

R&D Investment and Export Dynamics*

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Abstract

A positive correlation between firm productivity and export market participation has been well documented in producer micro data. Recent empirical studies and theoretical analyses have emphasized that the export-productivity relationship may be a reflection of the firm's other investment activities, particularly investments in R&D or new technology. These investments can both raise productivity and increase the payoff to exporting. In this paper we develop a dynamic structural model of the firm's decision to invest in R&D and participate in the export market. The investment decisions depend on the expected future profitability and the fixed and sunk costs incurred with each activity. We estimate the model using micro data from the Taiwanese electronics industry and find a complex set of interactions between R&D, exporting, and productivity. Both R&D and exporting have a positive direct effect on the firm's future productivity but, when modeled as discrete decisions, the effect of R&D is larger. The firm's choice to export or invest in R&D is affected by the firm's history of these activities because the future return to each activity is affected by the presence of the other one.

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1 Introduction

A large empirical literature exists documenting the relationship in micro data between exporting and productivity.¹ A universal finding is that, on average, exporting plants are more productive than nonexporters reflecting, at least partly, the self-selection of more productive firms into the export market. A related literature has measured the intertemporal correlations between exporting and productivity in an attempt to determine if firms that participate in the export market have higher productivity growth rates. The empirical evidence on this point is less uniform, with some studies finding higher productivity trajectories for firms after they begin exporting and others finding no effect.

One element that is missing from this literature is the possibility that firms undertake other investments that lead to both higher productivity and a higher propensity to export. Recently, several authors have begun to measure the potential role of the firms' own investments in R&D or technology adoption as another component of the productivity-exporting link. Baldwin and Gu (2004), Aw, Roberts, and Winston (2007), Bustos (2007), Lileeva and Trefler (2007), Aw, Roberts, and Xu (2008) have found evidence from micro data sets that exporting is also correlated with firm investment in R&D or adaption of new technology. Complementing this evidence, Criscuolo, Haskel, and Slaughter (2005) analyze survey data collected for E.U. countries and find that firms that operate globally devote more resources to assimilating knowledge from abroad and generate more innovations and productivity improvement. An implication of these studies is that attempts to identify export-productivity links from micro data on the timing of these activities may be reflecting spurious effects of the firm's other activities.

Two recent papers have formalized the potential linkages between the firm's productivity and its choices to export and/or invest in R&D or new technology using industry dynamic models. Atkeson and Burstein (2007) and Constantini and Melitz (2007) model the interdependence between these two choices and firm productivity. Both papers share several common features. First, productivity is the underlying state variable that distinguishes heterogeneous producers. Second, productivity evolution is endogenous, affected by the firm's innovation decisions, and contains a stochastic component. Third, while they differ in the specific structure of costs and

¹See Greenaway and Kneller (2007) for a recent survey of the micro econometric evidence on this topic.

information, they each analyze the pathways through which the dynamic export and investment decisions are linked. One pathway is that investment in innovation results in future productivity improvement, which then results in a higher probability of the firm being competitive in international markets. A second pathway is that firms that export have larger markets in which to operate which, in turn, results in a higher return to any cost-saving or demand-inducing innovations and raises the firms' probability of undertaking R&D investments. These mechanisms do not require that exporting has a direct effect on future productivity, what is often termed learning-by-exporting, but they generate an effect of current exporting on future productivity through the innovation linkage.

In this paper we develop and estimate a structural empirical model of firm exporting and R&D investment that incorporates these key features. We allow both the firm's R&D investment and export status to affect the distribution of its future productivity. We model the optimal firm decisions treating R&D and exporting as discrete choices. These decisions depend on the expected future profits and the current fixed or sunk costs the firm incurs with these choices. After estimating the process of productivity evolution and the behavioral rules, we can then explain the relative importance of R&D investment and exporting as the source of productivity change. The empirical estimates also provide a basis for simulating the future path of firm productivity under alternative demand conditions or policy regimes, such as trade liberalization or R&D subsidies.

We use the empirical model to study the sources of productivity change among Taiwanese manufacturing plants in the electronics products industry for the period 2000-2004. This industry is an excellent place to measure these relationships. It is characterized by high rates of productivity growth, significant export market participation (an export rate of approximately .39 in our plant data), and significant R&D investment by the plants (a .17 rate of participation in our sample). Our empirical results reveal a rich set of productivity determinants. The evolution of firm productivity differs significantly across firm's that undertake the different combinations of R&D investment and exporting. Both activities have a positive effect on future firm productivity but, when modeled as discrete activities, the impact of R&D is larger. The dynamic model recognizes this process and models how the firms investment behavior is affected

by it. We find that there are significant interactions between the two investment choices. There are substantial investment costs and export costs involved with R&D and exporting decisions. The decisions to invest in R&D and to export depend on both the firm's history of these activities and their expectation about future productivity improvement and export demand, because the return to each activity is affected by the presence of the other one.

The next section of this paper develops the theoretical model of the firm's dynamic decision to invest in R&D and exporting and the third section presents a two-stage estimation method for the model. The first stage exploits data on the firm's domestic revenue and total cost, among other things, to estimate the underlying process for firm productivity. The second stage uses these to estimate the dynamic decision rules for R&D and export market participation. The fourth section provides a brief discussion of the data source and the fifth section summarizes the empirical findings.

2 A Structural Model of Exporting and R&D

The theoretical model developed in this section is similar in several ways to the models of exporting developed by Clerides, Lach, and Tybout (1998), Melitz (2003), and Das, Roberts, and Tybout (2007) and the models of exporting and investment by Atkeson and Burstein (2007) and Constantini and Melitz (2007). We abstract from the decision to enter or exit production and instead focus on the investment decisions and process of productivity evolution. Firms are recognized to be heterogeneous in their productivity and this determines each firm's incentives to invest in R&D and export. In turn, these investments have feedback effects that can alter the path of future productivity for the firm. We divide the firm's decision making into a static component, where the firm's productivity determines its short-run profits from exporting, and a dynamic component where the firm makes optimal R&D investment and export-market participation decisions.

