Innovation Strategy and Total Factor Productivity Growth: Micro Evidence from Taiwanese Manufacturing Firms

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Abstract :

This paper investigates the relationship between firms' innovation practices and performance in Taiwan. Using a panel of 4000 firms, we examine the effects of importing technology (versus doing R&D) on Total Factor Productivity (TFP) growth. The relationship between these two innovation strategies is also explored. We find that R&D strongly contributes to the growth of TFP, whereas the importation of technology has no significant effect. However, the interaction effect of R&D and the importation of technology is only weakly significant, which makes it difficult to qualify the type of relationship (complementarity or substitutability) that exists between the two innovation strategies.

JEL classification: D24, L10, L60, F20, C23

Keywords: Importation of technology; Newly industrialized countries; Productivity growth; Firm-level panel data; Manufacturing industries.

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1. Introduction

Since the beginning of the 1990s, Taiwan has been increasingly challenged by international competition, especially from other Asian developing countries. A steep rise in labor costs put a heavy pressure on the Taiwanese economy, while the adoption of a (managed) floating exchange rate made Taiwanese exported products less competitive on the international market. As a result, Taiwan had to speed up its industrial upgrading process. Industrial policies encouraging traditional firms to upgrade their technological level have been implemented. Other policies, promoting Research and Development (R&D) activities, have been designed to accelerate the development of high-technology firms – expected to play a leading role in the new Taiwanese economy. Such policies are expected to increase the productivity growth at the industry level.

Technology upgrading in a newly industrialized country, however, cannot totally rely on its own R&D effort, but may also involve importing new knowledge from foreign countries. The importer's technology capacity should nonetheless be consistent with the complexity level of imported technologies. The more sophisticated the imported technology is, the more likely it is that the importer has to conduct substantial research, in order to adapt or absorb the new technology.

Very few empirical studies have examined the relative impacts of importing technology and doing R&D on productivity growth. Moreover, little is known about the relationship (complementarity or substitutability) between these two innovation strategies. The present research uses a sample of more than 4000 innovation firms (collected from 21 two-digit manufacturing industries) to investigate these topics. The data set includes a range of industrial sectors that is larger than in most previous studies. The paper is organized as follows: Section 2 details the aims and scopes of the study. Section 3 describes our data. Our econometric model is developed in Section 4, with the results of the estimations being given in Section 5. A final section summarizes our conclusions.

2. Aims and scope of the study

The idea that imported foreign technology may affect industrial progress was first proposed by Caves and Uekusa (1976). Using data on Japanese industry between 1958 and 1968, they estimated a model of labor productivity growth in which they sought to separate the influence of domestic and foreign sources of new knowledge. They suspected that, over this period, Japan depended, for the bulk of its productivity growth, on flows of new technology from abroad. However, their statistical results failed to show any significant relationship between these two variables[1]. Using a cross-section sample of 370 Japanese manufacturing firms, Odagiri (1983) obtained similar results: the effect of purchasing technology on sales growth remained dubious.

Investigating how firms in developing countries may improve their productivity by purchasing foreign technologies is a more recent concern. Using a panel of Indian firms observed from 1974 to 1981, Basant and Fikker (1996) find that the importation of foreign technologies has a significant positive effect on productivity growth. This result is consistent across models (i.e. doesn't vary qualitatively with the specification of the underlying statistical model).

A closely related issue is whether the acquisition of external technology (at the firm, industry or country level) may constitute an alternative to internal R&D. If that is the case, identifying, in a given context, the most effective of these innovation strategies, becomes a concern of critical importance. However, doing R&D and

[1] They argued that the weak statistical result regarding the flow of technology imports was probably due to a poor measure of the proxy variable (total number of imported licensed technologies by the Japanese industry).

importing technology may also be, to some extent, complementary. Many authors (e.g., Caves and Uekusa, 1976; Link, Tassey *et al.*, 1983) argue that firms must maintain some R&D capacity in order to keep their long-run competitive stance. This capacity allow firms to know what technology is available, at a given moment in time, for purchase or copy. Firms may also come to rely on their research capacity to modify and adapt foreign technologies, in order to tailor them to their specific needs. These reflections have led to the critical distinction between “absorptive” and “creative” R&D, the latter being oriented towards original inventions, and the former being dedicated to the adoption of foreign technology only (Blumenthal, 1979; Cohen and Levinthal, 1989, 1990).

Empirical evidence on complementarity has been provided by several studies: Caves and Uekusa (1976), Blumenthal (1979), Branstetter and Sakakibara (1998), Arora and Gambaradella (1990), Cassiman and Veugelers (2000). They all confirm that there exist at least some degree of complementarity between the two innovation strategies we consider here. Other studies (Katrak, 1983; Odagiri, 1983; Siddharthan, 1988) suggest that this complementarity is stronger in low-technology industries, while a substitutability relationship may prevail in the public sector in some countries.

