

# Export Market Participation, Investments in R&D and Worker Training, and the Evolution of Firm Productivity

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## 1. INTRODUCTION

**S**INCE the 1960s the countries in East Asia have achieved economic growth rates unsurpassed by any other group of countries in the world. During this period these countries actively embraced the globalisation of production and became successful competitors in international markets for a variety of manufactured goods. Substantial investments in both physical and human capital as well as gains in productivity have enabled these countries to meet the growing global demand for their exports. However, the extent to which the purposeful export orientation of these economies is related to their productivity growth remains an important open question.

Anecdotal evidence and numerous case studies performed in these Asian Tigers indicate that a key underlying source of their success lies in their effective assimilation of new and improved technology obtained from foreign purchasers of their exports.<sup>1</sup> However, econometric analyses of firm or plant-level data provide little evidence of any such learning-by-exporting. Several such studies, which use various methodologies and data sets, have concluded that the higher productivity generally exhibited by exporting firms can be better explained by

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<sup>1</sup> See Hobday (1995a) and Westphal (2002) for reviews of these studies.

the self-selection of more efficient firms into the export market rather than by any learning-by-exporting.<sup>2</sup>

These studies omit a potentially important element of the process of technical change, namely, the efforts by firms to absorb, assimilate and manage technical change. Researchers examining technological improvement in developing countries point to the critical role of investments, such as research and development and on-the-job training, that are undertaken by firms in order to assimilate newly-acquired technology from abroad.<sup>3</sup> Therefore, to understand the role of the transmission of technology from abroad, it is necessary to understand the heterogeneity of firms' in-house capabilities to assimilate new information. In this paper we estimate firms' discrete decisions to participate in the export sector and/or make investments in research and development (R&D) and/or worker training (WT) using a bivariate probit model. We then examine how participation in these activities influences a firm's future productivity trajectory using a selection model that accounts for the endogenous decision of a firm to exit production. Throughout the analyses we consider the potential complementarities between exporting and investing in R&D and worker training.

We estimate the model for the Taiwanese electronics industry using a panel data set constructed from firm surveys taken in 1986, 1991 and 1996. Questions regarding the assimilation of foreign technology are especially relevant in this Taiwanese industry because it is regularly cited as possessing the ideal characteristics for 'export-related technology transfer'.<sup>4</sup> In this industry a firm's ability to maintain global competitiveness hinges on its ability to continuously acquire and adapt new technologies. Many researchers working on technology development in East Asian countries have argued that the recent spectacular growth of

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<sup>2</sup> Clerides et al. (1998) use data from Colombia, Mexico and Morocco; Bernard and Jensen (1999) study US manufacturing firms; Aw et al. (2000) use data from Taiwan and South Korea; Bernard and Wagner (1997) for Germany; Liu et al. (1999) for Taiwan; Delgado et al. (2002) use data from Spain; Baldwin and Gu (2003) study Canada; and Greenaway and Kneller (2004) for the United Kingdom. All find evidence that more efficient producers self-select into the export market. Aw et al. (2000) also find evidence of productivity improvements following entry into the export market for a few Taiwanese industries. Baldwin and Gu (2003) find that there are subsequent productivity improvements (declines) for Canadian manufacturing plants that enter (exit) the export market. Greenaway and Kneller (2005) find that industry differences are an important marker for determining whether learning effects boost productivity after export market entry.

<sup>3</sup> Basant and Fikkert (1996), Bell and Pavitt (1993), Cohen and Levinthal (1989 and 1990), Dollar (1992) and Griffith et al. (2004) all emphasise that firm-level investments in absorptive capacity, such as R&D, have a complementary relationship with their acquisition of external sources of knowledge and stimulating innovation.

<sup>4</sup> This expression, attributed to Westphal (2002), refers to the transfer of technology that takes place through the export activity, such as when purchasers of exports transmit some of the technology required to fulfil their orders, in a way that significantly affects the technological development of the industry.

the industry would not have been possible without the combination of easy access to foreign technology and firms' efforts to assimilate this technology.<sup>5</sup> The electronics industry is also important because of its size and output growth. It is the largest industrial sector in Taiwan, accounting for over five per cent of GNP and 25 per cent of total exports between 1985 and 1988; furthermore, its output growth reached 37 per cent annually during the same period. High rates of export participation and large formal expenditures on both R&D and worker training, relative to other industries, make the electronics industry an appropriate focus of study of the interactions between exporting, R&D investment and productivity change.

Our results confirm a common empirical finding from the studies that use micro panel data to quantify the relationship between exporting and productivity. Export market participation exhibits significant persistence and is fundamentally related to firm-level variation in productivity. That is, firms with export experience, regardless of whether they also invest in R&D or worker training (WT), and firms with higher productivity are both more likely to export. This finding is consistent with the hypothesis that initial entry into the export market involves some sunk costs and that high-productivity firms are more likely to self-select into the export market.

We also find econometric evidence to support anecdotal and case study evidence suggesting that exporting firms benefit from technology that is transferred from foreign customers. While there are no complementarities between a firm's decision to export and invest in R&D/WT, these two activities do have complementary effects on a firm's future productivity. There is a robust, positive and statistically significant relationship between a firm's export market participation, with or without investments in R&D/WT, and its future productivity. Exporters that also invest in R&D/WT have significantly higher future productivity than firms that only export, a finding consistent with the view that expenditures on R&D and worker training facilitate a firm's ability to benefit from exposure to the export market.

Section 2 provides background regarding government policies toward export activities, R&D and worker training in Taiwan, a review of the relevant case study and econometric literature on learning-by-exporting and R&D/WT investments. We also provide a summary of exporting, R&D and worker training activities among the firms in our data. The theoretical framework underlying our empirical work is described in Section 3, followed by a description of the empirical model and the estimation results in Sections 4 and 5, respectively. The final section is a summary of the results and conclusions.

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<sup>5</sup> Hobday (1995b) and Westphal (2002) provide a case study of extraordinary export-related technology transfer in the electronics industry.