2.1 Static Decisions

We begin with a model of the firm's revenue in the domestic and export market. Firm i 's short-run marginal cost function is written as:

$$lnc_{it} = lnc(k_{it}, w_t) - x_{it} = \beta_0 + \beta_k \ln k_{it} + \beta_w \ln w_t - x_{it} \quad (1)$$

where k_{it} is firm capital stock, w_t is a vector of variable input prices common to all firms, and x_{it} is firm productivity.² Several features of the specification are important. The firm is assumed to produce a single output which can be sold in both domestic and export markets and marginal cost is identical across the two markets for a firm. There are two sources of short-run cost heterogeneity, capital stocks that are observable in the data and firm productivity that is observable to the firm but not observable in our data. Marginal cost does not vary with the firm's output level which implies that demand shocks in one market do not affect the static output decision in the other market and allows us to model revenue and profits in each market independently of the output level in the other market.³

Both the domestic and export market are assumed to be monopolistically competitive and segmented from each other. This rules out strategic interaction among firms in the each market but does allow firms to charge markups that differ across markets. The demand curves faced by firm i in the domestic and export markets are assumed to have the Dixit-Stiglitz form. In the domestic market it is:

$$q_{it}^D = Q_t^D (p_{it}^D / P_t^D)^{\eta_D} = \frac{I_t^D}{P_t^D} \left(\frac{p_{it}^D}{P_t^D} \right)^{\eta_D} = \Phi_t^D (p_{it}^D)^{\eta_D} \quad (2)$$

where Q_t^D and P_t^D are the industry aggregate output and price index, I_t^D is total market size, and η_D is the constant elasticity of demand. The firm's demand depends on the industry aggregates, represented by Φ_t^D , its price p_{it}^D , and the constant demand elasticity. In the export market we allow the firm's demand to depend on a firm-specific demand shifter z_{it} . By including this term we incorporate an exogenous source of firm-level variation which will allow a firm's relative demands in the domestic and export market to vary across plants and over time. The

²Other firm-level cost shifters can be included in the empirical specification. In this version we will focus on the heterogeneity that arises from differences in size as measured by capital stocks and productivity.

³The domestic market will play an important role in modeling the dynamic decision to invest in R&D developed later.

firm is assumed to observe z_{it} when making its export decision, but it is not observable in our data. The demand curve firm i faces in the export market is:

$$q_{it}^X = \frac{I_t^X}{P_t^X} \left(\frac{p_{it}^X}{P_t^X} \right)^{\eta_X} \exp(z_{it}) = \Phi_t^X (p_{it}^X)^{\eta_X} \exp(z_{it}) \quad (3)$$

Given it's demand and marginal cost curves, firm i chooses the price in each market to maximize the sum of domestic and export profits. The first-order condition for the domestic market price p_{it}^D implies that the log of domestic market revenue r_{it}^D is:

$$\ln r_{it}^D = (\eta_D + 1) \ln \left(\frac{\eta_D}{\eta_D + 1} \right) + \ln \Phi_t^D + (\eta_D + 1)(\beta_0 + \beta_k \ln k_{it} + \beta_w \ln w_t - x_{it}) \quad (4)$$

Specifically, the firm's revenue depends on the aggregate market conditions and the firm specific productivity and capital stock. Similarly, *if the firm chooses to export*, export market revenue is:

$$\ln r_{it}^X = (\eta_X + 1) \ln \left(\frac{\eta_X}{\eta_X + 1} \right) + \ln \Phi_t^X + (\eta_X + 1)(\beta_0 + \beta_k \ln k_{it} + \beta_w \ln w_t - x_{it}) + z_{it} \quad (5)$$

depending on the aggregate export market conditions, firm productivity, capital stock, and the export market demand shock. These two equations show how we will utilize the information on firm domestic and export revenue. Domestic revenue will provide information on marginal cost, in particular the productivity level x_{it} , for all firms in production. The export market revenue will provide information on the export demand shocks, but only for firms that are observed to export.

Given these functional form assumptions for demand and marginal cost, there is a simple link between firm revenue and profit in each market. The firm's profit in the domestic market is:

$$\pi_{it}^D = -\left(\frac{1}{\eta_D}\right)r_{it}^D(\Phi_t^D, k_{it}, x_{it}) \quad (6)$$

where revenue is given above. Similarly, if the firm chooses to export, the profits they will earn are linked to export market revenue as:

$$\pi_{it}^X = -\left(\frac{1}{\eta_X}\right)r_{it}^X(\Phi_t^X, k_{it}, x_{it}, z_{it}) \quad (7)$$

These equations will allow us to measure firm profits from observable data on revenue in each market. These short-run profits will be important determinants of the firm's decision to export and to invest in R&D in the dynamic model developed in the next two sections.

2.2 Transition of the State Variables

In order to model the firm’s dynamic optimization problem for exporting and R&D we begin with a description of the evolution of the process for firm productivity x_{it} and the other state variables $\ln\Phi_t^D$, $\ln\Phi_t^X$, z_{it} , and k_{it} . We assume that productivity evolves over time as a Markov process, that depends on the firm’s investments in R&D, its participation in the export market, and a random shock:

$$\begin{aligned} x_{it} &= g(x_{it-1}, d_{it-1}, e_{it-1}) + \xi_{it} \\ &= \alpha_0 + \alpha_1 x_{it-1} + \alpha_2 (x_{it-1})^2 + \alpha_3 (x_{it-1})^3 + \alpha_4 d_{it-1} + \alpha_5 e_{it-1} + \alpha_6 d_{it-1} e_{it-1} + \xi_{it} \end{aligned} \tag{8}$$

d_{it-1} is the firm’s R&D investment, e_{it-1} is the firm’s export market participation in the previous period, and ξ_{it} is an iid shock with zero mean and variance σ_ξ^2 . The second line of the equation gives the assumed functional form for this relationship: a cubic function of lagged productivity and a full set of interactions between lagged exporting and R&D. The inclusion of d_{it-1} recognizes that the firm may affect the evolution of its productivity by investing in R&D.

⁴ The inclusion of e_{it-1} allows for the possibility of learning-by-exporting, that participation in the export market is a source of knowledge or expertise that can improve future productivity. d and e can each be modeled as continuous variables, treating them as flows of R&D expenditure and export market sales, respectively. Alternatively, they can be modeled as discrete 0/1 variables that reflect whether or not the firm undertakes its own R&D in prior years or participates in the export market. In the empirical model developed below, we treat both variables as discrete. This is consistent with the evidence reported by Aw, Roberts, and Winston (2008) who estimate a reduced-form model consistent with the structural model we develop here. They find that productivity evolution for Taiwanese electronics producers is affected by the discrete export and R&D variables. They also find that firm productivity is a significant determinant of the discrete decision to undertake each of these activities, but find little evidence that productivity is correlated with the level of R&D spending and export market sales.

The firm’s capital stock will be treated as fixed over time k_i . We will recognize the differences in capital stocks across plants but not attempt to model the firm’s investment in capital. Given

⁴Doraszelski and Jaumendreu (2007) estimate a production function where productivity evolves endogenously with the firm’s choice of R&D. In contrast to this paper, they do not develop an estimable model of R&D choice.

the relatively short time series in our data, most of the variation in capital stocks is across firms and the intertemporal effects of changes in the capital stock on marginal cost are going to be difficult to quantify precisely in this data even without the complexity of productivity variation.

The firm's export demand shock will be modeled as a first-order Markov process:

$$z_{it} = \rho_z z_{it-1} + \mu_{it}, \mu_{it} \sim N(0, \sigma_\mu^2). \quad (9)$$

If a source of firm-level heterogeneity like z was not included in this model, there would be a perfect cross-section correlation between domestic and export revenue. In our application it is important to allow persistence in the evolution of z because it is going to capture factors like the nature of the firm's product, the set of countries they export to, and any long-term contractual or reputation effects that lead to persistence in the demand for its exports over time. Finally, the aggregate state variables $\ln\Phi_t^D$, $\ln\Phi_t^X$ are treated as exogenous first-order Markov processes that will be controlled for using time dummies in the empirical model.