The examination of the relationship between internal R&D and the acquisition of external technology raises some methodological issues. Older studies used cross-sectional data to regress a measure of R&D on a set of covariates, including a proxy for the import of technology. The most recent ones (Basant and Fikkert, 1996; Cassiman and Veugelers, 2000) regress a measure of firms’ output (or performance) on a set of explanatory variables, that includes proxies for R&D and the importation of technology, as well as an interaction effect. If the two strategies are complementary, the interaction effect should be positive. However, if innovation activities are affected by unobserved variables, estimates may be biased (Athey and Stern, 1998). The use of panel (rather than cross-section) data may provide more accurate insights on complementarity, as it offers more opportunities to control for unobserved heterogeneity. In the present paper, a regression approach will be implemented on a panel of Taiwanese innovation firms, using a measure of productivity as the dependent variable.

The case of Taiwan seems particularly relevant to study the relationship between R&D and the importation of technology. In 1990, Taiwan's government pronounced the "statute for upgrading industries", a program designed to enhance the competitiveness of traditional industries and to speed up the development of high technology industries. This policy is conducted primarily by promoting firms' R&D, and secondarily by encouraging firms to buy technology from other countries. However, there has been a strong increase in the overall payment for foreign technology in Taiwan since the late 1980s, with the share of imported technology in total expenditures rising from 18.6% in 1987 to 20.6% in 1995 (NSC, 1998).

Although a country can import technology through many channels[2], the most important one in Taiwan in the 1990s has been technology trading with foreign companies, which involves mainly *disembodied knowledge*. Many major Taiwanese inventions thus make use of patents held by foreign companies. This in turn implies that the R&D conducted in Taiwan is mostly of an *adaptive* (or "absorptive") nature. In the 1990s, Taiwanese focused their R&D effort on improving the production process, promoting product quality, upgrading industrial design capabilities. In doing, they often came to adopt *and* adapt foreign technologies.

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[2] See Cassiman and Veugelers (2000) and Bozeman and Link (1983) for a description of the various modes of technology acquisition.

On the basis of these stylized facts, our empirical analysis will address two main questions: (1) does importing technology contribute to total factor productivity growth in Taiwan? (2) Is there a complementary or substitutability relationship between doing R&D and importing technology in Taiwan; if yes, how much does it contribute to the growth of productivity?

3. The Taiwanese MOEA Panel Data

This paper uses census data on innovation firms collected by the Statistics Department of the Taiwanese Ministry Of Economic Affairs (hereafter MOEA) between 1992 and 1995. An "innovation firm" is defined as a firm having reported innovation activities for at least one year during the period. "Innovation activities" here include: doing R&D (*RD*), importing technology (*IT*) and exporting technology (*ET*), the latter always co-occuring with either one or both of the first two activities.

The data was not available for years 1991 and 1996; prior to 1991 it is generally of poor quality at the firm level. Although the MOEA data provides plant-level information, it will be referred to as "firm-level data". In Taiwan, most manufacturing firms are single-plant producers, so the distinction between plant and firms is not as important as in many industrialized countries. The original population was of 5219 innovation firms, with information on sales, wages and size of the labor force, capital, raw materials, R&D expenditures, and technology trading (c.f. Appendix I for more details). All observations with missing values had to be deleted in order to obtain a balanced sample. This cleaning process yielded a sample of 4024 firms, which seems rather representative of the original population. In particular, the composition by industrial sector is very similar in both datasets (cf. Table 1).

Insert Table 1 about here

We used the MOEA data to build three indicators of innovation strategy. The "R&D only" strategy consists in relying on R&D as the only source of knowledge. Alternatively, the "importing technology only" strategy consists in relying on the acquisition of foreign knowledge. A firm adopting either one of these strategies will be said to follow a "single strategy". These firms can be opposed to those following a "mixed strategy", i.e. relying (simultaneously or sequentially) on several innovation activities : doing R&D, importing technology, and/or exporting technology. Table 2 gives a breakdown, by type of innovation strategy, of both the sample and the initial population. Again, this table suggests that the sample is fairly representative of the initial population, and that missing values resulted from a random phenomenon rather than from some selection bias.

Insert Table 2 about here

4. Econometric Modeling and Analysis

4.1. Empirical measure of Total Factor Productivity growth

Building on extensions of Solow's residual model[3], we develop an empirical model of productivity growth, which allows us to estimate the effect of the *growth* of the knowledge input on Total Factor Productivity (TFP) growth. For a given firm *i* in year *t*, *Q* denotes the output, *C* the stock of physical capital, *L* the labor input, *M* the intermediate materials, and *K* the stock of knowledge. The output is related to the inputs by a conventional Cobb-Douglas production function with no assumption on returns to scale:

$$Q_{it} = A.C_{it}^{\alpha}.L_{it}^{\beta}.M_{it}^{\gamma}.K_{it}^{\theta} \tag{1}$$

3 We refer to the model developed by Solow (1957), and its extensions: Griliches (1973), Terleckyj (1974), Mansfield (1980), Terleckyj (1980), Griliches & Lichtenberg (1984), Goto & Suzuki (1989).