## 2. PATTERNS OF EXPORT PARTICIPATION, R&D AND WORKER TRAINING INVESTMENTS IN TAIWAN

The bulk of Taiwan's exports are made-to-order and sold under foreign buyers' brand names (see Hobday, 1995a). Case studies suggest that these foreign buyers, eager to purchase from a cheaper source, often provide Taiwanese manufacturers with product designs and technical assistance to upgrade their technology to meet international quality standards and specifications (see Evenson and Westphal, 1995; and World Bank, 1993). According to Gee and Kuo (1998), Taiwanese electronics firms benefited greatly from these new opportunities and gradually learned to design new products for different customers. To the extent that these contacts with foreign buyers lead to incremental and significant technological change, participation in the export market can be a source of productivity gains for the firm. In this paper, we treat exporting as both an outcome of a firm's profit maximisation decision as well as an investment intended to improve future productivity through learning-by-exporting.

However, building expertise or capability depends on more than just easy access to new technology. Research on the development of advanced technology in developing countries yields two principal messages relevant for our study. First, the most effective way of acquiring technological capability generally takes the form of continuous, incremental modifications, principally by firms, to adapt new technologies to fit specific situations or production conditions (Dosi, 1988; and Bell and Pavitt, 1993). Second, building technological capability depends fundamentally on firms' own investments in R&D and developing human resources and skills, particularly through on-the-job training (Cohen and Levinthal, 1989; Lucas, 1993; Hewitt and Wield, 1992; Mody, 1993; and Audretsch, 1995). According to these authors, R&D not only generates new information, but also enhances the firm's ability to assimilate and exploit existing information. Therefore, the productivity effect of knowledge gained through export experience may depend on the firm's own investment in R&D or worker training.

This facilitating role of R&D in improving firm efficiency has been recognised by many researchers. Griffith et al. (2004) use a panel of industries across 12 OECD countries and find evidence that R&D investments enhance technology transfer by improving firms' absorptive capacity. Consequently, industries in countries that lag behind the productivity frontier can catch-up particularly fast if they invest heavily in R&D. Klette (1996) also finds evidence among Norwegian manufacturing plants which suggests those plants with R&D investments in the past have higher productivity growth. Griliches (1979 and 1986) concludes that R&D contributes significantly to productivity growth, and that privately financed R&D expenditures have a significantly larger effect on private productivity and profitability than federally financed R&D. In Taiwan, private

investments in R&D and worker training have grown more quickly than public expenditures on the activities since the mid-1980s.

Aw and Batra (1998) is one of a few papers to analyse the interaction between exports and investments in R&D and worker training. Using firm-level cross-section data from the 1986 Taiwan Census of Manufactures, they find that the individual effects of the export activity and R&D/WT activity are positively and significantly correlated with an index of firm efficiency. Firms that simultaneously export and invest in R&D and worker training are about ten to 17 per cent more efficient than those that only export. Because their data are cross-sectional, the authors are unable to separate a firm's endogenous decision to export or invest in R&D from the effects of these activities on firm productivity. Finally, Baldwin and Gu (2004) use data on Canadian manufacturing plants to analyse the link between entry into export markets and increases in investments in R&D and training. They find that exporters are also more likely to invest in advanced technology to enhance their absorptive capacity.

#### *a. Taiwan Data*

To estimate the determinants of a firm's exporting and investments in R&D/WT and their subsequent effects on productivity evolution we would like micro data with sufficient cross-sectional and intertemporal variation in firm investments. The data we utilise are a survey of the larger and more technologically advanced firms in the electronics industry. Every five years the Statistical Bureau of Taiwan's Executive Yuan conducts a census of the Taiwanese manufacturing sector. Among the data collected are information on each firm's sales, total employment, value of capital stock, and expenditures on wages, materials and subcontracting. These data allow for the construction of a total factor productivity (TFP) measure for each firm. Since the observations in the cross-sections are linked across the years (1986, 1991 and 1996), these data can be used to track the evolution of a firm's productivity over time and track entry and exit patterns.

Since the census distinguishes domestic sales from foreign sales, it is possible to identify exporters and non-exporters and measure firms' export intensities. In each year a sample of firms are asked to provide information regarding their expenditures on R&D and worker training. R&D expenditures include those incurred to improve existing production technology, marketing, expenditures to upgrade the quality of sales and service, and in the development of new products. Thus, these expenditures reflect investments to reduce costs by improving the production process and to develop and introduce new and improved products. Worker training expenditures are defined as 'expenditures in on-the-job training of firm personnel, including salary and any costs incurred in improving employees' operational capabilities'. Since the census can be linked to the survey, it is possible to construct lagged TFP measures for firms that are not currently in the

TABLE 1  
Summary of Investment Activities among Taiwanese Electronics Firms

*Number of firms in each combination of activities (per cent of row total)*

<i>Year</i>	<i>Investment Activity</i>			
	<i>No R&amp;D/WT No Exporting</i>	<i>Only R&amp;D/WT</i>	<i>Only Exporting</i>	<i>Both R&amp;D/WT and Exporting</i>
1986	215 (22.42)	55 (5.74)	248 (25.86)	441 (45.99)
1991	713 (41.26)	90 (5.21)	508 (29.40)	417 (24.13)
1996	476 (33.50)	90 (6.33)	355 (24.98)	500 (35.19)

survey. In our paper we combine data on investments in R&D and worker training from the survey with data on export participation, inputs and outputs from the census to analyse the effects of these investments on a firm's TFP.<sup>6</sup>

The primary focus of the empirical analysis is to distinguish the locations of firms in the cross-sectional distributions and the role that characteristics of the firm in prior years (such as physical location, export participation, investments in R&D/WT) play in determining current investment decisions and productivity. The data provide information on the output and input variables that are necessary to measure TFP at the firm level: sales, employment, book value of the capital stock, and expenditures on labour and different types of intermediate inputs. Because there are, at most, only three time-series observations, 1986, 1991 and 1996, for a firm, we will not be able to make progress in identifying detailed lag structures or diffusion patterns between knowledge investments and productivity.

In the empirical analysis we combine expenditures on R&D and worker training into one variable, R&D/WT. We do so because only a small group of firms in each year chose to invest in one of the two activities but not the other, and thus it is difficult to identify the separate effects of the two activities in the empirical model. Instead, we focus on separating the effects of exporting from the effects of internal investments in either R&D or worker training.