2.3 Dynamic Decisions - R&D and Exporting

In this section we develop the firm's dynamic decision to export and invest in R&D. A firm entering the export market will incur a nonrecoverable sunk cost and this implies that the firm's past export status is a state variable in the firm's export decision. This is the basis for the dynamic models of export participation developed by Roberts and Tybout (1997) and Das, Roberts, and Tybout (2007). In this paper there is an additional intertemporal linkage in the firm's investment decisions. The firm's export and R&D choices can affect its future productivity as shown in equation 8.

While the static profits 6 and 7 earned by the firm are one important component of its decisions, these will also depend on the combination of markets it participates in and the fixed and sunk costs it must incur. It is necessary to make explicit assumptions about the timing of the firm's decision to export and undertake R&D. We assume that the firm first observes values of the fixed and sunk costs of exporting, γ_{it}^F and γ_{it}^S , and makes its discrete decision to export in year t . Following this, it observes its value of the fixed cost of investment γ_{it}^I and makes the

discrete decision to undertake R&D.⁵ All three costs are assumed to be iid draws from a known joint distribution G^γ .

The firm's value function in year t before it observes its fixed and sunk costs can be written as:

$$V_{it}(z_{it}, k_i, x_{it}, \Phi_t, e_{it-1}) = \int (\pi_{it}^D + \max_{e_{it}} \{(\pi_{it}^X - \gamma_{it}^F - (e_{it-1} = 0)\gamma_{it}^S) + V_{it}^E, V_{it}^D\}) dG^\gamma \quad (10)$$

where V_{it}^E is the value of an exporting firm after it makes its optimal R&D decision. Similarly, V_{it}^D is the value of a non-exporting firm after it makes its optimal R&D decision. This equation shows that the firm chooses to export in year t when the current plus expected gain in future export profit exceeds the fixed cost plus the sunk cost, if relevant. In this equation the value of investing in R&D is subsumed in V_{it}^D and V_{it}^E . Specifically,

$$V_{it}^E = \int \max_{d_{it} \in (0,1)} \{ \delta E_t V_{it+1}(\cdot | e_{it} = 1, d_{it} = 1) - \gamma_{it}^I, \delta E_t V_{it+1}(\cdot | e_{it} = 1, d_{it} = 0) \} dG^{\gamma^I} \quad (11)$$

The first term shows that if the firm chooses to undertake R&D ($d_{it} = 1$) then it pays the current investment cost and has an expected future return which depends on how R&D affects future productivity. If they do not invest ($d_{it} = 0$) they have a different productivity path. The larger the impact of R&D on future productivity, the larger the difference between the expected returns of doing R&D versus not doing R&D and thus the more likely the firm is to invest in R&D. Similarly, the value of R&D to a non-exporting firm is:

$$V_{it}^D = \int \max_{d_{it} \in (0,1)} \{ \delta E_t V_{it+1}(\cdot | e_{it} = 0, d_{it} = 1) - \gamma_{it}^I, \delta E_t V_{it+1}(\cdot | e_{it} = 0, d_{it} = 0) \} dG^{\gamma^I} \quad (12)$$

where the firm faces the same tradeoff, but now the future productivity paths will be those for a non-exporter. Finally, to be specific the expected future value conditional on different choices for e_{it} and d_{it} is:

$$E_t V_{it+1} = \int \int \int V_{it+1}(\cdot | e_{it}) dF(x' | x_{it}, e_{it}, d_{it}) dF(z' | z) dG(\Phi' | \Phi) \quad (13)$$

⁵ An alternative assumption is that the firm simultaneously chooses d and e . This will lead to a multinomial model of the four possible combinations of exporting and R&D investment. In the empirical application, it is more difficult to calculate the probability of each outcome in this environment.

In this equation, V_{it+1} is conditional on e_{it} because of the sunk entry cost. The evolution of productivity is conditional on both e_{it} and d_{it} because of the assumption in equation 8

A special case of this model is an environment where the sunk cost of exporting is always zero and exporting does not affect the evolution of productivity in equation 8. In this case exporting becomes a static decision and $V_{it}^E = V_{it}^D$, an exporter and a non exporter will have the same valuation of R&D investment.⁶ This model illustrates that when there are sunk costs of entry and/or learning by exporting then exporters will value R&D investment differently than nonexporters.

To summarize the model, firm's differ in their past export market experience, capital stocks, productivity, and export demand and these determine their short-run profits in the domestic and export market. The firm can affect its future productivity and thus profits by investing in R&D or acquiring expertise in the export market. These processes, combined with fixed and sunk costs of exporting and fixed cost of R&D investments, determine the firm's optimal decisions on export market participation and whether or not to undertake R&D. In the next section we detail how we estimate the structural parameters of the profit functions, productivity process, and costs of exporting and conducting R&D.

3 Empirical Model and Estimation

The model of the last section can be estimated using firm-level panel data on export market participation, export market revenue, domestic market revenue, capital stocks, and the discrete R&D decision. In this section we develop a maximum likelihood estimator based on the probabilities of exporting and undertaking R&D. The model will be developed and estimated in two stages. In the first stage, parameters of the cost and demand functions and the productivity evolution process will be estimated and used to derive estimates of firm productivity. In the second stage, the export and R&D decision will be used to estimate the fixed and sunk cost of exporting, the fixed cost of R&D, and the remaining export demand parameters. The likelihood

⁶This does not imply that the ability to export has no effect on the firm's choice of R&D. Atkeson and Burstein's (2007) model treats exporting as a static decision but the expectation of lower future fixed costs in the export market increases the firm's incentive to invest in current R&D. They study the implications of this market size effect on the evolution of industry structure and productivity.

estimator is based on the method used by Das, Roberts, and Tybout (2007) where their model is augmented with the R&D decision and a more general process for productivity evolution, which will require modeling the domestic side of the firm’s production. The full set of model parameters is the market demand elasticities η_X and η_D , the aggregate demand shifters, Φ_t^X and Φ_t^D , the marginal cost parameters β_0, β_k , and β_w , the function describing productivity evolution $g(x_{it-1}, d_{it-1}, e_{it-1})$, the variance of the productivity shocks σ_ξ^2 , the distribution of the fixed and sunk cost of exporting and the fixed cost of investment, G^γ and the Markov process parameters for the export demand shocks, ρ_z and σ_μ^2 .