Following Griliches and Lichtenberg (1984), we treat the stock of knowledge as a distinct factor of production; by doing so, we assume that θ represent the excess returns to knowledge. Equation (1) can then be rewritten as:

$$\frac{Q_{it}}{C_{it}^{\alpha}.L_{it}^{\beta}.M_{it}^{\gamma}} = A.K_{it}^{\theta} \tag{2}$$

Using a logarithmic transformation before differentiating Equation (2) with respect to time *t*, and using $\mu = \alpha + \beta + \gamma$, we have:

$$\frac{\dot{Q}_{it}}{Q_{it}} - (1-\beta-\gamma)\frac{\dot{C}_{it}}{C_{it}} - \beta\frac{\dot{L}_{it}}{L_{it}} - \gamma\frac{\dot{M}_{it}}{M_{it}} = \theta.\frac{\dot{K}_{it}}{K_{it}} + (\mu-1)\frac{\dot{C}_{it}}{C_{it}} \tag{3.a}$$

For our empirical purposes, we define the left hand-side of Equation (3.a) as the growth of Total Factor Productivity:

$$\frac{T\dot{F}P_{it}}{TFP_{it}} = \theta.\frac{\dot{K}_{it}}{K_{it}} + (\mu-1)\frac{\dot{C}_{it}}{C_{it}} \tag{3.b}$$

This definition is not as arbitrary as it may seem: it is a transposition of the classical definition of TFP (with constant returns to scale) to a situation where no assumption is made on returns to scales. The term $(\mu - 1).(\dot{C}_{it}/C_{it})$ is therefore *not* included in the empirical measure of TFP growth, but is included in the regression model, where it yields information on returns to scale.

Empirically, the growth of TFP is calculated using the following formula, derived from the left hand-side of Equation (3.a):

$$\begin{aligned}\frac{TFP_{i(t+1)} - TFP_{it}}{TFP_{it}} \equiv \frac{Q_{i(t+1)} - Q_{it}}{Q_{it}} &- \left(\frac{1}{4}\sum_{t=1}^{4}(1-\beta_{it}-\gamma_{it})\right).\frac{C_{i(t+1)} - C_{it}}{C_{it}} \\ &- \left(\frac{1}{4}\sum_{t=1}^{4}\beta_{it}\right).\frac{L_{i(t+1)} - L_{it}}{L_{it}} - \left(\frac{1}{4}\sum_{t=1}^{4}\gamma_{it}\right).\frac{M_{i(t+1)} - M_{it}}{M_{it}}\end{aligned} \tag{4}$$

where, for any given firm *i* observed at time *t*, β_{it} = (Wages)$_{\text{it}}$ / (Sales)$_{\text{it}}$ and γ_{it} = (Material expenditure)$_{\text{it}}$ / (Sales)$_{\text{it}}$.

4.2. A Regression Model of the Growth of Total Factor Productivity

Our econometric specification is derived from Equation (2):

$$\frac{Q_{it}}{C_{it}^{\alpha}.L_{it}^{\beta}.M_{it}^{\gamma}} = A.K_{it}^{\theta}.e^{\varepsilon_{it}} \tag{5}$$

where ε_{it} is a random error term. Following Griliches and Mairesse (1984), we decompose ε_{it} into a firm-specific effect u_i, an independent year effect (or "time fixed effect") ν_t, and a transitory effect ω_{it} (accounting for purely random disturbances). We thus write: $\varepsilon_{it} = u_i + \nu_t + \omega_{it}$ (cf. Griliches and Mairesse, 1984, footnote 5, p. 345).

Differentiating, with respect to time t, the log transform of Equation (5) eliminates the firm-specific effect and we get:

$$\frac{\dot{Q}_{it}}{Q_{it}} - (1-\beta-\gamma)\frac{\dot{C}_{it}}{C_{it}} - \beta\frac{\dot{L}_{it}}{L_{it}} - \gamma\frac{\dot{M}_{it}}{M_{it}} = \theta\frac{\dot{K}_{it}}{K_{it}} + (\mu-1)\frac{\dot{C}_{it}}{C_{it}} + \dot{\nu}_t + \dot{\omega}_{it} \tag{6.a}$$

where $\dot{\omega}_{it} = \omega_{i(t+1)} - \omega_{it}$ is a set of moving-average errors and where $\dot{\nu}_t = \nu_{t+1} - \nu_t$. Substituting Equation (3.b) in Equation (6.a) yields:

$$\frac{T\dot{F}P_{it}}{TFP_{it}} = \theta\frac{\dot{K}_{it}}{K_{it}} + (\mu-1)\frac{\dot{C}_{it}}{C_{it}} + \dot{\nu}_t + \dot{\omega}_{it} \tag{6.b}$$

Now, it comes from Equation (1) that θ is the elasticity of output with respect to the stock of knowledge, and can thus be written:

$$\theta = \frac{\partial Q_{it}/Q_{it}}{\partial K_{it}/K_{it}} = \frac{\partial Q_{it}}{\partial K_{it}}.\frac{K_{it}}{Q_{it}} \tag{7}$$

Substituting Equation (7) into Equation (6.b) and rearranging terms leads to:

$$\frac{T\dot{F}P_{it}}{TFP_{it}} = \rho.\frac{\dot{K}_{it}}{Q_{it}} + (\mu-1)\frac{\dot{C}_{it}}{C_{it}} + \dot{\nu}_t + \dot{\omega}_{it} \text{ where } \rho = \frac{\partial Q_{it}}{\partial K_{it}} \tag{8}$$

