D over the period was influenced by the prior changes in exportations, whereas the decision to import technology is affected by the current changes. Firm size is found to affect both decisions in a non-linear way, large (but not very large) firms having a significantly higher probability to innovate. Older firms are less incented to innovate, while market structure doesn't have any significant impact.

Focusing on the high-tech industries only brings important differences to the light: the effect of internation competition becomes weaker, while the positive effect of size on the probability to import technology is extented to very large firms (more than 1000 employees, which is very large in Taiwan). Most important, the effect of age is no longer significant, whereas the influence of market structure (as measured by the Herfindhal index) becomes apparent: a higher concentration increases both the probability to do R&D and the probability to import technology.

Finally, estimated probabilities provided by the Bivariate Probit specification shows "doing R&D only" as the preferred innovation strategy of Taiwanese manufacturing firms. Looking at the conditional probabilities (of doing R&D conditional on importing technology, and conversely) suggests the possible existence of complementarities between the two strategies, and the potential absence of "absorptive" or "adaptive" R&D in Taiwan. In other words, Taiwanese firms' R&D effort seems to strive towards substantive innovation, rather than to be simply dedicated to the adaptation of complex foreign technologies.

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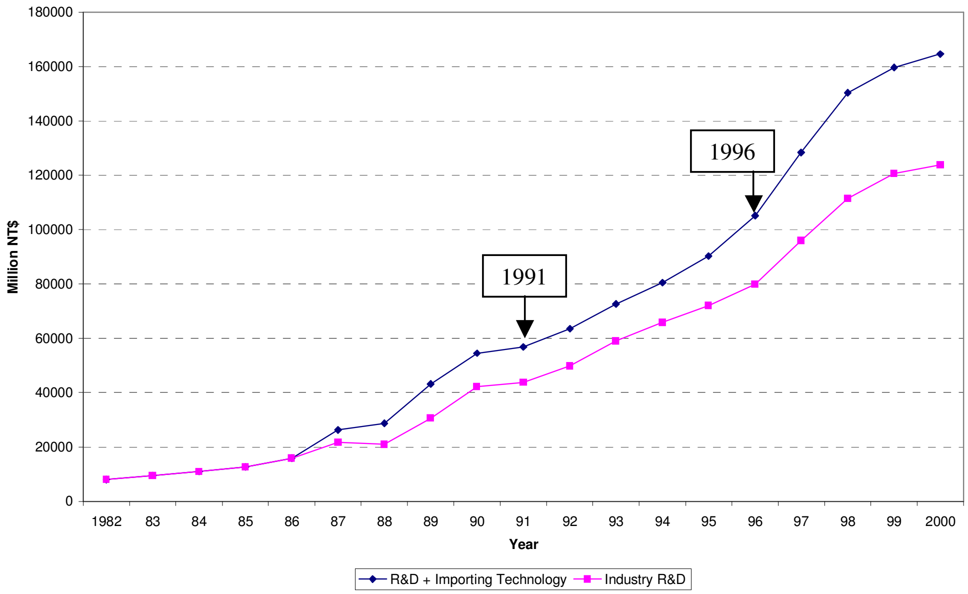
Table 1: Exportations Intensity (and variation) in Taiwan by Industry