Tables 1 and 2 present counts of firm participation patterns in these activities. Table 1 classifies each firm according to whether it participated in neither activity, export only, R&D/WT only, or both activities and reports the number of firms in the survey in each group in each year. In 1986, almost 52 per cent of all firms in the survey had expenditures on either R&D and/or WT and almost 72 per cent participated in the export market. In each year a substantial share of the exporting firms chose to invest in R&D/WT as well. Over the period covered by the panel, between 24 and 46 per cent participated in both activities, and between

<sup>6</sup> We measure TFP with the multilateral Tornqvist index developed by Caves et al. (1982). Details of our TFP measure are provided in Aw et al. (2001).

TABLE 2  
Transition Matrix of Investment Activities between Years  $t$  and  $t + 1$ , 1986–1996

<i>Number of firms (row proportion)</i>				
<i>Investment Activity Year <math>t</math> (number of firms in year <math>t</math>)</i>	<i>Year (<math>t + 1</math>)</i>			
	<i>Start R&amp;D/WT</i>	<i>Stop R&amp;D/WT</i>	<i>Start Exporting</i>	<i>Stop Exporting</i>
No R&D/WT and No Exporting (185)	24 (12.97)	–	50 (27.03)	–
Only R&D/WT (82)	–	36 (43.90)	42 (51.22)	–
Only Exporting (276)	73 (26.45)	–	–	52 (18.84)
R&D/WT and Exporting (530)	–	156 (29.43)	–	40 (7.55)

22 and 41 per cent of the firms in each year did not participate in either activity. Overall, the export activity was more prevalent among firms than participation in R&D and/or worker training. While 25 to 30 per cent of the firms in each year chose to export but not invest in R&D/WT, there are relatively few firms, approximately five per cent per year, that invested only in R&D/WT.

While Table 1 summarises firm investment behaviour in each cross-section, does not indicate how firm participation decisions persist or change over time, Table 2 summarises information about *changes* in firms' investment choices and illustrates how the initial state of investment activities is related to the decision to start or stop each activity. The columns in Table 2 report the number and share of firms that initiate or cease each investment activity in period  $t + 1$ , conditional on each firm's initial state in period  $t$ . For example, column 1 reports the number and proportion of firms in each of the four initial states that began investing in R&D/WT.

Two general transition patterns emerge from Table 2. First, regardless of their initial state, a higher proportion of firms begin exporting than initiate investments in R&D/WT and a lower proportion of firms cease exporting than cease investing in R&D/WT. For example, of the 185 firms that did not participate in either activity in the initial period, 27 per cent began exporting in the next period, whereas only 13 per cent began investing in R&D/WT. Of the 530 firms that participated in both activities in year  $t$ , only eight per cent ceased to export while almost 30 per cent stopped R&D/WT investments in year  $t + 1$ . Second, firms that participated in more activities in the initial year were less likely to cease their initial activity and more likely to have added an additional activity in year  $t + 1$ . For example, in column 2, while only 29 per cent of the firms that participated in both activities in the initial year ceased their investments in R&D/WT, almost 44 per cent of the firms that only invested in R&D/WT in the initial year ceased that activity. Similarly, in the next column, only 27 per cent of firms that did not participate in either activity in the initial year chose to start exporting. In contrast,

51 per cent of firms that invested in R&D/WT in the initial year chose to start exporting.

Taken together, we find evidence from simple counts of various activities in the panel data that history matters substantially in determining current investment choices. In particular, export participation demonstrates more persistence than R&D/WT investment behaviour and firms that participate in more activities initially are more likely to add new activities and less likely to cease their initial activity.

### 3. A THEORETICAL MODEL OF A FIRM'S INVESTMENT IN KNOWLEDGE

The links between investments in knowledge-producing activities and productivity have long been the subject of empirical research, beginning with the focus on the importance of R&D and on-the-job training in the productivity of firms in more advanced countries to the emphasis on export-related technology transfer in rapidly growing countries in East Asia. If new technologies diffuse from developed to developing country markets through firm contacts in the export market then an exporting firm may have higher productivity because foreign innovations become available to them or the contacts prevent wasteful duplication of the resources needed to duplicate the foreign innovation.

In this section we outline a theoretical model of a firm's investments in two types of activities that produce or acquire knowledge. The first type of activity includes investments in R&D or worker training that generate knowledge internally in the firm. The second type of activity includes investments in acquiring knowledge external to the firm and could include experience gained through the export market or membership in industry trade groups. The dividing line between these categories is not precise and we use them only as a useful shorthand for thinking about the range of activities the firm can undertake to increase its knowledge and expertise.

Our theoretical framework follows the model of physical investment and market participation developed by Olley and Pakes (1996) and we will only outline the key pieces needed for the estimating model here. We begin by treating R&D and worker training expenditures  $r_t$  in year  $t$  as a flow of investment that creates a stock of knowledge  $R_t$  through the accumulation equation  $R_{t+1} = \delta_r R_t + r_t$ , where  $\delta_r$  is the retention rate for internally-generated knowledge. Similarly,  $x_t$  is defined as the flow of investment devoted to acquiring knowledge from external sources and this produces a stock of externally-generated knowledge  $X_t$  through the accumulation equation  $X_{t+1} = \delta_x X_t + x_t$ .

These knowledge stocks enter directly into the firm's production function as productive inputs, along with a firm-specific productivity or efficiency level  $\omega$ . The productivity level  $\omega$  captures a number of factors including managerial

efficiency and output quality that can lead to differences in measured output, holding inputs fixed. The firm's production function is represented as  $y_t(V_t, \omega_t, R_t, X_t)$  where  $y$  is output and  $V$  are all inputs, both variable and fixed. The firm's short-run profit function is denoted as  $\pi_t(Z_t, \omega_t, R_t, X_t)$  where  $Z$  is a set of exogenous prices for output and variable inputs and the levels of any fixed inputs. In this formulation  $\omega_t, R_t, X_t$  effectively act as fixed inputs into the firm's production in year  $t$ .