The term ρ denotes the marginal product of (or rate of return to) knowledge, which can be interpreted as the contribution of the change in the stock of knowledge to the growth of TFP. In earlier works (Griliches, 1973; Terleckyi, 1980), the ratio $\dot{K}_{it}/Q_{it}$ was written:

$$\frac{\dot{K}_{it}}{Q_{it}} = \frac{RD_{it} - \delta K_{it}}{Q_{it}} \tag{9}$$

where RD_{it} denotes R&D expenditures for firm i in year t, and δ denotes the average rate of depreciation of knowledge. Equation (9) simply means that knowledge is put to practical use in the firms' R&D effort. Griliches (1973), Terleckyi (1980), and Griliches & Lichtenberg (1984) assume that δ is close to zero, which allows them to express the growth of TFP as a function of R&D intensity. This can be done by setting δ = 0 in Equation (9) and substituting in Equation (8):

$$\frac{T\dot{F}P_{it}}{TFP_{it}} = \rho.\frac{RD_{it}}{Q_{it}} + (\mu - 1)\frac{\dot{C}_{it}}{C_{it}} + \dot{v}_t + \dot{\omega}_{it} \tag{10}$$

In the present study, however, the knowledge used in the firm's innovation process may have three possible sources: in-house R&D exclusively, acquisition of foreign technology exclusively, or a mix of both. Assuming the rate of depreciation of knowledge to be zero, this can be written as:

$$\frac{\dot{K}_{it}}{Q_{it}} = \frac{p_1.RD_{it} + (1-p_1).IT_{it}}{Q_{it}} + p_2.p_1.(1-p_1)\frac{RD_{it} \times IT_{it}}{Q_{it}^2}, \quad 0 \le p \le 1, 0 \le q \le 1 \tag{11}$$

where RD_{it} denotes, as previously, the R&D expenditures of firm i at time t, and IT_{it} denotes the spending on foreign (imported) technologies.

We assume that firms conduct in-house R&D (resp. import technology) with a probability p_1 (resp. $1 - p_1$), and that interaction effects between R&D and the purchase of technology occur with probability p_2. We thus obtain a general model of TFP growth by substituting Equation (11) in Equation (10):

$$\frac{T\dot{F}P_{it}}{TFP_{it}} = \rho_1.\frac{RD_{it}}{Q_{it}} + \rho_2.\frac{IT_{it}}{Q_{it}} + \rho_3.\frac{RD_{it} \times IT_{it}}{(Q_{it})^2} + (\mu - 1)\frac{\dot{C}}{C} + \dot{v}_t + \dot{\omega}_{it} \tag{12}$$

where $\rho_1 = \rho.p_1$, $\rho_2 = \rho.(1 - p_1)$ and $\rho_3 = \rho.p_2.p_1.(1 - p_1)$. No assumption is made regarding the value of μ -1.

The term $\dot{\omega}_{it}$, defined above as a set of moving-average errors $\omega_{i(t+1)}$ - ω_{it}, is iid and satisfies the usual assumptions of the Gauss-Markov theorem, while the term $\dot{v}_t$ is being represented by a set of period-specific dummies. Thus, Equation (12) can be estimated by the Ordinary Least Squares (OLS) method. The results of the three estimations are provided in the following section.

5. Empirical Results

Table 3 provides the means and standard deviations of all variables for the whole sample (12072 observations on 4024 firms) and for two sub-samples: the "single strategy" firms (9978 observations on 3326 firms), and the "mixed strategy" firms (2094 observations on 698 firms). "Single" and "mixed" strategies refer here to the definitions given in Section 3. The "single strategy" sub-sample is further divided in two groups of firms: those relying on R&D only (9423 observations on 3141 firms), and those relying on IT only (555 observations on 185 firms).

Insert Table 3 about here

We first consider the specific case where $p_2 = 0$ and estimate a model without interaction effect on the whole sample, on the mixed-strategy sub-sample and on the two single-strategy groups (RD only and IT only). In these two groups, we consider that $p_1 = 1$ and $p_1 = 0$ respectively. The model with an interaction effect ($p_2 > 0$) is estimated on the whole sample and the mixed-strategy sub-sample. In order to interpret our results in the light of the actual Taiwanese industry policy, the mixed strategy sub-sample was further divided in 3 groups, according to the type of industry: traditional, basic and high-tech. The exact composition of each group is given in Appendix III. Every regression incorporate 16 industry dummies to control for differences in technological opportunities across industries (Appendix II provides more detail about these industry dummies). An additional dummy (ET) controls for the effect of the exportation of technology, since firms that export technology may have specific innovations patterns, or be affiliates of multinational companies.

Table 4 presents the results of the estimation of Equation (12) when $q = 0$. Let us first remark that the estimated value of μ - 1 (i.e. the parameter associated to the growth of the capital input) is always negative, which suggests decreasing returns to scale in our production function. The intensity of internal R&D has a significant positive effect on the growth of TFP across all specifications. The returns to R&D expenditure are similar in the whole sample and in the "R&D-only" group. However, in the "mixed strategy" sub-sample, the effect of R&D intensity is twice as high as in the other groups. Although this result is rather difficult to interpret, it suggests that firms from this group may use R&D both as a source of new knowledge and as a mean to absorb recently acquired foreign knowledge.

