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

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Abstract

This paper uses micro panel data for firms in the Taiwanese electronics industry in 1986, 1991, and 1996 to investigate a firm's decision to invest in two sources of knowledge - participation in the export market and investments in R&D and/or worker training - and assesses the effects of these investments on the firm's future total factor productivity. The empirical model is a set of reduced-form equations based on a theoretical model that describes a firm's dynamic decisions to export, to invest in R&D and/or worker training, and to exit. The firm's joint decisions to export and invest in R&D and/or worker training are modeled with a multinomial probit model that recognizes the interdependence of the decisions. We then estimate how participation in these investment activities alters the firm's future productivity trajectory while controlling for the selection bias introduced by endogenous firm exit.

The findings indicate that past experience in exporting increases the likelihood that a firm currently exports, but that past experience in R&D and/or worker training does not have lasting effects on a firm's investment decisions. These results are consistent with the belief that exporting is less costly for firms that have already incurred some necessary sunk costs. In addition, the results indicate that larger firms and more productive firms are more likely to participate in each activity. The findings also suggest that, on average, firms that export but do not invest in R&D and/or worker training have significantly higher future productivity than firms that do not participate in either activity. In addition, firms that export *and* invest in R&D and/or worker training have significantly higher future productivity than firms that only export. These findings are consistent with the hypothesis that export experience is an important source of productivity growth for Taiwanese firms and that firm investments in R&D and worker training facilitate their ability to benefit from their exposure to the export market.

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I. Introduction

Since 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 globalization 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.[1] 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.[2] 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 the self-selection of more efficient firms into the export market rather than by any learning-by-exporting.[3]

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

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[1] There is general disagreement over the rate of productivity growth in the East Asian economies. While the World Bank declared the region to have achieved miraculous productivity growth rates, Young (1995) and others argue that the productivity growth has been strong but warrants no special explanation.

[2] See Hobday (1995a) and Westphal (forthcoming) for reviews of these studies.

[3] Clerides, Lach and Tybout (1998) use data from Colombia, Mexico and Morocco; Bernard and Jensen (1999) study U.S. manufacturing firms; Aw, Chung and Roberts (2000) use data from Taiwan and South Korea; Bernard and Wagner (1997) for Germany; Liu, Tsou, and Hammitt (1999) for Taiwan; Delgado, Farinas and Ruano (2001) use data from Spain: and Baldwin and Gu (2002) study Canada. All find evidence that more efficient producers self-select into the export market. Aw, Chung, and Roberts (2000) also find evidence of productivity improvements following entry into the export market for a few Taiwanese industries. Baldwin and Gu (2002) find that there are subsequent productivity improvements (declines) for Canadian manufacturing plants that enter (exit) the export market.

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.[4] 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 multinomial 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."[5] 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 the industry would not have been possible without the combination of easy access to foreign technology and firms' efforts to assimilate this technology.[6] The electronics industry is

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[4] Basant and Fikkert (1996), Bell and Pavitt (1993), Cohen and Levinthal (1989 and 1990) and Dollar (1992) all emphasize that firm-level investments in absorptive capacity, such as R&D, have a complementary relationship with their acquisition of external sources of knowledge.

[5] This expression, attributed to Westphal (forthcoming), 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.

[6] Hobday (1995b) and Westphal (forthcoming) cite case study evidence of extraordinary export-related technology transfer in the electronics industry. Aw and Batra (1998), using firm-level cross-section data for Taiwanese

also important because of its size and output growth. It is the largest industrial sector in Taiwan, accounting for over 5% of GNP and 25% of total exports between 1985 and 1988; furthermore its output growth reached 37 percent 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 II 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

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industries in 1986, conclude that both exports and R&D and worker-training investments at the firm level are positively correlated with firm efficiency.

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 III, followed by a description of the empirical model and the estimation results in Section IV. The final section is a summary of the results and conclusions.

II. 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 buyer's brand names.[7] 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.[8] According to Gee and Kuo (1998), Taiwanese electronics firms benefitted 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 maximization decision as well as an investment intended to improve future productivity through learning-by-exporting.

However, the successful accumulation of technology depends on more than just easy access to new knowledge. 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; Bell and Pavitt, 1993). Second, building technological capability depends fundamentally on firms' own investments in

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[7] See Hobday (1995a).

[8] See Evenson and Westphal (1995) and World Bank (1993).

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 recognized by many researchers. Griliches (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 analyze 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. More importantly, they also show that firms that simultaneously export and invest in R&D and worker training are about 10-17 percent more efficient than those that only export. Because their data is 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. We are able to address these econometric issues using firm-level panel data which includes measures of firms' participation in the export market and expenditures on R&D and worker training.

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 utilize is a survey of the larger and more technologically advanced firms in the electronics industry.[9] 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 percent of all firms in the survey had expenditures on either R&D and/or WT and almost 72 percent 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 percent participated in both activities and between 22 and 41 percent 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 percent of the firms in each year choose to export but not invest in R&D/WT, there are relatively few firms, approximately 5 percent per year, that invested only in R&D/WT.[10]

While Table 1 summarizes firm investment behavior in each cross section but it does not indicate how firm participation decisions persist or change over time. Table 2 summarizes 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

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[9] The empirical analysis in this chapter will be limited to the firms that are included in the survey and, thus, our conclusions will be relevant only for the subset of larger electronics producers. This limitation is necessary because the firm-level R&D and worker-training expenditures were not collected as part of the census after 1986.

[10] 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.

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 percent began exporting in the next period whereas only 13 percent began investing in R&D/WT. Of the 530 firms that participated in both activities in year *t*, only 8 percent ceased to export while almost 30 percent 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 percent of the firms that participated in both activities in the initial year ceased their investments in R&D/WT, almost 44 percent of the firms that only invested in R&D/WT in the initial year ceased that activity. Similarly, in the next column, only 27 percent of firms that did not participate in either activity in the initial year chose to start exporting. In contrast, 51 percent 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 behavior and firms that participate in more activities initially are more likely to add new activities and less likely to cease their initial activity. There is also some evidence that firms tend to enter the export sector before beginning to invest in R&D/WT.