In addition to their direct effect on output, the investments in internal or external knowledge acquisition can also affect the productivity level of the firm in future years by, for example, giving the firm access to a broader range of production techniques or allowing them to increase product quality. To capture this possibility, we assume the firm's productivity level evolves over time as a Markov process where the firm's investments in knowledge activities,  $r$  and  $x$ , shift the probability distribution of future productivity levels. Specifically, the evolution of firm productivity over time is represented by a distribution function:

$$F(\omega_{t+1}/\omega_t, r_t, x_t). \quad (1)$$

Conditional on current productivity, firms that make investments in  $r$  and  $x$  should have a more favourable distribution for their productivity level in the future.<sup>7</sup>

In each year  $t$ , an incumbent firm makes two decisions. The first is a decision to continue in operation or to exit production. The decision to continue is made by comparing the maximum of the sum of the future discounted profits with the scrap value that could be earned by exiting. Second, given that the firm remains in operation, they choose the optimal levels of the investments  $r_t$  and  $x_t$ . Olley and Pakes provide a characterisation of the optimal investment and shut-down decision of the firm. The solution to this optimisation problem generates a shut-down rule for the firm that takes the form:

$$S_t = 1 \text{ if } \underline{\omega}_t \geq \omega_t(R_t, X_t) \\ = 0 \text{ otherwise.} \quad (2)$$

$S_t$  is a discrete random variable that equals 1 if the firm remains in business in year  $t$ . It indicates that if firm productivity  $\omega_t$  is above a threshold level  $\underline{\omega}_t(R_t, X_t)$  then the firm will choose to remain in operation rather than take the scrap value

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<sup>7</sup> The model of Olley and Pakes (1996) assumes that the distribution of future productivity is only dependent on current productivity so that the firm has no direct effect on the evolution of its future productivity. Ericson and Pakes (1995) develop a theoretical model of market evolution in which the distribution of future productivity is dependent on both current productivity and a single continuous investment variable which the firm chooses.

and exit the industry. This discrete continuation decision will be one of the equations we estimate in the empirical section.

Second, the model produces demand equations for the two investment variables:

$$r_t = r_t(\omega_t, R_t, X_t, Z_t) \quad \text{and} \quad x_t = x_t(\omega_t, R_t, X_t, Z_t). \quad (3)$$

The period  $t$  state variables,  $\omega_t$ ,  $R_t$  and  $X_t$ , are determinants of the firm's decision to shut down, invest in R&D and export; equations (2) and (3). In addition, exogenous demand and cost shifters, including variable factor prices, output price and the levels of fixed factors contained in  $Z_t$ , are also determinants of profits and are necessary as controls.

#### 4. AN EMPIRICAL MODEL OF FIRM INVESTMENT, SURVIVAL AND PRODUCTIVITY

The empirical model consists of the investment-expenditure equations (3), the probability of firm survival equation (2), and the assumption about the determinants of productivity evolution equation (1). The general goal of the empirical model is to quantify the relationships between productivity, export participation and investments in R&D and/or worker training and to test if some of the intertemporal links do not exist. Given the hypothesised complementarities between R&D/WT investments and export participation, we are especially interested in empirical evidence about interaction effects between these variables.

##### *a. Export Participation and R&D/WT Investment Expenditures*

The theoretical model specifies a firm's export decision as a binary choice and its R&D/WT decision as a continuous choice. However, both decisions can be thought of as being either discrete or continuous. Non-convexities in the cost of R&D/WT may emphasise the discrete nature of that investment decision. Likewise, the sunk costs of export may vary with export intensity and introduce a continuous dimension to the export decision. Recognising these possibilities we first treat a firm's decisions to invest in R&D/WT and participate in the export market as discrete choices and analyse the effects of the firm's state variables on these joint decisions. Second, for firms that participate in each activity, we estimate the effect of the state variables on the intensity of their investments in R&D/WT or exports. Thus, we examine how the state variables affect both a firm's probability of participating in the activities as well as its scale of participation.

Equation (5) specifies that firm  $i$ 's decision to invest in R&D/WT in year  $t$  depends on its stock of R&D and worker skills,  $R_{it}$ , as well as its stock of export experience,  $X_{it}$ , at the beginning of year  $t$  as well as other profit-shifting firm characteristics. Given that these stock variables are not observable, we proxy

them with dummy variables that indicate which combination of the export and R&D/WT activities each firm chose in the previous year,  $t - 1$ .<sup>8</sup> The theoretical model specifies that a firm's discrete export participation decision also depends on its stocks of R&D/WT and export experience. In addition, each decision depends on  $\omega_{it}$  and the  $Z^d$  and  $Z^f$  variables that determine the firm's profit given their investment and export decisions.

We estimate a standard bivariate probit model where R&D/WT investment and exporting are treated as two separate binary decisions. The export and R&D/WT equations can be written as:

$$\begin{aligned} I(\text{Export}_{it}) = & a_0 + a_t + a_1 \log(a_{it}) + a_2 I(E_{it}) + a_3 \log(k_{it}) \\ & + a_4 \log(\text{pwage}_{it}) + a_5 I(\text{multiplant}_{it}) + a_6 \omega_{it} + a_7 (\omega_{it})^2 \\ & + \sum_{k=1}^3 f_k I(\text{Choice}_{it-1}^k) + \sum_{k=1}^3 g_k \omega_{it} I(\text{Choice}_{it-1}^k) + \varepsilon_{it} \end{aligned} \quad (7)$$

$$\begin{aligned} I(\text{R\&D/WT}_{it}) = & b_0 + b_t + b_1 \log(a_{it}) + b_2 I(E_{it}) + b_3 \log(k_{it}) \\ & + b_4 \log(\text{pwage}_{it}) + b_5 I(\text{multiplant}_{it}) + b_6 \omega_{it} + b_7 (\omega_{it})^2 \\ & + \sum_{k=1}^3 h_k I(\text{Choice}_{it-1}^k) + \sum_{k=1}^3 l_k \omega_{it} I(\text{Choice}_{it-1}^k) + \varepsilon_{it}, \end{aligned}$$

where  $I(\text{Export}_{it})$  is an indicator variable for firms that export and  $I(\text{R\&D/WT}_{it})$  is an indicator variable for firms that invest in R&D. This specification does not include any source of intertemporal correlation but it does allow the contemporaneous correlation between the two choices,  $\text{Corr}(\varepsilon_{it}, \varepsilon_{it})$ , to be non-zero.<sup>9</sup>