Insert Table 4 about here

However, the coefficient associated to IT intensity is significant in the whole sample (and at the 10% level) only. The import of technology activity has no significant effect in any of the other specifications where it had been included. Moreover, the effect of the ET dummy is not significant in any group which suggest that firms exporting technology do face any specific advantage/disadvantage. It thus seems that innovation in Taiwan relies primarily on R&D. Combined with the comparatively strong effect of R&D in the mixed strategy group, the results regarding IT suggest that the importation of technology may be successful in Taiwan if and only if a significant amount of absorptive R&D is conducted. Overall, our results would thus plead for complementarity between both innovation strategies.

The model with an interaction effect, described by Equation (12) when $q > 0$, allows us to investigate this matter more deeply. The estimates of this model are provided in Table 5. Again, one can remark that exporting technology does not significantly influence firms' TFP, and that the negative value of (μ-1) suggests a production process in which returns to scale are decreasing. Finally, the time-specific effect is strongly significant in all specifications.

The interaction effect is significantly positive in the whole sample and in the High-Tech industry group. The effect of R&D intensity remains strongly positive in all groups, whereas IT intensity is insignificant in all groups. Overall, the results presented in Table 5 suggest that there may be a complementarity relationship between R&D and the importation of technology: while the latter doesn't seem to have any direct effect on the growth of TFP, the former may be of an absorptive nature (foreign technology being absorbed and put to use in further R&D activities). Another interpretation could be that the importation of technology has no effect whatsoever, and that the effect of the interacted being only weakly significantly, TFP growth in Taiwanese innovation firms is solely driven by R&D. Importing technology may thus be a requirement (to keep up with the technological level of western countries, for instance) that doesn't spur growth. Further research is needed to distinguish between these two conflicting interpretations.

Insert Table 5 about here

6. Conclusions

The objective of this paper was to evaluate the impact of innovation strategies on TFP growth among Taiwan's innovating firms. This was done by estimating an empirical model of productivity growth on a panel of 4000 innovation firms over the 1992-1995 period. One of the most original aspects the present contribution is that it considers two innovation strategies: doing R&D, and importing technology. Moreover, the nature of the relationship between these two strategies is thoroughly investigated. Our main finding is that R&D intensity has a strongly significant positive effect on the growth of Total Factor Productivity, regardless of the model specification, whereas the influence of IT intensity is overall insignificant.

Another important result is that the effect of the interacted term (R&D intensity × IT intensity) is overall insignificant, or only weakly significant. This result, which is strongly consistent across all industry groups, could be interpreted as an indication that the two innovation strategies are, to some extent, complementary. In that case, R&D would be both the main driving force of TFP, and a mean to absorb recent technological knowledge. This conclusion would echoe the findings of recent studies (Arora and Gambaradella, 1990; Cassiman and Veugelers, 2000). An alternative interpretation of that result is the significance of the interacted term is so weak that it could be ignored; in that case, the productivity growth of Taiwan's innovation firms would be solely driven by R&D. Further investigations are needed in order to choose between these conflicting interpretations.

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Table 1: distribution of innovative firms across industries (sample versus original population)

Code	Manufacturing Sector	Sample (4024 firms)		Original (5219 firms)	
		Number	*%*	*Number*	*%*
11	Food	337	8.4*	490	9.4*
13	Textile	311	7.7*	365	7.0*
14	Wearing apparel & accessories	53	1.3	69	1.3
15	Leather, Fur & Products	61	1.5	76	1.5
16	Wood, Bamboo Products	24	0.6	30	0.6
17	Furniture	115	2.9	144	2.8
18	Paper, Pulp	88	2.2	115	2.2
19	Print	38	0.9	61	1.2
21	Chemical Materials	197	4.9	238	4.6
22	Chemical Products	382	9.5*	441	8.4*
23	Petroleum & Coal Products	6	0.1	7	0.1
24	Rubber Product	60	1.5	75	1.4
25	Plastic Products	234	5.8	298	5.7
26	Non-Metal Miner Products	181	4.5	249	4.8
27	Basic Metal	207	5.1	258	4.9
28	Fabricated Metal Products	301	7.5*	413	7.9*
29	Machinery & Equipment	288	7.2*	414	7.9*
31	Electric & Electronic Machinery	566	14.1*	731	14.0*
32	Transport Equipment	307	7.6*	400	7.7*
33	Precision Instrument	109	2.7	139	2.7
39	Miscellaneous Industry	159	4.0	206	3.9
Total		4024	100	5219	100

Note: the * denotes that the industry is one of the seven most important in terms of % of the total.