III. 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 develop 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.

The theoretical model treats these activities as producing a flow of new information that augments the existing stock of firm knowledge. This stock enters directly into the firm's production function as a productive input, along with a firm-specific productivity or efficiency level, and both enter the firm's short-run profit function. Current firm investments in these activities can have two effects on the firm's future. First, by increasing the stock of knowledge, they increase the inputs available to the firm in future periods and thus directly affect future output and profits. Second, the investments may directly affect the likely future productivity level of the firm.[11] Either, or both, of these channels could be present.

To model the firm's demand for these investments we must be specific about the firm's profit. Each firm faces a constant marginal cost of production and a downward-sloping demand curve for its output in each of the domestic and foreign market. These assumptions allow the firm to choose the profit-maximizing output level separately in each market and allows us to specify the firm's profit function in each market. Each firm is characterized by a productivity level ω with higher values

[11] Olley and Pakes (1996) develop a model of physical investment which includes the first effect, while Ericson and Pakes (1995) develop a model in which current investments affect the stochastic evolution of future productivity.

representing more productive firms. The productivity level ω captures a host of factors including differences in managerial efficiency, output quality, or returns to scale that lead to profitability differences. The firm's profit function in year *t* in the domestic market is represented as $\pi_t^d\,(Z_t^d\,,\,\omega_t\,,\,R_t\,,\,X_t\,)$ where Z^d is a set of domestic demand and marginal cost shifters, where the latter includes both fixed factors of production and the prices of variable inputs, ω is the firm's productivity level, *R* is the stock of firm knowledge generated by its past internal investment activities, and *X* is the stock of knowledge acquired externally. Similarly, the maximum profit the firm can earn in the export market is represented as $\pi_t^f\,(Z_t^f\,,\,\omega_t\,,\,R_t\,,\,X_t\,)$ where Z^f is a set of demand and cost shifters in the foreign market.

The state variables of interest are the firm's productivity level ω and the stocks of knowledge *R* and *X* . Each state variable evolves over time as the firm invests additional resources in each area. Let r_t denote the flow of internal investment in R&D and/or worker training in year *t* and x_t denote the flow of investment in acquiring external knowledge. The knowledge stocks evolve over time according to:

$$R_{t+1} = \delta_r R_t + r_t \quad \text{and} \quad X_{t+1} = \delta_x X_t + x_t \qquad (1)$$

where the δ's are retention rates for each of the capital stocks. The firm's productivity level is assumed to evolve over time as a Markov process that depends on the firm's investments in knowledge activities, *r* and *x*. The firm is assumed to know its current productivity level at the time it makes its investment decisions and these investments are assumed to affect the probability distribution of future productivity levels. The evolution of firm productivity over time is represented by a distribution function:

$$F(\omega_{t+1} \mid \omega_t ,\, r_t\,,\, x_t\,) \qquad (2)$$

Conditional on current productivity, firms that make investments in *r* and *x* should have a more favorable distribution for their productivity level in the future.[12]

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[12] The models by Hopenhayn (1992) and Olley and Pakes (1996) assume 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. Our empirical model will allow us to test if the evolution of firm productivity is exogenous, as in the first two papers, or affected by the firm investment choices as in Ericson and Pakes (1995).

There are costs associated with each investment activity. The cost of producing *r* units of internal knowledge is represented by the investment cost function $C(R, r)$. We are not explicit about the form of this cost function but it could represent either convex or nonconvex adjustment costs for investment.[13] Given that experience in the export market is considered an important source of external knowledge, we treat x_t as a discrete variable that takes the value 1 if the firm participates in the export market in year *t* and 0 if it does not. In this case the state variable X_{t+1} is incremented by one if the firm exports in year *t*. If knowledge gained in prior years of exporting never depreciates then $\delta_x = 0$ and X_{t+1} is the number of years of prior export experience. The cost of participating in the export market is viewed as a sunk cost Γ that is paid in the year of entry. As long as the firm remains in the export market, this cost does not recur. If the firm exits the export market it must pay Γ again if it reenters.[14]

In each year *t*, an incumbent firm makes 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 of the firm, Θ_t. The expected discounted value of its profit stream is maximized with respect to the stream of future investment expenditures $\{r\}$ and the sequence of future export market participation $\{x\}$. Since each firm's expected profits in year *t* can be expressed in terms of its state variables and investments in the previous period, the firm's value function, given it's information set Ω_t, in year *t* can be written as:

[13] Cooper and Haltiwanger (2000) discuss alternative forms that adjustment cost functions can take.

[14] Roberts and Tybout (1997) develop an empirical model of export market participation that allows the sunk entry costs to vary with the length of time the firm has been out of the export market. This leads to a model in which current participation depends on a distributed lag of prior participation variables. We have a very short time-series of data to use in this application and cannot allow more general patterns in the sunk costs.

$$V_t(\omega_t, R_t, X_t) = max \{ \Theta_t, \max_{x_t, t_t} [\pi_t^d(Z_t^d, \omega_t, R_t, X_t) + \pi_t^f(Z_t^f, \omega_t, R_t, X_t) x_t - C(R_t, r_t) -$$

$$\Gamma(1-x_{t-1}) x_t + \beta EV_{t+1}(\omega_{t+1}, R_{t+1}, X_{t+1}) / \Omega_t)] \} \quad (3)$$

Ericson and Pakes (1995) analyze a model very similar to this and provide a characterization of the optimal investment and shut-down decision of the firm.[15] The solution to this optimization problem generates a shut-down rule for the firm, an investment demand function for *r* and a rule describing participation in the export market. The shut-down rule takes the form:

$$S_t = 1 \ \ if \ \ \omega_t \geq \underline{\omega}_t(R_t, X_t) \quad (4)$$

$$= 0 \ \ otherwise.$$

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

Second, the model produces a demand equation for the R&D investment variable:

$$r_t = r_t(\omega_t, R_t, X_t) \quad (5)$$

Ericson and Pakes (1995) show that investment will vary with the level of firm productivity. There are three distinct regions for firm productivity that will give rise to different investment outcomes. A firm with low levels of current productivity will not find it profitable to invest in R&D. Once its productivity passes a lower threshold, the firm will actively invest in *r* to improve its future productivity. However, there is also an upper productivity cutoff, beyond which the firm will not find it profitable to invest in *r*.