The explanatory variables, in order, are a constant term, year dummy, the log of the firm's age, a dummy variable equal to one if the firm was an entrant between year  $t - 2$  and year  $t - 1$ , the log of the firm's capital stock, the log of the firm's average production worker's wage, a dummy variable equal to one if the firm has multiple plants. These right-hand-side variables capture the demand and marginal cost shifters specified by  $Z^d$  and  $Z^f$  in the theoretical model. The remaining explanatory variables are productivity, productivity squared, three dummy variables,  $I(\text{Choice}_{it-1}^k)$ ,

<sup>8</sup> This dynamic discrete choice specification is identical to a model in which the decision to invest is subject to a sunk cost that must be paid prior to investment. Roberts and Tybout (1997) develop a discrete model of firm diversification that leads to the discrete decision to participate being a function of the lagged participation decision. The regression coefficient on the lagged participation variable is a measure of the size of the sunk cost of entry. In this case a non-zero coefficient on lagged R&D or lagged worker training is consistent with sunk costs of adjustment on each variable.

<sup>9</sup> We also used a multinomial probit model to specify the probability of choosing each of four possible combinations of the two discrete investment choices of R&D and export activities. This specification is much richer in that it accounts for the inherent relationships between the activities through a very flexible error structure. However, the results of the multinomial model are very similar to the bivariate specification with very few exceptions that will be pointed out in the discussion of the empirical results.

$k \in \{1, 2, 3\}$ , that capture investments in R&D/WT and/or participation in the export market in year  $t - 1$ . Finally, there are three interaction terms that capture potential relationships between the past discrete choices and current productivity.

*b. Firm Survival and Productivity Evolution*

The theoretical model specifies that firms make their endogenous exit decisions based on their state variables, which include their current stocks of R&D/WT and export experience as well as the other profit shifters that enter into their investment decisions. Since their expected profit in year  $t + 1$  can be written in terms of their year  $t$  state variables we specify a model that predicts the probability that the firm remains in operation in year  $t + 1$  as:

$$\begin{aligned} S_{it+1} = & \eta_0 + \eta_t + \eta_1 \log(a_{it}) + \eta_2 I(E_{it}) + \eta_3 \log(k_{it}) + \eta_4 \log(k_{it})^2 \\ & + \eta_5 \log(\text{pwage}_{it}) + \eta_6 I(\text{multiplant}_{it}) + \eta_7 \omega_{it} \\ & + \sum_{k=1}^3 \eta^k I(\text{Choice}_{it}^k) + \sum_{k=1}^3 \eta^{kk} \omega_{it} I(\text{Choice}_{it}^k) + \xi_{ijt+1}. \end{aligned} \quad (8)$$

The theoretical model developed in Section 3 assumes that a firm's productivity evolves according to the Markov process specified in equation (2). An important element of the theoretical model is that the productivity evolution process is conditional on a firm's investments in R&D/WT and export market participation. In a special case of this formulation used by Hopenhayn (1992) and Olley and Pakes (1996), a firm's productivity follows an exogenous Markov process and a firm's investments play no role in altering the distribution of future productivity. The more general formulation used here, which allows the distribution of a firm's future productivity to shift with the firm's investment in R&D/WT or participation in the export market, is consistent with the theoretical model of Ericson and Pakes (1995). The empirical specification of equation (2) estimates the marginal contribution of current investments in R&D/WT and export market participation to the mean level of a firm's productivity in year  $t + 1$  while controlling for the firm's current level of productivity. The productivity equation is specified as:

$$\omega_{it+1} = \gamma_0 + \sum_{k=1}^3 \gamma_k I(\text{Choice}_{it}^k) + \gamma_4 \omega_{it} + v_{it+1}. \quad (9)$$

An additional complication arises when estimating the productivity process. Because we only observe  $\omega_{it+1}$  for the firms that survive to period  $t + 1$ , the estimated coefficients of the model may suffer from a selection bias if random factors that affect a firm's survival to period  $t + 1$  also affect its productivity in that year. For example, an unobserved firm-specific demand shock that boosts current productivity may induce the firm to remain in the market and thus introduce correlation between survival and future productivity. To correct for this bias

TABLE 3  
Discrete Investment Activity Equation

<i>Bivariate probit estimates</i>		
<i>Variables</i>	<i>Exporting</i>	<i>R&amp;D/WT</i>
intercept	-3.377 (0.647)*	-6.749 (0.626)*
year dummy	0.137 (0.108)	0.023 (0.096)
entrant dummy	0.647 (0.162)*	0.593 (0.199)*
log(age)	0.128 (0.070)	-0.209 (0.069)*
log( $k_{it}$ )	0.383 (0.038)*	0.496 (0.036)*
log( $pwage_{it}$ )	-0.319 (0.104)*	0.114 (0.100)
multiplant dummy	0.067 (0.127)	0.035 (0.111)
productivity ( $\omega_{it}$ )	1.120 (0.356)*	0.524 (0.283)
productivity squared ( $\omega_{it}^2$ )	-0.631 (0.272)*	-0.138 (0.215)
lagged Choice 1 dummy Exporting and R&D/WT	1.270 (0.297)*	0.711 (0.251)*
lagged Choice 2 dummy Exporting but not R&D/WT	0.921 (0.239)*	0.206 (0.263)
lagged Choice 3 dummy R&D/WT but not exporting	-0.130 (0.423)	0.329 (0.425)
( $\omega_{it}$ ) * lagged Choice 1 dummy	-0.036 (0.652)	0.193 (0.416)
( $\omega_{it}$ ) * lagged Choice 2 dummy	0.829 (0.464)	-0.045 (0.415)
( $\omega_{it}$ ) * lagged Choice 3 dummy	-0.599 (1.049)	0.246 (0.929)
Corr( $\varepsilon_{it}$ , $\varepsilon_{it}^*$ )	0.287 (0.059)*	

Notes:

\* Statistically significant at the  $\alpha = 0.05$  level.