Table 2: composition by type of innovation strategy (sample and original data)

Innovation strategy (1992-1995)	Sample (4024 firms)		Original (5219 firms)	
	Number	%	Number	%
Single strategy (I+II)	3326	83%	4391	84%
I. *R&D only*	*3141*	*78%*	*4143*	*79%*
II. *Importing Technology only*	*185*	*5%*	*248*	*5%*
III. Mixed Strategy	698	17%	828	16%
Total (I+II+III)	4024	100%	5219	100%

Table 3: Summary statistics

Variables	All firms	Single strategy		Mixed strategy
		R&D only	IT only	
	Mean (Std Dev.)	Mean (Std Dev.)	Mean (Std Dev.)	Mean (Std Dev.)
Labor Productivity (*q*) growth	0.20 (1.06)	0.20 (1.10)	0.201 (0.90)	0.17 (0.88)
Capital/Labor (*c*) growth	0.72 (3.15)	0.77 (3.33)	0.612 (2.53)	0.52 (2.44)
Material/Labor (*m*) growth	3.64 (9.51)	3.66 (9.62)	3.883 (10.3)	3.49 (8.80)
Labor (*L*) growth	0.12 (1.14)	0.12 (1.18)	0.18 (1.22)	0.11 (0.90)
R&D intensity (RD/Sales)	0.02 (0.04)	0.021 (0.04)	-	0.026 (0.04)
IT intensity (IT/Sales)	0.002(0.02)	--	0.017 (0.55)	0.01 (0.04)
ET dummy	0.02 (0.15)			
D1	0.083 (0.27)	0.091 (0.28)	0.050 (0.21)	0.059 (0.23)
D2	0.077 (0.26)	0.086 (0.28)	0.044 (0.20)	0.048 (0.21)
D3	0.062 (0.24)	0.073 (0.26)	0.050 (0.21)	0.021 (0.14)
D4	0.031 (0.17)	0.031 (0.17)	0.050 (0.21)	0.026 (0.16)
D5	0.048 (0.21)	0.042 (0.20)	0.033 (0.18)	0.080 (0.27)
D6	0.096 (0.29)	0.091 (0.28)	0.117 (0.32)	0.111 (0.31)
D7	0.014 (0.12)	0.012 (0.11)	0.016 (0.12)	0.025 (0.15)
D8	0.058 (0.23)	0.063 (0.24)	0.078 (0.26)	0.032 (0.17)
D9	0.044 (0.20)	0.047 (0.21)	0.028 (0.16)	0.038 (0.19)
D10	0.051 (0.22)	0.055 (0.22)	0.036 (0.19)	0.038 (0.19)
D11	0.074 (0.26)	0.075 (0.26)	0.101 (0.30)	0.049 (0.21)
D12	0.071 (0.25)	0.075 (0.26)	0.073 (0.26)	0.053 (0.22)
D13	0.140 (0.34)	0.117 (0.32)	0.101 (0.30)	0.245 (0.43)
D14	0.076 (0.26)	0.060 (0.23)	0.157 (0.36)	0.123 (0.32)
D15	0.027 (0.16)	0.029 (0.16)	0.012 (0.10)	0.022 (0.14)
D16	0.039 (0.19)	0.043 (0.20)	0.044 (0.20)	0.021 (0.14)
Observations	12072	9423	555	2094

Table 4: parameter estimates of the LP growth regression model (no interaction effect).

Variables	All firms (1)	Single Strategy		Mixed Strategy (4)
		Only RD (2)	Only IT (3)	
RD intensity	3.81 (0.46)***	3.04 (0.53)***	-	7.24 (0.87)***
IT intensity	1.84 (1.03)*	-	1.45 (2.02)	1.44 (1.22)
$\dot{C}/C$	-0.38 (0.008)***	-0.38 (0.009)***	-0.34 (0.05)***	-0.46 (0.03)***
$\nu_{93\text{-}94}$	-0.62 (0.05)***	-0.62 (0.06)***	-0.86 (0.31)***	-0.51 (0.11)***
$\nu_{94\text{-}95}$	-0.34 (0.05)***	-3.33 (0.06)***	-3.57 (0.31)***	-3.81 (0.11)***
$\nu_{92\text{-}93}$ *(ref.)*	-	-	-	.
ET dummy	0.05 (0.15)	-0.09 (0.23)	0.46 (0.73)	0.15 (0.18)
D1	0.10 (0.09)	0.12 (0.09)	-0.30 (0.56)	-0.03 (0.21)
D2	0.30 (0.09)***	0.24 (0.10)**	0.62 (0.64)	0.57 (0.22)***
D3	0.36 (0.10)***	0.31 (0.10)***	0.85 (0.61)	0.73 (0.36)**
D4	0.15 (0.13)	0.07 (0.15)	0.29 (0.57)	0.49 (0.30
D5	0.04 (0.11)	-0.05 (0.13)	0.50 (0.73)	0.24 (0.18)
D6	0.49 (0.08)***	0.51 (0.10)***	1.07 (0.42)**	0.28 (0.16)*
D7	0.13 (0.19)	0.45 (0.24)*	-1.30 (1.01)	-0.26 (0.30)
D8	0.14 (0.10)	0.12 (0.11)	-0.05 (0.50)	0.39 (0.27)
D9	0.43 (0.11)***	0.44 (0.12)***	0.26 (0.74)	0.43 (0.26)
D10	0.06 (0.11)	0.09 (0.12)	-0.49 (0.68)	0.02 (0.24)
D11	-0.01 (0.09)	-0.05 (0.10)	0.70 (0.45)	-0.07 (0.23)
D12	0.27 (0.91)***	0.28 (0.10)***	0.90 (0.51)*	0.008 (0.21)
D13	0.28 (0.07)***	0.27 (0.09)***	0.65 (0.44)	0.22 (0.12)*
D14	0.24 (0.09)***	0.24 (0.11)**	0.95 (0.37)**	0.07 (0.15)
D15*(ref.)*	-	-	-	-
D16	0.14 (0.12)	0.18 (0.13)	-1.26 (0.64)*	0.52 (0.34)
R^2	0.44	0.43	0.36	0.53
Adjusted R^2	0.44	0.43	0.34	0.53
Observations	12072	9423	555	2235