[15] Their model does not include the separate export decision and the investment variable only acts to shift the distribution of future productivity levels, so that the knowledge stocks do not appear as state variables in the model. An additional state variable in their model is the industry structure, summarized by the distribution of productivity levels across all firms in the industry. In this model they characterize the dynamic industry equilibrium and optimal investment and shut-down decisions of the incumbent firms.

The upper limit reflects the fact that investment in the Ericson and Pakes model increases the probability of moving to higher future productivity levels, so that the return to additional investment will be low for high productivity firms.

The model also produces an equation describing the discrete decision to export:

$$x_t = 1 \quad if \quad \pi_t^f (Z_t^f, \omega_t, R_t, X_t) + \beta [E(V_{t+1} \setminus x_t = 1) - E(V_{t+1} \setminus x_t = 0) \geq \Gamma(1 - x_{t-1}) \qquad (6)$$

$$= 0 \quad otherwise.$$

This equation says that a firm will participate in the export market in year *t* if the period *t* profit plus the increment to future expected profits from being an exporter in year *t* exceed the relevant entry cost. The relevant cost is Γ if the firm was not an exporter in the previous year $(x_{t-1} = 0)$ and zero if it was an exporter $(x_{t-1} = 1)$. The equation shows that, because of the presence of sunk costs that must be incurred upon entry to the export market, there is an explicit role for past export participation, x_{t-1}, in the current export decision. This dynamic effect would be present even if there was no knowledge accumulation resulting from exporting and no effect of export market experience on the distribution of future firm productivity.[16]

The period *t* state variables, ω_t, R_t, and, X_t, are determinants of the firm's decision to shut down, invest in R&D, and export (equations (4), (5) and (6), respectively). In addition, exogenous demand and cost shifters, such as variable factor prices, output prices, and the levels of fixed factors are also determinants of profits and are necessary as controls. An empirical representation of these three equations will be developed and estimated in section IV below. In addition, we will estimate an equation for the evolution of the firm's productivity, equation 2, to isolate the contribution of exporting and R&D investment to the firm's future productivity.

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[16] Equation 6 is the basis for the empirical model of export market participation estimated by Roberts and Tybout (1997), Clerides, Lach, and Tybout (1998), Bernard and Jensen (1999) and Bernard and Wagner (2001).

IV. An Empirical Model of Firm Investment, Survival and Productivity

The empirical model consists of the reduced form investment-expenditure equations, an equation describing the probability of firm survival, and an equation for productivity evolution. 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 hypothesized complementarities between R&D/WT investments and export participation, we are especially interested in empirical evidence about interaction effects between these variables.

Export Participation and R&D/WT Investment Expenditures

In equation (5) of the theoretical model, a firm's R&D/WT investment expenditures in year t are a function of the firm's productivity, its stocks of R&D/WT and export experience at the beginning of year t as well as other profit shifting firm characteristics. Equation (6) describes the firm's export participation decision as a function of these same variables. 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. Nonconvexities in the cost of R&D/WT may emphasize 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. Recognizing 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 analyze 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 RD/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.

As described in the literature, a firm's discrete R&D/WT investment decision is unlikely to be made independently of its discrete export participation decision. Recognizing the potential complementarity (or substitutability) of the two activities, we chose to characterize the firm's investment decisions with a multinomial discrete choice model that specifies the probability of choosing each of the four possible combinations of activities: export and R&D/WT, export only (no R&D/WT), R&D/WT only (no exports) or no export and no R&D/WT. We estimate a multinomial probit model that treats each *combination* of activities as a separate choice and accounts for the inherent relationships between the activities through a very flexible error structure.

This specification has several important advantages over other potential specifications of the model. The simplest option would be to estimate the two binary choices (export and R&D/WT) in two separate probit equations. However, this specification would not allow for potentially important correlation between the errors associated with each decision. A bivariate probit specification could account for this type of correlation but it would restrict the parameters of the R&D/WT equation to be the same for both exporters and non-exporters (and vice versa). The multinomial logit model is a third possible specification and would allow different parameter values for each of the possible combinations of activities, but it suffers from undesirable restrictions on the probabilities of each activity.[17]

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 each period. 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*.[18] The theoretical model specifies that a firm's discrete export participation decision also depends on

[17] The assumption of the independence of irrelevant alternatives implicit in the multinomial logit model implies that the probability that a firm chooses to export and not to invest in R&D/WT would be the same when it chooses *among* the two activities (exporting and/or R&D/WT) as it would be if the firm were forced to choose *between* the two activities (exporting or R&D/WT).

[18] 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 nonzero coefficient on lagged R&D or lagged worker training is consistent with sunk costs of adjustment on each

its stocks of R&D/WT and export experience. In addition, each decision depends on ω_{it} and the Z^d and Z^f variables that determine the firm's profit given their investment and export decisions.