Industry	*Exportations Intensity (%)*			*Variation in* EI	
	1986	1991	1996	1986-91	1991-96
	(I)	(II)	(III)	(IV)	(V)
Food, Textile and Other Industry	***52.4***	***36.4***	***29.4***	***-15.9***	***-7.0***
Food Manufacturing	26.3	19.4	18.3	-6.9	-1.2
Textile Mill Products	48.1	36.5	33.0	-11.7	-3.5
Wearing Apparel & Accessories	78.8*	58.2*	42.0*	-20.6	-16.2
Wood & Bamboo Products	51.7	24.6	19.2	-27.1	-5.5
Furniture & Fixtures	71.0*	49.7	36.5	-21.3	-13.2
Non-Metallic Mineral Products	19.8	10.4	7.2	-9.4	-3.2
Misc. Industrial Products	70.7*	56.3*	50.0*	-14.4	-6.4
Chemical Industry	***27.6***	***23.6***	***21.7***	***-4.0***	***-2.0***
Leather & Fur Products	71.4*	55.1*	42.6*	-16.3	-12.6
Pulp, Paper & Paper Products	7.1	10.6	10.7	3.4	0.2
Printing Processing	5.4	4.1	2.7	-1.4	-1.3
Chemical Matter Manufacturing	22.1	26.8	28.1	4.7	1.3
Chemical Products	11.0	13.4	13.6	2.4	0.2
Petroleum & Coal Products	5.6	3.3	8.5	-2.3	5.2
Rubber Products Manufacturing	45.6	42.7	39.7	-2.8	-3.1
Plastic Products Manufacturing	52.5	33.0	27.3	-19.5	-5.7
Metal and Machinery Industry	***28.1***	***19.4***	***20.5***	***-8.7***	***1.1***
Basic Metal Industries	11.7	9.7	12.2	-2.0	2.5
Fabricated Metal Products	39.4	24.5	22.1	-14.9	-2.4
Machinery & Equipment	34.6	25.9	27.8	-8.7	2.0
Transport Equipment	26.6	17.4	19.9	-9.2	2.5
Electronic Industry	***65.8***	***56.8***	***55.5***	***-9.0***	***-1.3***
Electrical & Electronic Machinery	66.8*	53.8*	55.8*	-13.0	2.0
Precision Instruments	64.8	59.7*	55.2*	-5.1	-4.6
Total	***39.6***	***30.2***	***27.2***	***-9.3***	***-3.0***

Note: a * denotes that the industry is one of the five highest in terms of export-intensity in each year.
Source: Directorate-General of Budget, Accounting and Statistics of Taiwan's Executive Yuan, *Report of Industrial and Commercial Census*, 1986, 1991,1996.

Figure 1 : R&D expenditures and importing technology in Taiwan (1982-2000)



Source: *Indicators of Science and Technology*, Taiwan.

Table 2: summary statistics

Variable	Definition	Whole population		Electronic & Precision	
		Mean	Std. Dev.	Mean	Std. Dev.
$Grexp_{91\text{-}86}$	Rate of growth of exportations between 1986 and 1991	0.22	1.08	0.23	0.78
$Grexp_{96\text{-}91}$	Rate of growth of exportations between 1991 and 1996	1.44	6.89	0.50	0.91
Size	Firm size (number of employees) small than 50	0.83	0.38	0.72	0.45
	Firm size (number of employees) between 50 and 100	0.15	0.36	0.23	0.42
	Firm size (number of employees) between 500 and 1000	0.01	0.08	0.02	0.14
	Firm size (number of employees) higher than 1000	0.02	0.13	0.02	0.14
Age	Firm's age in year	13.20	6.48	11.38	5.82
H	Herfindhal Index	0.05	0.07	0.05	0.05
Sub	1 if firm is subsidiary, 0 otherwise	0.13	0.34	0.17	0.38
ET	1 firm exports technology, 0 otherwise	0.00	0.04	0.01	0.08
	2-digits industry dummies (whole population)				
D1	1 if Food Industry (11), 0 otherwise	0.11	0.32		
D2	1 if Textile Industry (13), 0 otherwise	0.07	0.25		
D3	1 if Wearing Apparel, Leather, Wood, Furniture (14, 16, 17), 0 otherwise	0.08	0.27		
D4	1 if Paper & Printing (15, 18 or 19) and 0 otherwise	0.06	0.25		
D5	1 if Chemical Industry (21), 0 otherwise	0.02	0.15		
D6	1 if Chemical Products, Oil and Coal Products (22, 23), 0 otherwise	0.04	0.20		
D7	1 if Rubber Industry (24), 0 otherwise	0.01	0.11		
D8	1 if Plastic Industry (25), 0 otherwise	0.08	0.28		
D9	1 if Non-Metal Mineral Products (26), 0 otherwise	0.06	0.23		
D10	1 if Basic Metal Industry (27), 0 otherwise	0.05	0.23		
D11	1 if Fabricated Metal Products (28), 0 otherwise	0.12	0.32		
D12	1 if Machinery Industry (29), 0 otherwise	0.08	0.28		
D13	1 if Electronic Industry (31), 0 otherwise	0.07	0.25		
D14	1 if Transportation Industry (32), 0 otherwise	0.07	0.25		
D15	1 if Precision Instruments (33), 0 otherwise	0.02	0.14		
D16	1 if Miscellaneous (39), 0 otherwise	0.04	0.20		
	3-digits industry dummies (electronic & precision instruments industries)				
Electro1	1 if Power Supply Machinery, Wires and Cables (311), 0 otherwise			0.19	0.39
Electro2	1 if Electrical Appliances (312), 0 otherwise			0.10	0.30
Electro3	1 if Lighting Bulbs & Fixtures (313), 0 otherwise			0.12	0.33
Electro4	1 if Computer Hardware (314), 0 otherwise			0.05	0.23
Electro5	1 if Audio, Video & Electronic (315), 0 otherwise			0.09	0.29
Electro6	1 if Communication Equipment (316), 0 otherwise			0.04	0.21
Electro7	1 if Tube, Semi-Conductors and Electronic Components (317), 0 otherwise			0.15	0.36
Electro8	1 if Batteries (318), 0 otherwise			0.01	0.10
Precis1	1 if Scientific, Photographic & Optical instruments (331), 0 otherwise			0.17	0.37
Precis2	1 if Watches & Clock (332), 0 otherwise			0.05	0.22
Precis3	1 if Medical Equipment (333), 0 otherwise			0.02	0.15