3.1 Demand and Cost Parameters

We begin by estimating the domestic demand, marginal cost, and productivity evolution parameters. The domestic revenue function in equation 4 is appended with an iid error term u_{it} to give:

$$\ln r_{it}^D = (\eta_D + 1) \ln\left(\frac{\eta_D}{\eta_D + 1}\right) + \ln \Phi_t^D + (\eta_D + 1)(\beta_0 + \beta_k \ln k_{it} + \beta_w \ln w_t - x_{it}) + u_{it} \quad (14)$$

where the composite error term, $(\eta_D + 1)(-x_{it}) + u_{it}$ contains firm productivity.⁷ We utilize the insights of Olley and Pakes (1996) and Levinsohn and Petrin (2004) to rewrite the unobserved productivity in terms of some observable variables that are correlated with it.⁸ In our case, the firm’s choice of the variable input levels for materials, m_{it} , and electricity, n_{it} , will depend on the level of productivity (which is observable to the firm) and we will use the materials and electricity data to control for the productivity in equation 14.⁹ By combining the demand elasticity terms into an intercept γ_0 , and the time-varying aggregate demand shock and market-level factor prices into a set of time dummies D_t , equation 14 can be written as:

⁷This may be correlated with the firm’s capital stock because, as implied by the theoretical model in section 3, more capital intensive firms have a higher probability of investing in R&D which leads to an endogeneity problem.

⁸In estimating the static demand and cost parameters, we allow the firm’s capital stock to vary over time to get a more precise estimate of the productivity process. In the estimation of the dynamic export and R&D decisions in section 4.2 we simplify the process and divide the capital stock into fixed, discrete categories.

⁹See Akerberg, Benkard, Berry, and Pakes (forthcoming), section 2.4.3, for assumptions needed to map two observed variable inputs into a pair of unobserved state variables. In our case we observe total material and energy use by each firm and these are determined by firm productivity (x) and the export market demand shock (z).

$$\begin{aligned}
\ln r_{it}^D &= \gamma_0 + \sum_{t=0}^4 \gamma_t D_t + (\eta_D + 1)(\beta_k \ln k_{it} - x_{it}) + u_{it} \\
&= \gamma_0 + \sum_{t=0}^4 \gamma_t D_t + h(k_{it}, m_{it}, n_{it}) + v_{it}
\end{aligned} \tag{15}$$

where the function $h(\cdot)$ captures the combined effect of capital and productivity on marginal cost and domestic revenue. We specify $h(\cdot)$ as a cubic function of its arguments and estimate equation 15 with ordinary least squares. The fitted value of the $h(\cdot)$ function, which we denote $\hat{\phi}_{it}$, is an estimate of $(\eta_D + 1)(\beta_k \ln k_{it} - x_{it})$. Next, as in Olley and Pakes (1996) and Doraszelski and Jaumandreu (2007), we incorporate the assumption about the evolution of productivity in order to estimate the parameters of this process, equation 8 and construct a productivity series $(x_{i1}, x_{i2}, \dots, x_{iT})$ for each firm. Rewriting the unobserved x_{it} in terms of $\hat{\phi}_{it}$ and k_{it} and substituting into 8 gives an estimating equation:

$$\begin{aligned}
\hat{\phi}_{it} &= \beta_k^* \ln k_{it} + \alpha_0^* + \alpha_1^*(\hat{\phi}_{it-1} - \beta_k^* \ln k_{it-1}) + \alpha_2^*(\hat{\phi}_{it-1} - \beta_k^* \ln k_{it-1})^2 + \\
&\quad \alpha_3^*(\hat{\phi}_{it-1} - \beta_k^* \ln k_{it-1})^3 + \alpha_4^* d_{it-1} + \alpha_5^* e_{it-1} + \alpha_6^* d_{it-1} e_{it-1} + \xi_{it}^*
\end{aligned} \tag{16}$$

where the star represents that the α and β_k coefficients are multiplied by $(\eta_D + 1)$.¹⁰ This equation can be estimated with nonlinear least squares and the underlying α and β_k parameters can be retrieved given an estimate of η_D .

The final estimating equation in the static demand and cost model exploits the assumption that marginal cost is constant with respect to output and equal for both domestic and export output for a firm. As shown in Das, Roberts and Tybout (2007) this assumption implies that marginal cost is equal to marginal revenue in each market and thus total cost is an elasticity-weighted combination of total revenue in each market:

$$tc_{it} = r_{it}^D \left(1 + \frac{1}{\eta_D}\right) + r_{it}^X \left(1 + \frac{1}{\eta_X}\right) + \varepsilon_{it} \tag{17}$$

where the error terms reflects measurement error in total cost. This equation provides estimates of the two demand elasticity parameters.

¹⁰The only exceptions are that $\alpha_2^* = \alpha_2(1 + \eta_D)^{-1}$ and $\alpha_3^* = \alpha_3(1 + \eta_D)^{-2}$

Three key aspects of this static empirical model are worth noting. First, we utilize data on the firm’s domestic revenue to estimate firm productivity, an important source of firm heterogeneity that is relevant in both the domestic and export market. In effect, we use domestic revenue data to help estimate the underlying profit heterogeneity in the export market. Second, like Das, Roberts, and Tybout (2008) we utilize data on the firm’s total variable cost to estimate demand elasticities and markups in both markets. Third, the method we use to estimate the parameters of the productivity process can be extended to include other endogenous variables that impact productivity. This formulation provides estimates that are important in estimating the firm’s dynamic investment equations. The estimated parameters from equation 8 are used directly to construct the value functions that underlie the firm’s R&D and export choice.

3.2 Dynamic Parameters

The remaining parameters of the model, the fixed and sunk costs of exporting and investment, and the process for the export demand/profit shocks can be estimated using the discrete decisions for export market participation e_{it} and R&D d_{it} and export revenue r_{it}^X for the firm’s that choose to export. Intuitively, entry and exit from the export market provide information on the magnitude of the sunk entry costs γ^S and fixed cost γ^F respectively. The level of export revenue provides information on the magnitude of the demand shocks z_{it} conditional on exporting, which can be used to infer the unconditional distribution for the export shocks. The fixed cost of R&D investment is estimated from the discrete R&D choice.

The dynamic estimation is based on the likelihood function for the observed patterns of plant exporting, export revenue, and the patterns of plant R&D investment. To denote the time-series data for year 0 to year T for any variable (W) for firm i we will use the notation $W_{i0}^T = (W_{i0}, W_{i1}, \dots, W_{iT})$. Once we recover the first stage estimates and the firm-level productivity series x_{i0}^T , we can write the i th firm’s contribution to the likelihood, following Das, Roberts, and Tybout (2007), as:

$$\begin{aligned} P(e_{i0}^T, d_{i0}^T, r_{i0}^{xT} | k_i, x_{i0}^T, \Phi_0^T) &= P(e_{i0}^T, d_{i0}^T | z_i^+, k_i, x_{i0}^T, \Phi_0^T) h(z_i^+) \\ &= \left[\int_{\mu_i} P(e_{i0}^T, d_{i0}^T | z_0^T(z_i^+, \mu_i), k_i, x_{i0}^T, \Phi_0^T) \cdot f(\mu_i) d\mu_i \right] \cdot h(z_i^+) \end{aligned} \quad (18)$$