Since the discrete investments decisions are made jointly, we model four possible outcomes, one for each combination of the two discrete choices. The dependent variable $I(Choice_{it}^j)$ is a discrete variable equal to one if the firm chooses option *j* and zero if not. Choice *j* = 1 is the firm invests in both R&D/WT and exporting, Choice 2 is exporting but no R&D/WT, Choice 3 is R&D/WT but no exporting, and Choice 4 is neither R&D/WT nor exporting. We will normalize by the fourth choice. The estimating equation for the discrete investment choice *i* is:

$$I(Choice_{it}^j) = \alpha^j + \alpha_t^j + \alpha_1^j \log(a_{it}) + \alpha_2^j I(E_{it}) + \alpha_3^j \log(k_{it}) + \alpha_4^j \log(pwage_{it}) + \alpha_5^j I(multiplant_{it}) + \alpha_6^j \omega_{it} + \alpha_7^j (\omega_{it})^2 + \sum_{k=1}^{3} \beta_k I(Choice^k_{it-1}) + \sum_{k=1}^{3} \tau_k I(Choice^k_{it-1})\, \omega_{it} + \varepsilon_{it}^j \qquad j \in \{1,2,3\} \tag{7}$$

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, $I(Choice^k_{it-1})$, $k \in \{1,2,3\}$, 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.

The error term consists of two parts, $\varepsilon_{it}^j = \lambda \mu_i^j + (1-\lambda) \nu_{it}^j$ where both μ and ν are assumed to be normally distributed random variables and λ is a parameter. The random firm effect for each choice, μ_i^j,

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variable.

accounts for unobserved firm heterogeneity that might make any one choice more attractive to a particular firm throughout the estimation years. For example, all else being equal, a firm located near port facilities may be more likely to export. Given that such an unobserved firm characteristic may also affect the probability that a firm invests in R&D/WT, these firm errors are allowed to be correlated across choices. The second part of the random error for choice j, ν_{it}^{j}, are assumed to be independent across periods and firms but will be correlated across choices. The assumed covariances of each firm's errors are: $Cov(\mu_i^j, \mu_i^k) = \phi_{jk}$, $Cov(\nu_{it}^j, \nu_{it}^k) = \psi_{jk}$, $Cov(\mu_i^j, \nu_{it}^j) = 0$, $Cov(\mu_i^j, \nu_{it}^k) = 0$, $Cov(\nu_{it}^j, \nu^j_{it+1}) = 0$ and $Cov(\nu_{it}^j, \nu^k_{it+1}) = 0$. To identify the elements of the covariance matrix we impose one additional restriction, $Var(\varepsilon_{it}^1) = 1$.

For each firm we will have 2 years of data (1991 and 1996) and three (normalized) choices. The covariance matrix of the error term for firm i can be written in matrix notation as

$$\Sigma_i = E\left[\begin{bmatrix}\varepsilon_{91}^1\\ \varepsilon_{91}^2\\ \varepsilon_{91}^3\\ \varepsilon_{96}^1\\ \varepsilon_{96}^2\\ \varepsilon_{96}^3\end{bmatrix}\begin{bmatrix}\varepsilon_{91}^1\\ \varepsilon_{91}^2\\ \varepsilon_{91}^3\\ \varepsilon_{96}^1\\ \varepsilon_{96}^2\\ \varepsilon_{96}^3\end{bmatrix}^T\right] = \begin{bmatrix}\lambda\Phi + (1-\lambda)\Psi & \lambda\Phi\\ \lambda\Phi & \lambda\Phi + (1-\lambda)\Psi\end{bmatrix} \tag{8}$$

where λ is a measure of the proportion of the total variance that is due to the random firm effect. This structure imposes additional restrictions on the covariances of each firm's error terms: $Cov(\varepsilon_{it}^j, \varepsilon_{it}^k) = \lambda\phi_{jk}, + (1-\lambda)\psi_{jk}$ and $Cov(\varepsilon_{it}^j, \varepsilon^k_{it+1}) = \lambda\phi_{jk}$.

One additional complication arises when estimating the discrete choice model in (7) and (8). Because the random firm effects, μ_i^j, are potentially correlated with the lagged values of the investment variables that are used as regressors, coefficients on the lagged investment variables may be biased upward. To correct this initial-condition problem, Heckman (1981) suggested adding an auxiliary equation to the model that describes a firm's initial choice as a function of observable information in the initial period. In our case the data used to estimate equation (7) correspond to the firm's choices in 1991 and 1996. For the 1991 observations, the firms choices in 1986 are used as explanatory variables. Following Heckman's suggestion, we add information about each firm's characteristics and choices in 1986 to the model. For the firms that existed in 1986, we estimate their investment choice in that year ($t = 0$) as a function of their age, recent entrant status, productivity, and capital stock. The choice of activities for firm *i* in the initial year is modeled as:

$$I(Choice_{i0}^{j}) = \beta^{j} + \beta_1^{j} \log(a_{i0}) + \beta_2^{j} I(E_{i0}) + \beta_3^{j} \log(k_{i0})$$
$$+ \beta_4^{j} \log(pwage_{i0}) + \beta_5^{j} I(multiplant_{i0}) + \beta_6^{j} \omega_{i0} + \beta_7^{j} (\omega_{i0})^2$$
$$+ \epsilon_{i0}^{j} \qquad j = \{1,2,3\}. \tag{9}$$

where the subscript *0* denotes the initial year. The error term ϵ_{i0}^{j} is also assumed to be independent across firms. As with the estimation years, the errors in equation (9) may be correlated across the three choices, $Cov(\epsilon_{i0}^{j}, \epsilon_{i0}^{k}) = \theta_{jk}$.

Finally, to control for the initial conditions correlation, we allow ϵ_{i0}^{j} to be correlated with the shock to choice *j* in the later years, $Cov(\epsilon_{i0}^{j},\epsilon_{it}^{j}) = \rho_j$. Again, for identification of the initial year covariances, we restrict $Var(\epsilon_{i0}^{1}) = 1$. Without the initial conditions correction, such unobserved firm heterogeneity would wrongly be attributed to the lagged investment choices and upwardly bias those parameters. The extension of the model requires us to estimate three additional sets of parameters: the regression coefficients β in (9), the covariance matrix of the errors associated with each choice in the initial year, Θ, and three additional parameters, ρ_1, ρ_2 and ρ_3, that govern the covariance between each choice in the initial year and the same choice in the estimation years.