Table 3 : bivariate Probit estimates on the whole population (27754 firms)

Variables		Prob(*RD* = 1)			Prob(*IT* = 1)		
		Coeff.	Std. Dev.	p-value	Coeff.	Std Dev.	p-value
Constant		-0.1283	0.0384	0.001	-1.4249	0.0772	0.000
$Grexp_{91-86}$		0.0312	0.0052	0.000	0.0168	0.0115	0.143
$Grexp_{96-91}$		0.0005	0.0010	0.621	0.0049	0.0020	0.012
Size	*Less than 50*	-1.2389	0.0133	0.000	-1.0471	0.0246	0.000
	500-1000	1.1312	0.0653	0.000	0.8595	0.0583	0.000
	1000 or more	-0.7201	0.0409	0.000	-0.1123	0.0552	0.042
	50-500	.	.	.	.	.	.
Age		-0.0082	0.0009	0.000	-0.0107	0.0017	0.000
H Index		-0.0875	0.0925	0.344	0.0127	0.1677	0.940
Subsidiary	*Yes*	0.4944	0.0146	0.000	0.2947	0.0251	0.000
	No	.	.	.	.	.	.
Export Techno	*Yes*	1.1124	0.1126	0.000	1.4459	0.1034	0.000
	No	.	.	.	.	.	.
Year effect	*1993*	0.0382	0.0164	0.020	-0.0997	0.0314	0.001
	1994	-0.0311	0.0168	0.064	0.0279	0.0300	0.353
	1995	-0.0098	0.0169	0.562	-0.1391	0.0329	0.000
	1992	.	.	.	.	.	.
D1		-0.2989	0.0389	0.000	-0.1869	0.0818	0.022
D2		-0.3497	0.0404	0.000	-0.3985	0.0869	0.000
D3		-0.7153	0.0458	0.000	-0.5666	0.1059	0.000
D4		-0.4488	0.0426	0.000	-0.2561	0.0893	0.004
D5		0.3248	0.0455	0.000	0.5007	0.0844	0.000
D6		0.3014	0.0418	0.000	0.5274	0.0809	0.000
D7		-0.1128	0.0589	0.056	0.3521	0.1021	0.001
D8		-0.4028	0.0407	0.000	-0.2551	0.0871	0.003
D9		-0.3180	0.0454	0.000	-0.1758	0.0941	0.062
D10		-0.3623	0.0432	0.000	-0.2148	0.0908	0.018
D11		-0.3310	0.0395	0.000	-0.1524	0.0833	0.067
D12		-0.1461	0.0394	0.000	0.0664	0.0812	0.413
D13		0.2337	0.0387	0.000	0.3156	0.0769	0.000
D14		-0.1296	0.0399	0.001	0.3754	0.0774	0.000
D16		-0.1340	0.0443	0.002	-0.2106	0.0977	0.031
D15		.	.	.	.	.	.

Log-likelihood: -34286.4170

A Wald test led to the rejection of the Null Hypothesis ($\beta_j = 0$) at the 1% level of significance.

The estimated value of ρ was found to be significantly different from 0 (LR test at the 1% level of significance).