The first line of this equation rewrites the joint probability of the data into the joint probability

of the discrete e and d decisions, conditional on the export market shocks z , and the marginal distribution of z . The notation z_i^+ is used to denote that we only observe export market shocks for the years when firm i exports. The second line recognizes that, because of the serial correlation in z , each year of exporting provides information about the whole time series of z for the firm. The export market shocks in both exporting and non-exporting years, denoted by $z_0^T(z_i^+, \mu_i)$, can be imputed from the shocks, in the exporting years and knowledge of the process for z , as defined in equation 9.¹¹

A key part of the likelihood function is the joint probability of the discrete e and d series. Because of the sunk cost in entering the export market, the probability of exporting in any period depends on the prior period's choice. In the first year of our data, period 0, we do not observe the prior choice and this leads to an initial conditions problem in estimating the probability of exporting. We treat this using Heckman's (1981) suggestion and separately model the decision to export in period 0 with a probit equation.¹² We denote this by rewriting the probability of the export series in two parts, one capturing only period 0 and the other capturing the remaining years 1, 2, ... T :

$$P(e_{i0}^T, d_{i0}^T | z_0^T(z_i^+, \mu_i), k_i, x_{i0}^T, \Phi_0^T) = P(e_{i1}^T, d_{i0}^T | z_0^T(z_i^+, \mu_i), k_i, x_{i0}^T, \Phi_1^T, e_{i0}) \cdot P(e_{i0} | z_0(z_i^+, \mu_i), k_i, x_{i0}^T, \Phi_0) \quad (19)$$

The first term in this equation can be related directly to the model above. Under the assumption that γ 's are iid over time, we can write it as:

$$P(e_{i1}^T, d_{i0}^T | z_0^T(z_i^+, \mu_i), k_i, x_{i0}^T, \Phi_0^T, e_{i0}) = \prod_{t=1}^T P(e_{it} = 1 | z_{it}, k_i, x_{it}, \Phi_t, e_{it-1})^{e_{it}} \cdot P(e_{it} = 0 | z_{it}, k_i, x_{it}, \Phi_t, e_{it-1})^{1-e_{it}} \prod_{t=0}^T P(d_{it} = 1 | z_{it}, k_i, x_{it}, \Phi_t, e_{it})^{d_{it}} \cdot P(d_{it} = 0 | z_{it}, k_i, x_{it}, \Phi_t, e_{it})^{1-d_{it}} \quad (20)$$

This equation expresses the conditional choice probabilities for e_{it} and d_{it} as functions of the state variables, $z_{it}, k_i, x_{it}, \Phi_t$ and e_{it-1} .¹³

¹¹Evaluation of the likelihood function is done by simulating the values of μ_i , given the estimate of σ_μ^2 . The distribution $h(z_i^+)$ is normal with zero mean and a variance-covariance matrix that depends on the serial correlation parameter ρ_z and σ_μ^2 . See Das, Roberts and Tybout (2007) for details.

¹²The probability of exporting in year 0 is modeled as a probit function of the period 0 state variables x_{i0}, k_i, z_{i0} .

¹³We assume that the fixed and sunk costs are drawn from exponential distributions and therefore the condi-

Equations 11 and 12 show that the firm's conditional probability of investing in R&D is equal to:

$$P(d_{it} = 1 | z_{it}, k_i, x_{it}, \Phi_t, e_{it}) = P(\gamma_{it}^I \leq \delta E_t V_{it+1}(\cdot | e_{it}, d_{it} = 1) - \delta E_t V_{it+1}(\cdot | e_{it}, d_{it} = 0)) \quad (21)$$

The firm compares the increase in expected future value if it chooses to do R&D with the current period cost of R&D. Our model shows that this increase will differ for firms that export and those that do not for two reasons. First, exporting may directly affect future productivity as modeled in equation 8. If there is "learning-by-exporting" this would be the channel at work. Second, the increase in productivity resulting from R&D will increase the profits on each unit of output and firms that operate in both the domestic and export market will have a larger total gain. This is the mechanism emphasized by Constantini and Melitz (2007), Atkeson and Burstein (2006), and Lileeva and Trefler (2007).

Equation 10 shows the firm's decision to export depends on its previous export status because of the sunk entry cost. It also involves a comparison of the gains in the expected profits from exporting with the fixed cost, for previous period exporters, and the sum of the fixed and sunk cost for nonexporters. From this equation, the probability of exporting can be written as:

$$P(e_{it} = 1 | z_{it}, k_i, x_{it}, \Phi_t, e_{it-1}) = P(\gamma_{it}^F + (e_{it-1} = 0)\gamma_{it}^S \leq V_{it}^E + \pi_{it}^X - V_{it}^D) \quad (22)$$

The probabilities of investing in R&D and exporting in equations 21 and 22 depend on the value functions $E_t V_{it+1}$, V_{it}^E , and V_{it}^D . For a given set of parameters, these can be constructed by iterating on the equation system defined by 10, 11, 12, and 13.

4 Data

The model developed in the last section will be used to analyze the productivity change of the Taiwanese electronics industry over the period 2000-2004. The data used in the empirical estimation was collected by the Ministry of Economic Affairs (MOEA) in Taiwan of manufacturing

 tional choice probabilities can be evaluated with the exponential cdf.

plants over the period 2000 to 2004. The data is drawn from the annual manufacturing surveys, which, while not complete censuses of all producers, do have wide coverage of the sector, covering firms responsible for approximately 92 percent of manufacturing employment.

There are four broad product classes included in the electronics industry: consumer electronics, telecommunications equipment, computers and storage equipment, and electronics parts and components. The electronics industry has been one of the most dynamic industries in the Taiwanese manufacturing sector and is a major export industry. For instance, in 2000, the electronics subsector accounted for about 40 percent of total export orders in the manufacturing sector.

In addition, electronics has also been viewed as Taiwan's most promising and prominent "high-tech" industry. As reported by National Science Council of Taiwan, R&D expenditure in the electronics industry accounts for more than 72% of the manufacturing grand total in 2000. R&D Expenditure is reported as the sum of the salaries of R&D personnel (researchers and scientists), material purchases for R&D, and R&D capital (equipments and buildings) expenses.

5 Empirical Results

5.1 Empirical Transition Patterns for R&D and Exporting

The empirical model developed in the last section explains the firm's investment decisions. Before we report the estimation results we provide a summary of the patterns of R&D and exporting behavior for the firm's in the Taiwanese electronics sector over the period 2000-2004. Table 1 reports the proportion of firms that undertake each combination of the activities and the transition rates between pairs of activities over time. The first row reports the cross-sectional distribution of exporting and R&D averaged over all years. It shows that in each year, the proportion of firms undertaking neither of these activities is .563. The proportion that conduct R&D but do not export is .036, export only is .255, and do both activities is .146. Overall exporting is a more common activity than R&D investment, .401 to .182, but .437 of the firms engage in at least one of the investments. In the data there is a diverse mix of investment behavior across the firms and this is important in identifying the fixed costs of R&D and exporting.