The model is estimated using the method of simulated moments estimator for panel data developed by Keane (1994) and Geweke, Keane and Runkel (1996).

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:

$$S_{it+1} = \eta_0 + \eta_t + \eta_1 \log(a_{it}) + \eta_2 I(E_{it}) + \eta_3 \log(k_{it})$$
$$+ \eta_4 \log(pwage_{it}) + \eta_5 I(multiplant_{it}) + \eta_6 \omega_{it} + \eta_7 (\omega_{it})^2 +$$
$$\sum_{k=1}^{3} \eta^k I(Choice^k_{it}) + \sum_{k=1}^{3} \eta^{kk} \omega_{it} I(Choice_{it}^k) + \xi_{ijt+1} \qquad (10)$$

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:

$$\omega_{it+1} = \gamma_0 + \sum_{k=1}^{3} \gamma_k I(Choice_{it}^k) + \gamma_4 \omega_{it} + \upsilon_{it+1} \qquad (11)$$

An additional complication arises when estimating the productivity process. Because we only observe ω_{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 we employ Heckman's sample selection framework and jointly estimate the survival equation (10) and productivity evolution equation (11) using maximum likelihood. The model includes one additional parameter, the $Corr(\xi_{it+1}, \upsilon_{it+1})$, 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 ($I(E_{it})$, $log(a_{it})$, $log(k_{it})$, $log(k_{it})^2$, $log(pwage_{it})$, $I(multiplant_{it})$) that are omitted from the productivity equation and aid in identification.

V. Empirical Results

Investment Equations

The multinomial probit model is estimated using our three-year panel of surveyed firms. Choices in the initial year, 1986, are modeled using equation (8) and choices in 1991 and 1996 are modeled using equation (7). The parameter estimates for equation 7 are reported in Table 3. Generally, the parameters for the first choice (Export and R&D/WT) and the second choice (Export only) are estimated more precisely than the parameters of the third choice 3 (R&D/WT only). There are several similarities in the results across the three choice equations although the estimated parameters vary in their magnitude and significance.

The negative coefficients on the 1996 year dummy capture the fact that a smaller proportion of firms participated in each of the activities in 1996 than in 1991. The positive and significant coefficients on the entrant dummy indicate that firms that entered the market (not just the survey) in the five years before the previous census year are more likely to invest in each activity than older firms. This may reflect a tendency of recent entrants to choose products that are more oriented to the export market and require more technological capabilities to upgrade. The insignificance of the estimated parameters on $log(a_{it})$ indicates that, beyond entrant status, age does not seem to significantly affect a firm's decision to participate in the export and R&D/WT activities. The coefficient on $log(k_{it})$, which is a measure of firm size, is positive and highly significant in all three equations. Larger firms are more likely to turn to the export market to sell a portion of their output and they are more able to defray the per unit cost of investments in R&D and worker training. The differences in the coefficients on $log(k_{it})$ across the three equations point to differences in importance of size in each decision. Increases in size have the largest effect on the likelihood that a firm participates in both activities (0.790) and a similar effect on the likelihood that a firm only invests in R&D/WD (0.614). However, the effect of size on the decision to only export is significantly smaller (0.464). The coefficients on the average production worker's wage and multi-plant dummy are never statistically significant.

The coefficient on firm productivity ω_{it} is positive and significant for both choice 1 and choice 2. This result is consistent with the findings of self-selection of more productive firms into the export market found in several other empirical studies.[19] Firm productivity does not have a statistically significant effect on the likelihood of investing in R&D/WT only. The coefficients on ω_{it}^2 are all negative, indicating that the effect of productivity on each choice is diminishing, but none are statistically significant.

The lagged choice variables are used as proxies for a firm's stock of knowledge in each activity. Past choices that include export activity (Choice 1 and Choice 2) have a much greater impact on a firm's current decisions than R&D/WT experience on its own. The impacts of lagged Choice 1 and Choice 2 on

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[19] See Clerides, Lach and Tybout (1998); Bernard and Jensen (1999); Aw, Chung and Roberts (2000); Bernard and Wagner (1999); and Delgado, Farinas and Ruano (2001).

current Choice 1 as well as current Choice 2 are always positive and significantly different than zero. That is, past investments in exports (with or without R&D/WT) critically affect current decisions to export as well as undertake R&D/WT activities in addition to exports. Together, these findings indicate that initial entry into the export market is likely to involve sunk costs and that once in the export market, firms are more likely to also invest in R&D/WT. In contrast, lagged Choice 3 (only R&D/WT) does not have a statistically significant impact on any current investment decisions. Moreover, there appears to be little additional benefits to current export activity from adding investments in R&D/WT in the past. This can be seen by comparing the coefficients on lagged Choice 1 dummy to those on the lagged Choice 2 dummies in each equation in columns 1 and 2 of table 3. While the coefficients themselves are statistically significant, they are not significantly different from each other.

Case study literature about the interactions between exporting and R&D/WT suggests that firms that have accumulated large stocks of human capital through R&D/WT may have an added incentive to start exporting because they are better able to absorb export-related technology. This view implies a certain timing of the two investment activities, with R&D/WT preceding exports. The strong persistence in export market participation and lack of persistence in investments in R&D/WT in our empirical findings indicate that firms tend to enter the export market before beginning to invest in R&D/WT, a pattern consistent with our earlier observations from Table 2.

Each of the interaction terms between the lagged choices and ω_t have similar positive coefficients in the three choice equations, but none of them are statistical significance. The five years between our observations may be enough time for past R&D/WT investments to fully depreciate. If so, this would explain the lack of effect of these investments on a firm's current choices that is illustrated in Table 3.