Sample size = 1,384; all equations contain three-digit industry dummy variables.

we employ Heckman's sample selection framework and jointly estimate the survival equation (8) and productivity evolution equation (9) using maximum likelihood. The model includes one additional parameter, the  $\text{Corr}(\xi_{it+1}, v_{it+1})$ , which measures the correlation between the errors in the survival and productivity equations. Both equations also include a set of three-digit industry dummies to control for industry-level differences in the failure and productivity growth rates. The selection equation includes a set of plant-level variables ( $I(E_{it})$ ,  $\log(a_{it})$ ,  $\log(k_{it})$ ,  $\log(k_{it})^2$ ,  $\log(pwage_{it})$ ,  $I(\text{multiplant}_{it})$ ) that are omitted from the productivity equation and aid in identification.

## 5. EMPIRICAL RESULTS

### *a. Investment Equations*

The results of the bivariate specification are reported in Table 3. Firms with export experience, either on its own or in conjunction with R&D/WT experience, are more likely to export in the current period. While firms that have experience in both activities are more likely to invest in R&D/WT in the current period, experience in R&D/WT on its own has no significant effect on either current

decision. The interactions between  $\omega_{it}$  and a firm's past choices are insignificant in both equations. Recent entrants are significantly more likely to participate in either activity, firms with more capital are more likely to engage in either activity, and higher productivity increases the value of exporting for the firm but does not significantly affect the value of investing in R&D/WT. The diminishing effect of productivity in the export decision is significant, and the negative effect of higher production wages is also significant.<sup>10</sup> This is consistent with the hypothesis that firms that pay higher production wages are less competitive in the export market. The estimated value of  $\text{Corr}(\varepsilon_{x_{it}}, \varepsilon_{r_{it}})$  is a positive 0.287 and statistically significant. Shocks that lead a firm to participate in one activity tend to lead it to participate in both.

While the discrete choice models inform us about a firm's decisions to participate in the export market or invest in R&D/WT, they say nothing about the intensity with which firms engage in these activities. In contrast to the discrete choice models, it is difficult to construct useful measures of interactions between a firm's chosen export and R&D/WT intensities. Therefore, in assessing the effect of the state variables on a firm's R&D/WT and export intensities, we focus on a separate equation for each choice. We measure a firm's R&D/WT intensity as the share of total revenue that is invested in R&D and/or worker training. A firm's export intensity is similarly defined as the share of total revenue that it derives from exports. We replace the three lagged choice dummies with two lagged intensity measures and estimate each equation using only the firms that participate in the respective activities.<sup>11</sup> While this specification eliminates the possibility of errors correlated across the choices, we do retain the random firm effect. The estimated results of the two intensity equations are reported in Table 4.

Two differences in the Table 4 results stand out when compared to the probit specifications. First, while capital is an important determinant of a firm's discrete decisions to participate in the R&D/WT and export activities, it plays no significant role in determining the intensities of those that do participate. Second, while firms with high  $\omega_{it}$  are more likely to participate in the export market, productivity is either not significant (in the export intensity equation) or significantly negative (in the R&D intensity equation).<sup>12</sup> The latter finding is consistent with the prediction of the theoretical model that high productivity firms may have less

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<sup>10</sup> In the multinomial specification, the coefficient on the average production worker's wage and the diminishing effect of productivity in the export decision are not statistically significant. All other results from the multinomial specification are consistent with those from the bivariate model.

<sup>11</sup> An alternative would be to specify two Tobit equations that would each estimate both the discrete and continuous participation and investment decisions. However, the results from this specification are very similar to the bivariate probit results reported in Table 3.

<sup>12</sup> Aw et al. (2000) find a significant positive relationship between firm productivity and participation in the export market for Taiwanese electronics firms, but no relationship between productivity and export intensity.

TABLE 4  
Investment Shares among Firms with Positive Investment

<i>Random effects estimates</i>		
<i>Variables</i>	<i>Export Share of Revenue</i>	<i>R&amp;D/WT Share of Revenue</i>
intercept	0.806 (0.135)*	0.058 (0.040)
year dummy	0.015 (0.018)	0.021 (0.005)*
entrant dummy	0.157 (0.030)*	-0.027 (0.008)*
log(age)	0.011 (0.017)	-0.035 (0.005)*
log( $k_{it}$ )	0.002 (0.007)	0.001 (0.002)
log( $pwage_{it}$ )	-0.033 (0.022)*	0.011 (0.006)
multiplant dummy	-0.044 (0.023)	0.002 (0.007)
productivity ( $\omega_{it}$ )	0.056 (0.064)	-0.083 (0.020)*
productivity squared ( $\omega_{it}^2$ )	-0.062 (0.051)	0.037 (0.017)*
export revenue share $t - 1$	-0.062 (0.051)	-0.014 (0.009)
R&D revenue share $t - 1$	0.190 (0.284)	-0.456 (0.056)*
sample size	987	649
fraction of variance due to firm effect	0.705	0.833

Notes:

\* Indicates statistically significant at the  $\alpha = 0.05$  level with a one-tailed test.  
All regressions include three-digit industry dummies.

incentive to invest intensively because the return to further investments is low. It may be that some minimal investment in R&D/WT is necessary to maintain a firm's absorptive capacity, but that the return on investments intensity diminishes with the firm's productivity.

Finally, the results on the lagged intensity measures differ from those in the probit specifications. While past participation in R&D/WT investments had no significant effect on any current investment decisions in the discrete choice model, firms that made more intensive investments in R&D/WT in the previous period tend to invest less intensively in those activities today. This could reflect diminishing returns to these activities or an investment process in which periods of high investment are followed by periods of low investment. Given the five-year gap between our time observations, however, it is not possible to sort out these explanations. Similarly, firms that were intensive exporters in the past tend to export less intensively today although this coefficient is not statistically significant. There is little evidence of complementarities in that past intensity in one activity has no significant effect on a firm's current intensity of the other activity. Overall, the investment shares appear much less systematic and more likely to be driven by firm-specific unobservable factors than the discrete decision to engage in the activity. Year-to-year fluctuations in investment intensity are more likely to reflect noise than are the fluctuations in participation patterns and we prefer the discrete investment equations for this reason.