The transition patterns among R&D and exporting are also important for the model estimation. The last four rows of the table report the transition rate from each activity in year t to each activity in $t + 1$. Several patterns are clear. First, there is significant persistence in the status over time. Of the firms that did neither activity in year t , .871 of them are in the same category in year $t + 1$. Similarly, the probability of remaining in the same category over adjacent years is .336, .708, and .767 for the other three categories. This can reflect a combination of high sunk costs of entering a new activity and a high degree of persistence in the underlying sources of profit heterogeneity, which, in our model, are capital stocks k , productivity x and the export demand shocks z .

Second, firms that undertake one of the activities in year t are more likely to start the other activity than a firm that does neither. If the firm does neither activity in year t , it has a probability of .115 that it will enter the export market. This is lower than the .291 probability that a firm conducting R&D only will then enter the export market. This is consistent with the argument that a firm that conducts its own R&D will have a higher perceived return in the export market than a firm that does no R&D. This higher perceived path of future productivity by firms conducting R&D makes it more likely they will incur the sunk cost to enter the export market. Similarly, a firm that does neither activity has a .019 probability that it will start investing in R&D, but an exporting firm has a .080 probability of adding R&D investment to its activities. This is consistent with the firm's perception that R&D is more valuable to firms operating in both the domestic and export market. This is the market size effect on the incentive to conduct R&D that has been emphasized in the recent theoretical papers.

Third, for the same reasons discussed in the last paragraph, firms that conduct both activities in year t are less likely to abandon one of the activities than firms that only conduct one of them. Firms that both export and do R&D have a .171 probability of abandoning R&D and a .086 probability of leaving the export market. Firms that only do R&D have a .430 probability of stopping while firms that only export have a .223 probability of stopping.

The transition patterns reported in Table 1 illustrate the need to model the R&D and exporting decision jointly. In our model, there are two mechanisms linking these activities. One is that an investment in either activity can affect the future path of productivity as shown

in equation 8 and thus the return to both R&D and exporting. A second pathway is possible for exporting. Even if exporting does not directly enter the productivity evolution process, the return to R&D will be higher for exporting versus nonexporting firms, raising the probability that exporting firms will also conduct R&D.

5.2 Demand, Cost, and Productivity Evolution

The parameter estimates from the first-stage estimation of equations 16 and 17 are reported in Table 2. The coefficients on the x , d , and e variables are the α^* coefficients in equation 16. We report estimates in column 1 using the discrete measure of R&D, which we also use in the dynamic model. For comparison purposes, column 2 reports a set of estimates using the log of the R&D expenditure as the explanatory variable.

Focusing on the first column, the demand elasticity parameters are virtually identical in the domestic and export market. The implied value of η_D is -6.38 and the value of η_X is -6.10. These elasticity estimates imply markups of 1.186 for domestic market sales and 1.196 for foreign sales. The coefficient on lnk_{it-1} is an estimate of the elasticity of capital in the marginal cost function β_k multiplied by $1 + \eta_D$. It implies that β_k equals -0.064 (s.e.=.0052) which is a reasonable estimate. More interesting are the coefficients for productivity evolution. The coefficients α_1^* , α_2^* , and α_3^* measure the effect of the three powers of x_{it-1} on x_{it} . They imply a clear significant non-linear relationship between current and lagged productivity. The coefficient α_4^* measures the effect of the lagged discrete R&D investment on current productivity and it is positive and significant. This is consistent with the findings of Doraszelski and Jaumandreu (2007) using panel data from the Spanish manufacturing sector. The direct effect of past exporting on current productivity is given by α_5^* and is also positive and significant. This is a measure of the productivity impact of learning-by-exporting. The magnitude of the export coefficient is only .4 of the magnitude of the R&D variable implying a larger direct productivity impact from R&D than exporting. The last coefficient α_6^* measures an interaction effect from the combination of past exporting and R&D on productivity evolution. It is negative although not significant. There is no evidence in this short panel of annual data that there is a complementary effect of both activities on productivity.¹⁴ The final parameter $SE(\xi_{it}^*)$ is a measure of the stochastic

¹⁴Aw, Roberts, and Winston (2007) also studied this industry using data from a 10-year time period, analyzed

variation in the productivity process.

Column 2 of Table 2 repeats the estimation using the continuous level of R&D expenditure rather than the discrete variable. This change has no effect on any of the model coefficients except the two coefficients on R&D, α_4^* and α_6^* . The statistical significance of α_4^* and the insignificance of α_6^* is not affected. In either specification the conclusion about the important role of R&D is the same. We will utilize the discrete specification in the dynamic model. Overall, the process for the evolution of firm productivity is dependent on past productivity, exporting experience, the firm's decision to conduct R&D, and a stochastic component. This is the productivity process that underlies the estimates of our dynamic model of firm R&D and exporting choice reported in the next section.

Given the importance of the productivity process in the model of the firm's investment decisions, we next report some summary statistics of this process before turning to dynamic estimation. The series on firm productivity can be constructed from the estimated parameters as:

$$\hat{x}_{it} = -(\hat{\phi}_{it} - \hat{\beta}_k^* \ln k_{it}) / (1 + \hat{\eta}_D) \quad (23)$$

In the top panel of Figure 1 we present the mean path of productivity evolution over a twenty-five year period for firms with the four combinations of e and d consecutively for the whole period. Each series is expressed relative to the mean productivity path for the firms with no exporting or R&D investment $e = 0, d = 0$. Each of the groups has greater productivity improvement than the base but the magnitude differs substantially depending on the type of activity. As reflected in the Table 2 coefficients, the largest improvement is for the firms that both export and conduct R&D ($e = d = 1$), the second highest path is for firms that only conduct R&D ($d = 1, e = 0$), and the smallest improvement is for the firms that only export ($e = 1, d = 0$). After 25 years, the firms that only export are 34 percent more productive than the base group. The impact of R&D is much larger. Firms that only do R&D are twice as productive as the base group at the end of the period, while the firms that do both are 123 percent more productive.

at 5-year intervals, and found a more substantial role for past exporting on productivity. In particular, they found a significant, positive interaction between R&D and exporting.

While this provides a summary of the technology linkages between exporting, R&D, and productivity, it does not recognize the impact of this process on the firm's choice to enter exporting or conduct R&D. This behavioral response is the focus of the second stage estimation. At this point we can assess whether or not the productivity measure we have constructed is likely to impact the firm's R&D and export choice. In Table 3 we report estimates of a bivariate probit regression of exporting and R&D on the firm's productivity, capital stock, lagged export dummy, and a set of time dummies. This regression is similar to the reduced form policy functions that come from our dynamic model. The only difference is the fact that the export demand shocks z are not included. This is a reason for using the bivariate probit model which allows a correlation between the error terms of the two probit equations. In both probit models, the productivity variable is highly significant, as is the capital variable, and the lagged export variable. The correlation in the errors is also positive and statistically significant implying that the decisions are driven by some other common factors, such as the export market shocks z . It is important to recognize that this productivity measure has been estimated off the domestic market revenue data. It is clear from these regressions that it is measuring an important characteristic of the firm that is correlated with their export and R&D decisions.¹⁵ In the next section we report the estimates of the dynamic investment equations.