Table 4 reports the estimated parameters for the error covariance matrix. The coefficients are the elements of the Cholesky decompositions of the Ψ and Φ matrices defined in equation (8). The elements of Ψ indicate that there is significant contemporaneous covariance in the errors across the choices, implying the transitory shocks to the value of each choice tend to be correlated with each other. The small and statistically insignificant estimated value of λ indicates that there is little significant unobserved firm heterogeneity contained in the model's errors. The elements of the Cholesky decomposition of Φ, which capture intertemporal correlations for a firm, are not statistically significant and this reinforces the conclusion that correlations among different time observations for a firm are not important. Similarly, the three parameters ρ_1, ρ_2, and ρ_3 that allow correlation between the firm's choice in the initial year 1986 and later years are also not significant. The overall conclusion from the estimated covariance matrix is that there is no significant source of intertermporal correlation in the error terms and instead all correlations arise from contemporaneous shocks to the three choice equations. The lack of any evidence of intertemporal correlations in the firm errors helps to eliminate concerns about potential bias in the lagged choice coefficients.[20]

In addition to the flexibility in the error structure, much of which is unnecessary in our data, a second advantage of the multinomial probit model is that it allows the explanatory variables to have different impacts on the decision to undertake each combination of activities. However, from the estimated coefficients in table 3, there are few things that distinguish choice 1, both R&D investment and exporting, from choice2, exporting only. The magnitudes of most coefficients are similar and the patterns of statistical significance on size, productivity and the lagged investment choices are the same. In contrast, choice 3, R&D investment only, is not significantly affected by productivity or lagged

[20] Although the empirical model is technically identified, Keane (1992) points out that in practice parameter estimates in multinomial probit models may be very sensitive. In particular, it can be difficult to accurately separate covariance and slope parameters. Keane shows that including choice-specific variables would improve the identification by grounding each choice in a separate unique variable. Unfortunately, we do not have any such choice-specific variables in our data which we could include in our specification. However, to explore the sensitivity of our estimates we estimate an alternative specification in which each of the three equations contains only its own lagged choice dummy as an explanatory variable. The coefficients on the other two lagged choice dummies are restricted to be zero. The parameters of this restricted model are generally estimated with greater precision but the coefficient estimates for slope and covariance parameters are very similar in the two specifications and would lead to no changes in our interpretation of the results.

investment choices. A model which is much simpler to estimate, and which appears sufficient to capture the patterns in our data, is the 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

$$\begin{aligned} I(Export_{it}) = \; & a_0 + a_t + a_1 \log(a_{it}) + a_2 I(E_{it}) + a_3 \log(k_{it}) \\ & + a_4 \log(pwage_{it}) + a_5 I(multiplant_{it}) + a_6\, \omega_{it} + a_7 (\omega_{it})^2 + \\ & \sum_{k=1}^{3} f_k\, I(Choice^{k}_{it-1}) + \sum_{k=1}^{3} g_k\, \omega_{it}\, I(Choice^{k}_{it-1}) + \varepsilon x_{it} \end{aligned} \qquad (12)$$

$$\begin{aligned} I(R\&D/WT_{it}) = \; & b_0 + b_t + b_1 \log(a_{it}) + b_2 I(E_{it}) + b_3 \log(k_{it}) \\ & + b_4 \log(pwage_{it}) + b_5 I(multiplant_{it}) + b_6\, \omega_{it} + b_7 (\omega_{it})^2 + \\ & \sum_{k=1}^{3} h_k\, I(Choice^{k}_{it-1}) + \sum_{k=1}^{3} l_k\, \omega_{it}\, I(Choice^{k}_{it-1}) + \varepsilon r_{it} \end{aligned}$$

where $I(Export_{it})$ is an indicator variable for firms that export and $I(R\&D/WT_{it})$ 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, $Corr(\epsilon x_{it}, \epsilon r_{it})$, to be nonzero.

The results of the bivariate specification, which are reported in Table 5 are consistent with those of the multinomial model. In particular, 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. Again, the interactions between ω_{it} and a firm's past choices are insignificant in both equations. As in the multinomial model, 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. There are a few differences between the multinomial and bivariate models. Unlike the multinomial probit model, the diminishing effect of productivity in the export decision is significant in the bivariate probit specification, and the negative effect of higher production wages is significant in the bivariate probit specification. This is consistent with the hypothesis that firms that pay higher production wages are less competitive in the export market. The estimated value of $Corr(\epsilon x_{it}, \epsilon r_{it})$ 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.[21] 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 6.

Two differences in the Table 6 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 ω_{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

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[21] 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 5.

R&D intensity equation).[22] The latter finding is consistent with the prediction of the theoretical model that high productivity firms may have less 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 pervious 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 intensely 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.

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 7 indicate the

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[22] Aw, Chung, and Roberts (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.

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 10% 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 likely to reflect the fact that firms with large capital stocks are more likely to be able to cover their variable costs. The negative and significant coefficient on $log(k_i)^2$ 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 8 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 ω_{it+1} from the distribution, $F(\omega_{t+1} \ / \ \omega_t , r_t , x_t)$. The empirical result can be viewed as the effect of changes in ω_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 8 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 percent 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 percent higher productivity in the next period. In addition, a Wald test reveals that the coefficient on Choice 1 is significantly different from the coefficient on Choice 2 at the 5% 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 multinomial probit and bivariate specifications, high productivity firms may gain more than low productivity firms from participating in each combination of activities. 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 ω_{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 8. The intercept, year dummy, and productivity coefficients in the second of 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 ω_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 6% 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 ($Corr(\xi_{it}, \upsilon_{it}) = -0.152$). However, the standard error on the estimated correlation is 0.218 and a likelihood ratio test can not reject the hypothesis of independence between the survival equation and the productivity evolution equation. Therefore, it appears that the issue of endogenous exit of firms has little effect on the parameters of the evolution equation.[23] 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 ω_t. We perform a modified Breusch-Godfrey test for serial correlation of the error terms by

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[23] 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.

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.

V. 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 specializing in areas of comparative advantage, these economies are thought to have benefitted from a significant transfer of technology from the 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 use 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 reduced-form 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 modeled with the multinomial probit model. The productivity evolution equation is estimated while controlling for the selection bias that arises from 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 heterogenous 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 utilize 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.