*b. Firm Survival and Productivity Evolution*

The second part of the empirical model focuses on the effect of these investments on the firm's survival and future productivity growth. The estimated parameters reported in Table 5 indicate the determinants of a firm's survival. The theoretical model predicts that higher productivity firms are more likely to survive. When all other factors are accounted for, current productivity does improve a firm's chances of survival, but the 0.290 estimated effect is only significant at the ten per cent level. Both entrant status and capital stock are important determinants of a firm's survival. Recent entrants are more likely to fail, a finding that is consistent with many firm-level empirical studies in both developed and developing countries. Firms with larger capital stocks have a higher probability of remaining in operation and this is likely to reflect the fact that firms with large

TABLE 5  
Survival Equation Estimates

<i>Maximum likelihood estimation of selection model</i>	
<i>Dependent Variable: <math>S_{t+1}</math></i>	
<i>Variables</i>	<i>Coefficient Estimates</i>
intercept	-3.964 (1.171)*
year dummy	0.108 (0.081)
entrant dummy	-0.225 (0.086)*
log(age)	-0.021 (0.060)
log $k_{it}$	0.520 (0.198)*
(log $k_{it}$ ) <sup>2</sup>	-0.018 (0.008)*
log( <i>pwage<sub>it</sub></i> )	0.118 (0.080)
multiplant dummy	-0.025 (0.080)
productivity ( $\omega_{it}$ )	0.290 (0.158)
Choice 1 dummy Exporting and R&D/WT	-0.042 (0.126)
Choice 2 dummy Exporting but not R&D/WT	-0.076 (0.104)
Choice 3 dummy R&D/WT but not Exporting	0.084 (0.189)
<i>Industry Dummies</i>	
power generation	0.986 (0.218)*
electrical appliances	0.418 (0.187)*
wire and cable	0.576 (0.201)*
lighting	0.223 (0.200)
repair	0.836 (0.206)*
video and radio equipment	0.314 (0.174)
electronic parts and components	0.657 (0.172)*
wired communication equipment batteries	0.468 (0.209)*
non-electronics	1.123 (0.229)*
batteries	0.393 (0.308)

Note:

\* Statistically significant at the  $\alpha = 0.05$  level.

capital stocks are more likely to be able to cover their variable costs. The negative and significant coefficient on  $\log(k_{it})^2$  indicates that this effect is diminishing in firm size. Beyond its entry status, a firm's age does not have a significant effect on its survival and multi-plant firms are no more likely to survive than single-plant firms. The positive and significant coefficients on the industry dummies indicate that there is substantial variation in survival rates across more disaggregated electrical product industries.

The results on the prior investment variables indicate that firm survival is generally not significantly related to prior exporting or R&D/WT investments. These findings are not consistent with the theoretical model, which predicts that participation in these activities affects a firm's survival decision. It also contrasts with the findings of Bernard and Jensen (1999) who find that, while export experience played little role in a firm's productivity growth in US data, it did improve a firm's probability of survival. However, the insignificance of participation in R&D/WT and export found in our data may be due to the length of time between our observations. Over the span of five years there are many opportunities for shocks to drive a firm out of the market.

Table 6 reports the coefficient estimates for the productivity evolution equation. The positive and significant coefficient on current productivity (0.280) fits with the predictions of the theoretical model. In the theoretical model firms draw their  $\omega_{it+1}$  from the distribution,  $F(\omega_{it+1}/\omega_t, r_t, x_t)$ . The empirical result can be viewed as the effect of changes in  $\omega_t$  on the mean of this distribution such that firms with higher current productivity will, on average, have higher future productivity. The significant coefficient on the year dummy captures the general productivity growth between 1991 and 1996.

The coefficients on the firm's prior discrete export participation and R&D/WT investment decisions support the hypothesis that R&D/WT and export experience have complementary effects on a firm's productivity. The argument put forth in both the case study and theoretical literature is that firms that invest in R&D and worker training are better equipped to absorb the ideas and technologies supplied by the foreign buyers. Therefore firms that invest in R&D/WT in addition to exporting should experience an additional return on their exposure to the export market.

The coefficient estimates in Table 6 indicate that the complementarities exist. The coefficient on Choice 3 (only investing in R&D/WT) is positive but insignificant, which indicates that such investments do not have a significant long-lasting effect on a firm's productivity. However, the positive and significant coefficient on Choice 2 indicates that firms that only export in the current period have 4.2 per cent higher productivity, on average, five years later. The coefficient on Choice 1 is also significantly different from zero, and indicates that firms that participate in both activities have, on average, 7.8 per cent higher productivity in the next period. In addition, a Wald test reveals that the coefficient on Choice 1

TABLE 6  
Productivity Evolution

*Joint maximum likelihood estimation of selection and productivity evolution models*

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*Dependent Variable:  $\omega_{t+1}$*

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<i>Variable</i>	<i>Coefficient Estimates</i>	
intercept	0.182 (0.063)*	0.179 (0.068)*
year dummy	0.074 (0.016)*	0.072 (0.016)*
productivity ( $\omega_t$ )	0.279 (0.034)*	0.311 (0.060)*
Choice 1 dummy Exporting and R&D/WT	0.078 (0.020)*	0.077 (0.032)*
Choice 2 dummy Exporting but not R&D/WT	0.042 (0.019)*	0.060 (0.030)*
Choice 3 dummy R&D/WT but not Exporting	0.047 (0.034)	0.115 (0.055)*
( $\omega_t$ ) * Choice 1 dummy		-0.004 (0.080)
( $\omega_t$ ) * Choice 2 dummy		-0.066 (0.083)
( $\omega_t$ ) * Choice 3 dummy		-0.263 (0.161)
Corr( $\xi_{it}, v_{it}$ )	-0.152 (0.213)	-0.182 (0.222)
log likelihood	-926.998	-923.288
sample size	1,779	1,779

Notes:

\* Indicates statistically significant at the  $\alpha = 0.05$  level with a one-tailed test.  
All regressions include three-digit industry dummies.

is significantly different from the coefficient on Choice 2 at the five per cent level. This indicates that firms that combine R&D/WT and export participation experience a larger productivity increase than the firms that only export. This result is consistent with the claim that firms that invest in R&D/WT are better able to absorb the knowledge gained from exporting.