Standard errors are reported in brackets. Significance levels are: *10%, **5%, and ***1%.
For a complete description of the industry dummies, see Appendix II.

Table 5: parameter estimates of the LP growth model with interaction effects

Variables	All firms (5)	Mixed Strategy (6)	Traditional industries (7)	Basic industries (8)	High -Tech. industries (9)
RD intensity	3.67 (0.47)***	6.9 (0.93)***	11.41 (1.78)***	10.38 (2.86)***	4.95 (1.16)***
IT intensity	0.81 (1.19)	0.40 (1.57)	2.73 (5.71) (2.32)	-2.28 (2.96)	2.01 (2.10)
RD int* IT int	13.23 (7.47)*	8.25 (7.80)	-31.75 (51.61)	-2.73 (15.0)	17.88 (9.73)*
$\dot{C}/C$	-0.38 (0.008)***	-0.46 (0.03)***	-0.39 (0.05)***	-0.67 (0.07)***	-0.43 (0.03)***
$\nu_{93\text{-}94}$	-0.61 (0.05)***	-0.51 (0.11) ***	-0.57 (0.19)***	-0.36 (0.18)**	-0.490 (0.17)***
$\nu_{94\text{-}95}$	-3.42 (0.05)***	-3.80 (0.11) ***	-3.66 (0.20)***	-3.73 (0.18)***	-3.85 (0.17)***
$\nu_{92\text{-}93}$ *(ref.)*	-	-	-	-	-
ET dummy	0.05 (0.15)	0.16 (0.18)	-0.03 (0.37)	0.46 (0.41)	0.04 (0.24)
D1	0.10 (0.08)	-0.02 (0.21)	*(ref.)*		
D2	0.30 (0.09)***	0.57 (0.22)***	0.47 (0.22)**		
D3	0.36 (0.10)***	0.73 (0.36)**	0.66 (0.34)**		
D4	0.16 (0.13)	0.51 (0.30)*	0.30 (0.29)		
D5	0.04 (0.11)	0.24 (0.18)		*(ref.)*	
D6	0.49 (0.08)***	0.33 (0.16)*		0.23 (0.19)*	
D7	0.12 (0.19)	-0.27 (0.30)		-0.28 (0.32)	
D8	0.14 (0.10)	0.39 (0.27))		0.34 (0.30)	
D9	0.43 (0.11)***	0.44 (0.26)*	0.30 (0.25)		
D10	0.06 (0.11)	0.03 (0.24)		0.01 (0.26)	
D11	-0.01 (0.09)	- 0.06 (0.23)		-0.12 (0.25)	
D12	0.27 (0.09)***	0.02 (0.21)			0.07 (0.23)
D13	0.28 (0.07)***	0.24 (0.13)**			0.30 (0.15)**
D14	0.24 (0.09)***	0.08 (0.15)			0.10 (0.17)
D15	*(ref.)*	*(ref.)*			*(ref.)*
D16	0.14 (0.12)	0.53 (0.34)	0.36 (0.32)		
R^2	0.44	0.53	0.56	0.51	0.55
Adjusted R^2	0.44	0.53	0.55	0.50	0.54
Observations	12072	2094	435	720	939

Standard errors are reported in brackets. Significance levels are: *10%, **5%, and ***1%.
Note: the industry dummies that are not relevant for a given industry group (traditional, basic and high-tech) are indicated in the table by shaded gray cells.

Appendix I: Data and Variables

The data used in this paper is a compilation of the Industrial Census, collected by the Statistical Bureau of Taiwan's Ministry of Economic Affairs (MOEA) from 1992 to 1995. The Statistical Bureau of the MOEA conducts a yearly investigation and collects data on each operating plant that holds a registered certificate in the manufacturing sector. The investigation was suspended for years 1991 and 1996 while the Industrial and Commercial Census was hold by the Directorate-General of Budget, Accounting and Statistics of Taiwan's Executive Yuan. However, the Director General of Executive Yuan collects census data every five years on each plant in operation (registered or not). This data could not be included in our database, since it does not contain information on the value of foreign technologies purchases.

In any case, the Statistical Bureau of MOEA provides information on sales, employment (size of personnel, as well as total sum of gross wages), total value of fixed assets in operation at the end of the year, and total expenditures on raw materials. Furthermore, the Bureau of MOEA also provides information on R&D expenditures as well as on the "technological balance of payments at the plant level". This balance is defined as the value of exporting technology minus the value of importing technology.