Estimated value of ρ : 0.45 Standard Deviation: 0.01

Table 4 : bivariate Probit estimates on the high-technology group (2478 firms)

Variables		Prob(*RD* = 1)			Prob(*IT* = 1)		
		Coeff.	Std. Dev.	p-value	Coeff.	Std Dev.	p-value
Constant		-0.2233	0.0718	0.002	-1.2007	0.1099	0.000
$Grexp_{91-86}$		-0.0712	0.0878	0.417	-0.2839	0.1463	0.052
$Grexp_{96-91}$		0.0227	0.0422	0.590	-0.0250	0.0542	0.645
Size	*Less than 50*	-1.2029	0.0356	0.000	-1.0556	0.0623	0.000
	500-1000	1.2727	0.1804	0.000	0.9387	0.1048	0.000
	1000 or more	-0.1101	0.1124	0.327	0.4056	0.1217	0.001
	50-500	.	.	.	.	.	.
Age		-0.0021	0.0029	0.470	0.0020	0.0044	0.648
H Index		0.7126	0.3549	0.045	1.1386	0.6034	0.059
Subsidiary	*Yes*	0.5122	0.0401	0.000	0.1829	0.0601	0.002
	No	.	.	.	.	.	.
Export Techno	*Yes*	1.1531	0.2696	0.000	1.0572	0.1871	0.000
	No	.	.	.	.	.	.
Year effect	*1993*	0.0677	0.0455	0.137	-0.0726	0.0744	0.329
	1994	-0.0006	0.0465	0.990	0.0073	0.0732	0.920
	1995	0.0071	0.0470	0.880	-0.1777	0.0791	0.025
	1992	.	.	.	.	.	.
Electro2		0.1341	0.0658	0.042	-0.2552	0.1169	0.029
Electro3		-0.1337	0.0799	0.094	-0.5632	0.1553	0.000
Electro4		0.9561	0.2501	0.000	0.9058	0.3870	0.019
Electro5		0.1343	0.0940	0.153	-0.2298	0.1496	0.125
Electro6		0.3958	0.0983	0.000	0.0754	0.1449	0.603
Electro7		0.0543	0.1144	0.635	-0.4124	0.1876	0.028
Electro8		0.3599	0.1663	0.030	0.5469	0.2047	0.008
Electro1		.	.	.	.	.	.
Precis2		0.0550	0.0856	0.521	-0.0970	0.1603	0.545
Precis3		0.2165	0.1221	0.076	0.0020	0.2554	0.994
Precis1		.	.	.	.	.	.

Log-likelihood: -5020.7423

A Wald test led to the rejection of the Null Hypothesis ($\beta_j = 0$) at the 1% level of significance.

The estimated value of ρ was found to be significantly different from 0 (LR test at the 1% level of significance).
Estimated value of ρ : 0.44 Standard Deviation: 0.03

Table 5: Estimated Probabilities

	Whole population		High-Tech Group	
	Mean	Std Dev.	Mean	Std Dev.
Prob(RD=1, IT=1)	0.01	0.04	0.04	0.08
Prob(RD=1, IT=0)	0.10	0.12	0.20	0.17
Prob(RD=0, IT=1)	0.01	0.01	0.01	0.01
Prob(RD=0, IT=0)	0.88	0.15	0.76	0.24
Prob(RD=1 | IT=1)	0.43	0.16	0.57	0.19
Prob(IT=1 | RD=1)	0.05	0.06	0.08	0.09