Appendix

Description of Data and TFP Measure

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 analyze 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 survey. In our paper we use data on investments in R&D, worker training from the survey and data on export participation, inputs and outputs from the census to analyze the effects of these investments on a firm's TFP.

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 labor 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.

Firm output is defined as total firm sales deflated by a wholesale price index defined at the two-digit industry level. It is deflated by a producer price index defined at the two-digit industry level. We model each producer as using four inputs in production: labor, capital, materials, and subcontracting services. The labor input is measured as the number of production plus non-production workers. Total payments to labor are measured as total salaries to both groups. The measure of capital input is the book value of capital stock of the firm or plant. We have adjusted the book values to control for price level changes in new capital goods that will cause the book value to change over time with investment in new equipment. The expenditure share on capital is calculated as the residual after subtracting the expenditure on labor, material inputs, and subcontracting from the value of output.

The material input is defined to include raw materials, fuel, and electricity. In Taiwan, raw material expenditures are deflated by a general producer price index which covers both manufacturing and nonmanufacturing output in the country. Fuel and electricity expenditures are deflated by an aggregate energy price index. Fuel expenditures are deflated by an energy producer price index and electricity expenditure is deflated by an electricity price index.

The final input is a measure of expenditure on subcontracting services. Many producers in both countries hire subcontractors to perform pieces of the manufacturing process and payments to these subcontractors are reported as a separate expenditure by the firm or plant in the census data. To construct a subcontracting input we deflate the payments to subcontractors by the output price of the industry in which the firm or plant operates. While this is not an ideal price index to use in deflating subcontracting expenditures, the overall inclusion of the subcontracting input is important since it recognizes that the inputs of producers that subcontract some of the production steps need to be increased, and thus their *TFP* reduced, relative to the producers that do not subcontract.

Measuring Firm Productivity

The total factor productivity index captures many factors that can lead to profit differences across firms, including differences in technology, age or quality of capital stock, managerial ability, scale economies combined with size differences, or differences in output quality. Total factor productivity (*TFP)* is calculated for each firm in each period using a multilateral index method that was developed by Caves, Christensen, and Diewert (1982), extended by Good, Nadiri, and Sickles (1997) and applied by Aw, Chen and Roberts (forthcoming). To guarantee that comparisons between any two firm-year observations are transitive, the index expresses each firm's inputs and outputs as deviations from a single reference point, a hypothetical average firm for each period. This average firm produces the arithmetic mean of industry output using the arithmetic means of industry inputs. The productivity of this average firm is calculated as its output less the weighted sum of its inputs, where the weights are the industry averages of the shares of output paid to each input. The TFP measure is then linked over time by calculating the TFP of the average firm in each period relative to the TFP of the average firm in the previous period.

Let each firm f in year t produce a single output, Y_{ft}, using the set of n inputs, X_{ift}, where $i=1,2,...n$. The firm's expenditure on input X_{ift}, as a share of total revenue, is denoted by S_{ift}. Let $\overline{S_{it}}$, $\overline{lnY_t}$, $\overline{lnX_{it}}$, be the arithmetic means of the corresponding firm level variable over all firms in year t. The total factor productivity index for firm f in year t is defined as:

$$\omega_{ft} = \left(lnY_{ft} - \overline{lnY_t}\right) + \sum_{s=2}^{t}\left(\overline{lnY_s} - \overline{lnY_{s-1}}\right)$$
$$- \left[\sum_{i=1}^{n}\frac{1}{2}\left(S_{ift} + \overline{S_{it}}\right)\left(lnX_{ift} - \overline{lnX_{it}}\right)\right.$$
$$\left. + \sum_{s=2}^{t}\sum_{i=1}^{n}\frac{1}{2}\left(\overline{S_{is}} + \overline{S_{is-1}}\right)\left(\overline{lnX_{is}} - \overline{lnX_{is-1}}\right)\right]$$

The first line of the equation measures firm output and consists of two parts. The first expresses firm output in year t as a deviation from the mean output in that year and thus embodies the information in the cross-sectional distribution of output. The second part sums the change in the mean output across all years, effectively capturing the shift of the output distribution over time by chain-linking the movement in the output reference point. The next two lines in the equation perform the same operation for each input, X_i. The inputs are summed using a combination of the input revenue share for the firm, S_{ift}, and the average revenue share, $\overline{S_{it}}$, in each year as weights. The index provides a measure of the proportional difference in total factor productivity for firm *f* in year *t* relative to the hypothetical firm in the base time period.

The sales data for 1991 and 1996 are reported in millions of Taiwanese dollars. Therefore, TFP cannot be calculated for firms that did not have sales of at least one million Taiwanese dollars; thus those firms are dropped form the sample. To aviod a smapling bias, the same one million dollar threshold os used to determine which firms to retain from the 1986 data. This and other data requirements results in the elimination of almost half of the total population of firms in each census year.

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Table 1: **Summary of Investment Activities in Survey data, 1986-1996**

(Number of firms in each combination of activities, Percent of row total)

	Activity Combination			
Year	No R&D/WT No Export	Only R&D/WT	Only Export	R&D/WT and Export
1986	215 (22.42)	55 (5.74)	248 (25.86)	441 (45.99)
1991	713 (41.26)	90 (5.21)	508 (29.4)	417 (24.13)
1996	476 (33.5)	90 (6.33)	355 (24.98)	500 (35.19)

Table 2: Transition Matrix of Investment Activities Between Year *t* and Year *t+1*, 1986-1996

Number of Firms (Row Proportion)

Investment Activity in year *t* (number of firms in year *t*)	year *(t + 1)*			
	Start R&D/WT	Stop R&D/WT	Start Exporting	Stop Exporting
No R&D/WT and No Export (185)	24 (12.97)	–	50 (27.03)	–
Only R&D/WT (82)	–	36 (43.90)	42 (51.22)	–
Only Export (276)	73 (26.45)	–	–	52 (18.84)
R&D/WT and Export (530)	–	156 (29.43)	–	40 (7.55)