In Taiwan, over 85 percent of the manufacturing firms are single-plant producers, according to Aw, Chung and Roberts (1998)[4]. In the sample used in this

[4] Aw et al. (1998) conduct an empirical study about productivity and the decision to export, using manufacturing data from the Directorate-General of Budget, Accounting and Statistics, Executive Yuan, Taiwan. In this data, over 95 percent of manufacturing firm in 1991 were single-plant producers, according to our own calculations.

work, over 70 percent of innovation firms are single-plant producers; hence, we refer to this data as “firm level data” in the main body of the present paper.

In our study, firms’ output is defined as firms’ sales deflated by a wholesale price index defined at the three-digit industry level. This price index was normalized to 1 in 1991. The wholesale price index was obtained from "*Commodity-Price Statistics Monthly in Taiwan,"* published by Directorate-General of Budget, Accounting and Statistics of Taiwan's Executive Yuan, 1996.

The labor input is defined as the number of employees. The capital input is measured by the total value of fixed assets in operation at the end of the year. The proxy for the materials input is the value of raw materials consumed per year, deflated by the intermediate input-output price index (defined at the two-digit industry level). The intermediate input-output price index was obtained from "*Commodity-Price Statistics Monthly in Taiwan,"* published by Directorate-General of Budget, Accounting and Statistics of Taiwan's Executive Yuan, 1996.

The R&D (*RD*) intensity is defined as the ratio of R&D expenditures to sales. Imported technology (*IT*) is defined as advanced technology obtained from abroad either through technology licensing (such as patents, trademark, licenses, and royalties) or technology instruction (such as technical training and consulting). The IT intensity is defined as the ratio of payments for imported technology to sales. Both *RD* and *IT* are remarkably stable over time, in the whole sample and in the various sub-samples (c.f. table below). The exported technology is defined as domestic technology provided to foreign buyers by way of technological cooperation, technology licensing, technology instruction and investing foreign hi-tech industries.

Evolution of mean R&D and IT intensities from 1992 to 1994

Year	Full Sample		Mixed strategy		Traditional		Basic		High-Tech	
	RD	IT	RD	IT	RD	IT	RD	IT	RD	IT
1992	0.03	0.003	0.03	0.01	0.02	0.01	0.02	0.01	0.04	0.01
	(0.06)	(0.02)	(0.07)	(0.04)	(0.08)	(0.03)	(0.04)	(0.05)	(0.08)	(0.04)
1993	0.02	0.002	0.02	0.01	0.01	0.004	0.02	0.01	0.03	0.01
	(0.04)	(0.02)	(0.04)	(0.02)	(0.03)	(0.02)	(0.03)	(0.01)	(0.05)	(0.03)
1994	0.02	0.003	0.03	0.01	0.02	0.01	0.02	0.01	0.04	0.01
	(0.05)	(0.02)	(0.05)	(0.05)	(0.03)	(0.04)	(0.03)	(0.05)	(0.07)	(0.05)

Figures in brackets indicate standard deviations

Appendix II: Industry Dummies

The industry dummies are defined at the two-digit industry level. The complete description of dummy variables is given in the table below :

The industry dummies*:	
D1:	(11) Food Manufacturing
D2:	(13) Textile Mill Products
D3:	(14) Wearing Apparel & Accessories (15) Leather & Fur Products, (16) Wood & Bamboo Products, and (17) Furniture & Fixtures
D4:	(18) Pulp, Paper & Paper Products, and (19) Printing Processing
D5:	(21) Chemical Matter Manufacturing
D6:	(22) Chemical Products, and (23) Petroleum & Coal Products
D7:	(24) Rubber Products Manufacturing
D8:	(25) Plastic Products Manufacturing
D9:	(26) Non-Metallic Mineral Products
D10:	(27) Basic Metal Industries
D11:	(28) Fabricated Metal Products
D12:	(29) Machinery & Equipment
D13:	(31) Electrical & Electronic Machinery
D14:	(32) Transport Equipment
D15:	(33) Precision Instruments
D16:	(39) Misc. Industrial Products

* Figures in brackets are 2-digit industry codes.

Appendix III: Industry Categories.

The Three Industry Categories

Traditional Industry:

(11) Food;
(13) Textile Mill Products;
(14) Wearing Apparel & Accessories;
(15) Leather & Fur Products;
(16) Wood & Bamboo Products;
(17) Furniture & Fixtures;
(18) Pulp, Paper & Paper Products;
(19) Printing Processing;
(26) Non-Metallic Mineral Products
(39) Misc. Industrial Products.

Basic Industry:

(21) Chemical Matter Manufacturing;
(22) Chemical Products;
(23) Petroleum & Coal Products;
(24) Rubber Products Manufacturing;
(25) Plastic Products Manufacturing;
(27) Basic Metal Industries;
(28) Fabricated Metal Products

High Technology Industry:

(29) Machinery & Equipment;
(31) Electrical & Electronic Machinery;
(32) Transport Equipment;
(33) Precision Instruments

Figures in brackets are 2-digit industry codes.