Appendix : Bivariate Probit Model with 3-years lag of the H index

Table A : bivariate Probit on the whole population (27754 firms) for year 1995

Variables		Prob(*RD* = 1)			Prob(*IT* = 1)		
		Coeff.	Std. Dev.	p-value	Coeff.	Std Dev.	p-value
Constant		-0.0706	0.0775	0.362	-1.8511	0.2142	0.000
$Grexp_{91\text{-}86}$		0.0308	0.0108	0.004	0.0287	0.0220	0.192
$Grexp_{96\text{-}91}$		0.0017	0.0021	0.412	0.0056	0.0048	0.241
Size	*Less than 50*	-1.3341	0.0270	0.000	-1.1721	0.0578	0.000
	500-1000	1.0163	0.1277	0.000	0.8399	0.1191	0.000
	1000 or more	1.3789	0.2117	0.000	0.8804	0.1537	0.000
	50-500	.	.	.	.	.	.
Age		-0.0085	0.0019	0.000	-0.0075	0.0038	0.050
H Index Lag 3		-0.2581	0.1654	0.118	-0.1640	0.3907	0.675
Subsidiary	*Yes*	0.4624	0.0301	0.000	0.3306	0.0560	0.000
	No	.	.	.	.	.	.
Export Techno	*Yes*	0.4966	0.2334	0.033	1.5952	0.2152	0.000
	No	.	.	.	.	.	.
D1		-0.2705	0.0799	0.001	0.1379	0.2246	0.539
D2		-0.3477	0.0829	0.000	-0.1465	0.2328	0.529
D3		-0.6853	0.0945	0.000	-0.6971	0.3639	0.055
D4		-0.4325	0.0876	0.000	-0.0655	0.2445	0.789
D5		0.2690	0.0935	0.004	0.7246	0.2283	0.002
D6		0.3320	0.0855	0.000	0.8491	0.2222	0.000
D7		-0.0178	0.1175	0.879	0.7200	0.2557	0.005
D8		-0.3444	0.0840	0.000	-0.0464	0.2418	0.848
D9		-0.2912	0.0937	0.002	0.0087	0.2563	0.973
D10		-0.3756	0.0890	0.000	0.0920	0.2393	0.701
D11		-0.3436	0.0814	0.000	0.1001	0.2298	0.663
D12		-0.1923	0.0816	0.018	0.3511	0.2245	0.118
D13		0.2171	0.0794	0.006	0.5513	0.2153	0.010
D14		-0.1151	0.0817	0.159	0.6486	0.2164	0.003
D16		-0.1187	0.0911	0.193	0.0273	0.2633	0.917
D15		.	.	.	.	.	.

Log-likelihood: -7750.7633

A Wald test led to the rejection of the Null Hypothesis ($\beta_j = 0$) at the 1% level of significance.

The estimated value of ρ was found to be significantly different from 0 (LR test at the 1% level of significance).

Estimated value of ρ : 0.38 Standard Deviation: 0.03

Table B : bivariate Probit on the high-technology group (2478 firms) for year 1995

Variables		Prob(RD = 1)			Prob(IT = 1)		
		Coeff.	Std. Dev.	p-value	Coeff.	Std Dev.	p-value
Constant		-0.2394	0.1484	0.107	-1.4079	0.2473	0.000
$Grexp_{91-86}$		-0.1097	0.1795	0.541	-0.6537	0.3635	0.072
$Grexp_{96-91}$		0.1296	0.0884	0.143	-0.0888	0.1265	0.483
Size	*Less than 50*	-1.2604	0.0727	0.000	-1.2246	0.1553	0.000
	500-1000	1.0401	0.2886	0.000	0.8812	0.2077	0.000
	1000 or more	1.3692	0.4749	0.004	1.0253	0.2696	0.000
	50-500	.	.	.	.	.	.
Age		-0.0001	0.0059	0.988	0.0157	0.0096	0.102
H Index Lag 3		0.7578	0.8373	0.365	0.8689	1.7895	0.627
Subsidiary	*Yes*	0.5000	0.0823	0.000	0.0437	0.1368	0.750
	No	.	.	.	.	.	.
Export Techno	*Yes*	0.9105	0.6367	0.153	1.0817	0.4067	0.008
	No	.	.	.	.	.	.
Electro2		0.1086	0.1353	0.422	-0.1481	0.2514	0.556
Electro3		-0.0503	0.1649	0.760	-0.7951	0.4217	0.059
Electro4		0.8009	0.5208	0.124	1.9389	0.9618	0.044
Electro5		0.1155	0.1924	0.548	-0.5748	0.3495	0.100
Electro6		0.2776	0.2015	0.168	0.1527	0.3212	0.635
Electro7		-0.0448	0.2323	0.847	-0.6736	0.4356	0.122
Electro8		0.1150	0.3433	0.738	0.8971	0.4460	0.044
Electro1		.	.	.	.	.	.
Precis2		0.1292	0.1759	0.463	-0.2731	0.4771	0.567
Precis3		0.2788	0.2485	0.262	0.6618	0.5161	0.200
Precis1		.	.	.	.	.	.

Log-likelihood: -1142.6869

A Wald test led to the rejection of the Null Hypothesis ($\beta_j = 0$) at the 1% level of significance.

The estimated value of ρ was found to be significantly different from 0 (LR test at the 1% level of significance).

Estimated value of ρ : 0.40 Standard Deviation: 0.08