5.3 Dynamic Estimates

The remaining cost and export demand parameters are estimated in the second stage of our empirical model using the likelihood function that is the product over the firm specific joint probability of the data given in equation 18. The coefficients are reported in Table 4 under the columns labeled Model 1. First, we will summarize the estimates of the fixed and sunk cost parameters then we will describe the estimates of the export demand shocks. Each of the three costs, fixed cost of R&D investment, fixed cost of exporting, and the sunk cost of exporting, are modeled as draws from an iid exponential distribution with position parameters γ^I, γ^F and γ^S respectively. In addition, we allow the means to differ across different groups of

¹⁵Similar results are reported in Aw, Roberts, and Winston (2007). They estimate a bivariate probit investment model and find that productivity is significant in both investments. They also find that the lagged exporting status is also an important determinant of the current investments, which is consistent with the presence of sunk costs of exporting.

firms. In this case we divided the firms into two groups based on the size of the capital stock and allow the cost distributions to differ for the small and large firms. There are a total of 6 cost parameters that are estimated. The R&D investment cost parameters indicate that the mean for the group of firms with small capital stocks is 78.42 million TW dollars (2.31 million U.S. dollars). The large firms face a higher mean investment cost of 143.66 million TW dollars (4.23 million U.S. dollars). Of course, the innovators tend to get favorable cost draws, so the average R&D cost incurred are lower. In contrast, the estimated export fixed costs are much smaller than investment costs. Its mean is 6.08 million TW dollars (178,800 U.S. dollars) for the group of small firms, and 13.3 million TW dollars (391,200 U.S. dollars) for the group of large firms. Finally, the mean sunk cost that potential exporters face is 57.37 million TW dollars (1.68 million U.S. dollars) for the group of small firms and 62.80 million TW dollars (1.85 million U.S. dollars) for the group of large firms. The final group of parameters describe the stochastic process driving the export demand shocks z . This is characterized by a first-order autoregressive process with serial correlation parameter equal to 0.709 and a standard deviation for the transitory shocks equal to 0.790. This positive serial correlation parameter indicates that the z for any firm persists over time, which will lead to persistence in the firm's export status and export revenue if they choose to be in the market.

In the last two columns of Table 4 we report estimates from an extended version of the empirical model that allows for the innovation decision to be subject to a sunk start-up cost as well as a fixed cost that the firm incurs each period. Only the parameter estimates for the innovation costs are affected, the parameters related to export costs and the export demand process are virtually unchanged. The results for Model 2 indicate that much of the cost of innovation activity is a sunk cost related to the start-up of the activity and a much smaller per-period fixed cost. The new sunk cost parameters are statistically significant in both size classes. Both the fixed and sunk cost are lower for the smaller plants than the larger plants. The results from Model 2 will form the basis for the rest of the analysis.

5.4 In-Sample Model Performance

To assess the overall fit of Model 2, we take all estimated parameters and perform two sets of simulation experiments. First, taking the initial year status $(x_i^0, z_i^0, e_i^0, k_i)$ of all plants in our data as given, we simulate their next three sample year's export demand shocks z_{it} , R&D investment costs γ_{it}^I , and export costs $\gamma_{it}^F, \gamma_{it}^S$. We then use equations 10, 11, 12, and 13 to solve each plant's optimal R&D and export decisions year by year. Since each plant's productivity x_{it} evolves endogenously according to 8, we need to simulate each plant's trajectory of productivity jointly with its dynamic decisions. Note that these simulations do not use any data information on plants characteristics after their first year. We calculate each plant's domestic and export revenues using our estimated revenue and marginal cost functions. So the simulations depend on both the results in static and dynamic estimations. For each plant, we repeat the simulation 100 times. Since our focus is the co-movement of firm's dynamic decisions of R&D, export, and the evolution of their productivity, we report in Table 5 the cross-simulation averages of the percentage of R&D performers, export market participation rate, and industry mean productivity. Overall, the simulations do a good job of replicating these average data pattern for all three variables.¹⁶

Second, we summarize the transition patterns of each plant's export and R&D status in table 6 and compare them with the actual data patterns. Our simulated panel performs reasonably well on the transition patterns for all four groups of plants. In particular for the two groups that account of 81.8 percent of the sample observations, those who engage in neither activities and those who only export, the predicted transition patterns match the data very closely. Probably the most difficult transition patterns to fit closely are the ones related to starting or stopping R&D. Given that the plant conducts R&D in year t , the model tends to overpredict the proportion of plants that will stop R&D and underestimate the proportion that will continue in year $t + 1$. This pattern is still much more closely explained with the results of Model 2 than those of Model 1.

¹⁶If we conduct the same exercise using the results of Model 1, which does not allow a sunk cost of R&D, the model fit remains very good for productivity and exporting but deteriorates for R&D. The predicted mean rates for conducting R&D vary from .140 to .148 across the three years, which are always less than the observed rate. The sunk cost of R&D is helpful in fitting the data on the incidence of R&D.

The model simulations also capture the inter-dependence of the two activities. Firms that undertake one of the activities in year t are more likely to start the other than a firm that does neither. If a firm does neither activity in year t , it has a probability of .111 of entering the export market, lower than the .278 probability that a firm conducting R&D only will enter the export market. Similarly, a firm that does neither activity has a .024 probability of starting R&D, but an exporting firm has a .075 probability of starting R&D. This inter-dependence come from the two mechanisms we emphasized in our theoretical model. First, either activity can change firm's future path of productivity and thus affect the return to the other. Second, for exporting firms, R&D is more valuable because they've already paid their sunk cost to operate in both the domestic and export market.

6 Conclusions

This paper develops and estimates a dynamic structural model that captures both the behavioral and technological linkages between R&D, exporting, and productivity. It characterizes firms' joint dynamic decisions process, which depend on their heterogeneity in productivity, export demand, size, export experience, and investment and export costs. It also describes how firms' R&D and exporting affect their future productivity trajectories. Both pathways are important to understand the effect of export promotion or R&D subsidies policies on firm productivity. It's not necessary for exporting to directly affect productivity (i.e. learning-by-exporting), but it can occur through the impact of serving a larger market on the incentives to undertake R&D.

We fit this model to plant-level data for the Taiwan electronics industry. Our estimation results show that there are significant technological impacts of R&D and exporting on productivity. The discrete R&D decision has a bigger effect than the export decision. There are substantial investment costs and export costs involved with R&D and exporting decisions. The decisions to invest in R&D and to export depend on both the firm's history of these activities and their expectation about future productivity improvement and export demand, because the return to each activity is affected by the presence of the other one.