As suggested by the results of the bivariate probit specifications, high-productivity firms may gain more than low-productivity firms from participating in each investment activity. Therefore, one would expect that a firm's return to each activity (in terms of higher future productivity) to depend on its current productivity. This hypothesis can be tested by including interactions between  $\omega_{it}$  and each of the three choice dummies in the model. The results of this alternative specification are reported in the second column of results in Table 6. The intercept, year dummy and productivity coefficients in the second results column are similar to those in the first column. While the coefficient on Choice 1 remains relatively unchanged, the coefficients on Choice 2 and Choice 3 increase and are now statistically significant. Although not statistically significant, the negative coefficients on the interaction terms between  $\omega_t$  and the three choices are consistent with the prediction that higher productivity firms benefit less from participating in these activities than do lower productivity firms. The combined effect of the choice dummies and their interactions indicate that, for the average firm with  $\omega_t = 0.258$ , there is still a significant difference between the effect of

exporting only (Choice 2) and exporting in conjunction with R&D/WT (Choice 1) at the six per cent confidence level. For firms with higher productivity this difference becomes even more significant. This indicates that the contributions of R&D and worker training to a firm's absorptive capacity depend on its current productivity.

The final result of the empirical model indicates that unexplained shocks that increase a firm's chance of survival are negatively correlated with its future productivity if it does survive ( $\text{Corr}(\xi_{it}, v_{it}) = -0.152$ ). However, the standard error on the estimated correlation is 0.218 and a likelihood ratio test cannot reject the hypothesis of independence between the survival equation and the productivity evolution equation. Therefore, it appears that the issue of the endogenous exit of firms has little effect on the parameters of the evolution equation.<sup>13</sup> One additional empirical issue that arises in such a model is the possibility of serial correlation in the error terms. Differences in productivity may induce firms to make other investments or decisions that would have lasting effects on the evolution of their productivity. The effect of these unaccounted-for actions could result in serially correlated errors and a biased coefficient on  $\omega_i$ . We perform a modified Breusch-Godfrey test for serial correlation of the error terms by regressing the estimated errors on their lagged values. We find no evidence to suggest that the errors are serially correlated.

Our key results from the estimation of the productivity evolution equation are twofold: first, firms with higher investments in exports, with or without R&D/WT, have higher future productivity; second, the returns, in the form of higher future productivity, are almost twice as large for firms that export and invest in R&D/WT relative to those that only export. The first result is consistent with learning-by-exporting among large Taiwanese electronic firms and the second result is consistent with the view that export-related technology absorption is facilitated by investments in R&D/WT.

## 6. SUMMARY AND CONCLUSIONS

Many observers have suggested that the success of the Asian economies is at least partly based on their substantial export sectors. Beyond the gains from trade associated with specialising in areas of comparative advantage, these economies are thought to have benefited from a significant transfer of technology from the

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<sup>13</sup> Because the sample selection is not critical to the estimation, we also estimate the productivity evolution equation using a random effects model that does not account for the selection bias. The results of this alternative specification are very similar to the results presented in Table 8. The only difference is that the coefficient on Choice 3 (R&D/WT only) is significant while it is not significant in the first column of Table 8.

developed countries of the world. In this paper we develop a theoretical and empirical model linking export market participation, investments in R&D and worker training, and firm productivity, and quantify the relationships using firm-level data for the Taiwanese electronics producers.

In the theoretical model, a firm's productivity evolves over time in a way that depends on initial productivity, current investments in R&D and worker training, and experience gained in the export market. Each firm makes decisions to remain in operation, invest in R&D and participate in the export market. All of these decisions are affected by the firm's initial productivity level. The empirical model consists of equations for the firm's R&D investment, export market participation, survival and productivity evolution. The R&D and export decisions are treated as discrete and modelled with the bivariate probit model. The productivity evolution equation is estimated while controlling for the selection bias that arises from the endogenous firm exit.

Our findings indicate that the decision to export is affected by firm productivity. Higher productivity producers are more likely to be in the export market and this mirrors the findings of most other empirical studies of this relationship. Firms with prior export market experience are also more likely to participate and this is consistent with previous empirical findings that focus on sunk entry costs as a determinant of persistence in exporting patterns. Prior exporting and R&D investments also increase the probability the firm invests in both activities, but prior R&D expenditures alone do not have a significant effect on the firm's current investments. Overall, there appears to be more persistence in the firm's exporting than in their R&D spending.

We also find a positive, statistically significant and robust relationship between a firm's export market participation and its future productivity. The effect is larger if the firm has also made investments in R&D. Researchers who have conducted case studies of Taiwanese industries have argued that firms that export benefit from technology that is transferred from their foreign customers, and that this transfer is enhanced if the firm makes its own simultaneous investments to improve its ability to assimilate the new technology. Our empirical finding of higher future productivity for these firms is consistent with this argument.

Overall, the empirical findings are consistent with a development process in which firms are heterogeneous in their underlying productivity but can affect their future productivity path by making investments that increase their knowledge base. In turn, higher productivity increases the return to these investments which results in additional investments that further expand the knowledge base. In the case of Taiwan, it has been argued that the two tools that have augmented the firm's knowledge base are export market contacts with developed country buyers and investments in R&D which give them the capability to assimilate and utilise the new technology or ideas they gain from their foreign contacts. Our empirical

findings are consistent with this process. In particular, for the electronics industry we find that export market participation is more than just the self-selection of more efficient firms into the export market. We find evidence consistent with the learning-by-exporting hypothesis whereby firms that export have significantly higher productivity growth than those that do not export. The robustness of the relationship between exports and future productivity suggests that the export activity is an important mechanism for technology transfer in this industry.

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