Table 3: Discrete Investment Activity Equation

Multinomial Probit Estimates (standard errors in parentheses)

Sample size = 2108

Variables	Choice 1 R&D/WT and Exporting	Choice 2 Exporting but not R&D/WT	Choice 3 R&D/WT but not Exporting
intercept	-9.849 (1.009)*	-4.973 (1.077)*	-8.167 (2.528)*
year dummy	-0.034 (0.107)	-0.209 (0.103)*	-0.461 (0.242)
entrant dummy	1.266 (0.221)*	0.667 (0.196)*	0.546(0.275)*
log(age_{it})	-0.056 (0.072)	0.091 (0.069)	-0.146 (0.196)
log (k_{it})	0.790 (0.054)*	0.464 (0.09)*	0.614 (0.125)*
log(pwage$_{it}$)	-0.076 (0.103)	-0.186 (0.100)	0.067 (0.233)
multiplant dummy	0.065 (0.122)	-0.084 (0.122)	-0.201 (0.185)
productivity (ω_{it})	1.187 (0.309)*	0.715 (0.311)*	0.493 (0.445)
ω_{it}^2	-0.296 (0.286)	-0.282 (0.284)	-0.273 (0.39)
lagged Choice 1 dummy Exporting and R&D/WT	1.672 (0.299)*	0.991 (0.303)*	0.578 (0.517)
lagged Choice 2 dummy Exporting but not R&D/WT	1.190 (0.271)*	1.072 (0.279)*	0.657 (0.518)
lagged Choice 3 dummy R&D/WT but not Exporting	0.330 (0.451)	0.294 (0.439)	0.590 (0.605)
ω_{it} * lagged Choice 1 dummy	0.152 (0.513)	0.105 (0.535)	0.105 (0.688)
ω_{it} * lagged Choice 2 dummy	0.446 (0.43)	0.561 (0.418)	0.433 (0.628)
ω_{it} * lagged Choice 3 dummy	0.472 (0.954)	0.564 (0.952)	0.616 (1.139)

* statistically significant at the α=.05 level.

All equations contain 3 digit industry dummy variables.

Table 4: Estimates of the Error Covariance Matrix

Parameter	Estimated Values (standard error)
λ	0.163 (0.224)
Estimated elements of Cholesky decomposition of Φ	
l_{21}	-0.216 (1.340)
l_{22}	0.676 (1.148)
l_{31}	-0.806 (2.338)
l_{32}	0.037 (4.000)
l_{33}	0.132 (15.543)
Estimated elements of Cholesky decomposition of Ψ	
m_{21}	0.901 (0.412)*
m_{22}	0.986 (0.33)*
m_{31}	1.322 (0.567)*
m_{32}	1.242 (0.593)*
m_{33}	0.144 (0.272)
Estimated elements of Cholesky decomposition of Θ	
n_{21}	1.044 (0.070)*
n_{22}	0.230 (0.282)
n_{31}	1.054 (0.674)
n_{32}	-0.129 (1.678)
n_{33}	1.194 (1.455)
Estimated covariance between initial year and estimation years	
ρ_1	0.009 (0.033)
ρ_2	0.032 (0.096)
ρ_3	0.023 (0.103)

* statistically significant at the α=.05 level.

Table 5: Discrete Investment Activity Equation

Bivariate Probit Estimates

Sample size = 1384

Variables	Exporting	R&D/WT
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 (ω_{it})	1.12 (0.356)*	0.524 (0.283)
$(\omega_{it})^2$	-0.631 (0.272)*	-0.138 (0.215)
lagged Choice 1 dummy Exporting and R&D/WT	1.27 (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)
(ω_{it}) * lagged Choice 1 dummy	-0.036 (0.652)	0.193 (0.416)
(ω_{it}) * lagged Choice 2 dummy	0.829 (0.464)	-0.045 (0.415)
(ω_{it}) * lagged Choice 3 dummy	-0.599 (1.049)	0.246 (0.929)
$Corr(\varepsilon x_{it}, \varepsilon r_{it})$	0.287 (0.059)*	

* statistically significant at the α=.05 level.

All equations contain 3-digit industry dummy variables

Table 6: Investment Shares Among Firms with Positive Investment

Random effects estimates

Variables	Export share of revenue	R&D/WT share of revenue
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 (ω_{it})	0.056 (0.064)	-0.083 (0.020)*
productivity squared (ω^2_{it})	-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

* indicates statistically significant at the α=.05 level with a one-tailed test

All regression include 3-digit industry dummies

Table 7: Survival Equation Estimates

Maximum Likelihood Estimation of Sample Selection Model
with 3-digit industry dummies

Dependent Variable: S_{t+1}

Variables	Coefficient Estimates
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})^2	-0.018 (0.008)*
$log(pwage_{it})$	0.118 (0.080)
multiplant dummy	-0.025 (0.080)
productivity (ω_{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)
Industry dummies	
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)

* statistically significant at the α=.05 level

Table 8: Productivity Evolution

Maximum Likelihood Estimation of Selection Model with 3-digit industry dummies
Dependent variable: ω_{it+1}

Variable	Coefficient Estimates	
intercept	0.182 (0.063)*	0.179 (0.068)*
year dummy	0.074 (0.016)*	0.072 (0.016)*
productivity (ω_{it})	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)*
(ω_{it}) * Choice 1 dummy		-0.004 (0.080)
(ω_{it}) * Choice 2 dummy		-0.066 (0.083)
(ω_{it}) * Choice 3 dummy		-0.263 (0.161)
$Corr(\xi_{it}, \upsilon_{it})$	-0.152 (0.213)	-0.182 (0.222)
log likelihood	-926.998	-923.288
sample size	1779	1779

* indicates statistically significant at the α=.05 level with a one-tailed test