References

- [1] Atkeson, Andrew and Ariel Burstein (2007), "Innovation, Firm Dynamics, and International Trade," Department of Economics, UCLA, working paper.
- [2] Aw, Bee Yan, Mark J. Roberts and Tor Winston (2007), "Export Market Participation, Investments in R&D and Worker Training, and the Evolution of Firm Productivity," *The World Economy*, Vol. 14, No. 1, pp. 83-104.
- [3] Aw, Bee Yan, Mark J. Roberts and Daniel Yi Xu (2008), "R&D Investments, Exporting, and the Evolution of Firm Productivity," *American Economic Review, Papers and Proceedings*, Vol.98, No.2 (May), pp. 451-456.
- [4] Baldwin, John R and Wulong Gu (2004), "Export Market Participation and Productivity Performance in Canadian Manufacturing," *Canadian Journal of Economics*, Vol. 36, pp. 634-657.
- [5] Bustos, Paula (2005), "Multilateral Trade Liberalization, Exports and Technology Upgrading: Evidence on the Impact of MERCOSUR on Argentinean Firms," CREI, Universitat Pompeu Fabra, working paper.
- [6] Clerides, Sofronis K., Saul Lach, and James R. Tybout (1998), "Is Learning By Exporting Important? Micro-Dynamic Evidence from Colombia, Mexico, and Morocco," *Quarterly Journal of Economics*, pp. 903-947.
- [7] Cohen, Wesley M. and Daniel A. Levinthal (1989), "Innovation and Learning: The Two Faces of R&D," *Economic Journal*, Vol. 99, pp. 569-596.
- [8] Constantini, James A., and Marc J. Melitz (2007), "The Dynamics of Firm-Level Adjustment to Trade Liberalization," Princeton University, working paper.
- [9] Criscuolo, Chiara, Jonathan Haskel, and Mathew Slaughter (2005), "Global Engagement and the Innovation Activities of Firms," NBER working paper 11479.

- [10] Das, Sanghamitra, Mark J. Roberts and James R. Tybout (2007), "Market Entry Costs, Producer Heterogeneity, and Export Dynamics," *Econometrica*, Vol.75, No.3 (May), pp. 837-873.
- [11] Doraszelski, Ulrich and Jordi Jaumandreu, (2007), "R&D and Productivity: Estimating Production Functions When Productivity is Endogenous," Department of Economics, Harvard University, working paper.
- [12] Greenaway, David and Richard Kneller (2007), "Firm heterogeneity, Exporting and Foreign Direct Investment," *Economic Journal*, Vol 117, (February), pp. F134-F161.
- [13] Lileeva, Alla and Daniel Trefler (2007), "Improved Access to Foreign markets Raises Plant-Level Productivity... for Some Plants," Department of Economics, University of Toronto, working paper.
- [14] Melitz, Marc J. (2003), "The Impact of Trade on Aggregate Industry Productivity and Intra-Industry Reallocations," *Econometrica*, 71(6), pp. 1695-1725.
- [15] Roberts, Mark J. and James R. Tybout (1997), "The Decision to Export in Colombia: An Empirical Model of Entry with Sunk Costs," *American Economic Review*, Vol. 87, No. 4 (September), pp. 545-564.
- [16] Xu, Daniel Yi (2008), "A Structural Model of R&D, Firm Heterogeneity, and Industry Evolution," Department of Economics, New York University, working paper.

Status year t	Status Year t+1			
	Neither	only R&D	only Export	Both
All Firms	.563	.036	.255	.146
Neither	.871	.014	.110	.005
only R&D	.372	.336	.058	.233
only Export	.213	.010	.708	.070
Both	.024	.062	.147	.767

Table 2		
Demand, Cost and Productivity Evolution		
Parameter Estimates		
Parameter	Discrete R&D	Continuous R&D
$1 + 1/\eta_D$.8432 (.0195)*	.8432 (.0195)*
$1 + 1/\eta_X$.8361 (.0164)*	.8361 (.0164)*
β_k^*	.3403 (.0279)*	.3478 (.0276)*
α_0^*	.4727 (.1068)*	.4655 (.1044)*
α_1^*	.5925 (.0519)*	.5982 (.0511)*
α_2^*	.0705 (.0170)*	.0702 (.0170)*
α_3^*	-.0050 (.0020)	-.0055 (.0020)*
α_4^*	.2576 (.0533)*	.0359 (.0067)*
α_5^*	.1052 (.0245)*	.1059 (.0242)*
α_6^*	-.0635 (.0620)	-.0123 (.0073)
$SE(\xi_{it}^*)$.5916	.5907
sample size	3703	3703

Variable	R&D (d_{it})	Exporting (e_{it})
productivity (x_{it})	2.356 (.209)*	1.718 (.157)*
capital (lnk_{it})	.356 (.024)*	.077 (.018)*
lagged export (e_{it-1})	.581 (.068)*	1.814 (.056)*
dummy year 2	-.125 (.078)	-.103 (.065)
dummy year 3	-.076 (.077)	-.129 (.065)
intercept	-6.172 (.253)*	-2.50 (.171)*
Corr errors ρ	.210(.045)*	

Table 4
Dynamic Parameter Estimates

Parameter	Model 1		Model 2	
	Estimate	St Error	Estimate	St Error
γ_I^1 (Innov FC, size 1)	78.417	7.663	31.476	3.731
γ_I^2 (Innov FC, size 2)	143.656	1.354	49.571	2.342
γ_D^1 (Innov SC, size 1)			271.649	29.141
γ_D^2 (Innov SC, size 2)			360.721	13.196
γ_F^1 (Export FC, size 1)	6.081	0.235	6.130	0.271
γ_F^2 (Export FC, size 2)	13.342	0.259	13.872	0.513
γ_S^1 (Export SC, size 1)	57.371	3.864	58.342	5.061
γ_S^2 (Export SC, size 2)	62.802	2.106	67.736	4.577
Φ_X (Export Rev Intercept)	3.903	0.013	3.886	0.041
ρ_Z (Export Rev AR process)	0.709	0.012	0.726	0.012
$\log \sigma_\mu$ (Export Rev Std Err)	-0.236	0.010	-0.260	0.001

Table 5			
R&D Investment Rates, Export Rates, and Productivity			
	Year 2002	Year 2003	Year 2004
Export Market Participation Rate			
Actual Data	.395	.392	.390
Predicted	.379	.380	.382
R&D Investment Rate			
Actual Data	.177	.170	.169
Predicted	.172	.162	.158
Average Productivity			
Actual Data	.436	.444	.436
Predicted	.449	.440	.432

Status year t		Status Year t+1			
		Neither	only R&D	only Export	Both
Neither	Predicted	.860	.023	.110	.001
	Actual	.871	.014	.110	.005
only R&D	Predicted	.473	.249	.106	.172
	Actual	.372	.336	.058	.233
only Export	Predicted	.263	.010	.663	.065
	Actual	.213	.010	.708	.070
Both	Predicted	.044	.028	.167	.762
	Actual	.024	.062	.147	.767