

R&D Investments, Exporting, and the Evolution of Firm Productivity

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A large empirical literature has documented that firm-level differences in productivity, size, ownership status, and other characteristics are crucial to understanding differences in firms' decisions to export. The evidence strongly supports the self-selection of more productive firms into export markets, but there has been more mixed evidence on the subsequent feedback effects of exporting on the future path of firm productivity. Several recent papers have introduced a new dimension into this export-productivity relationship: firm-level investments in productivity-enhancing activities such as R&D. James A. Costantini and Marc J. Melitz (2007), Alla Lileeva and Daniel Trebler (2007), and Paula Bustos (2006) explore the linkages between investments in innovation, productivity, and the decision to export in the context of the liberalization of trade regimes. Aw, Roberts, and Tor Winston (2007) have also found a significant role for firm R&D investments in explaining Taiwanese firm export patterns, as well as interaction effects between firm R&D and export choices in explaining productivity change.

In this paper we summarize some empirical results from our research project to develop an estimable structural model of the joint export-investment decision. In the theoretical model, firms invest in R&D and physical capital, which can affect the path of future productivity for the firm. R&D investment, through its effect on future productivity, increases the profits from exporting, and participation in the export market raises the return to R&D investments.

The theoretical model yields equations for the policy functions for R&D investment, physical investment, and the exporting decision, as well as the evolution of firm-level profitability, that can be estimated with micro datasets containing

information on exporting, productivity or profitability, and investments in R&D. We estimate these equations using annual firm-level data for the Taiwanese electronics industry from 2000 to 2004. The empirical results indicate significant interactions between the firm's choice of R&D investment and export market participation which support the recent emphasis on modeling the export decision as one component of a broader investment strategy by the firm.

I. A Model of Knowledge Accumulation and Exporting

We briefly outline a theoretical model of firm investment in R&D, physical capital, and the decision to export. It shares many features with the dynamic models of exporting developed by Melitz (2003) and Sanghamitra Das, Roberts, and James R. Tybout (2007) and the model of exporting and investment by Constantini and Melitz (2007). We abstract from the decision to enter or exit production, and instead focus on investment decisions and the evolution of productivity. Firms are heterogeneous in their productivity and each firm's return to investment in R&D, physical capital, and exporting depends on its level of productivity. In turn, these investments have feedback effects that can alter the path of future productivity for the firm.

A. Short-Run Profits

In the short run, at the beginning of period t a firm has a known productivity x_t and a capital stock k_t . Firm output q_t is given by a Cobb-Douglas production function:

$$q_t = \exp(x_t)(l_t^\alpha(k_t)^{1-\alpha})^\gamma,$$

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where l_t is labor input. The firm produces a differentiated product (which implies x_t can also be interpreted as a measure of product quality) and faces a Dixit-Stiglitz demand function:

$$q_t = (I_t/P_t)(p_t/P_t)^\eta,$$

where p_t is the firm's price, P_t is the industry price index, and I_t is total market size. Assume that the firm chooses its labor input to maximize its short-run profits, given fixed levels of productivity and capital. Defining $\varphi_t \equiv \exp(x_t)(k_t^{1-\alpha})^\gamma$, the contribution of productivity and capital to output, the firm's short-run profits are

$$(1) \quad \pi(\varphi_t, s_t) = I_t(1 - (1 + 1/\eta)\alpha\gamma) \frac{\varphi_t^\sigma}{\sum_{\varphi, s_t}(\varphi)\varphi^\sigma},$$

where $s_t(\varphi)$ is defined as the number of firms whose $\varphi_t = \varphi$ and $\sigma = (1 + \eta)/(\eta - (1 + \eta)\alpha\gamma)$. From this equation, it can be seen that φ_t is a measure of the firm's relative profitability and results from differences in firm productivity and capital stocks, and both markup and return-to-scale parameters. The revenue of the firm $r(\varphi_t, s_t)$ is equal to the last term in the profit equation multiplied by market size. We can now derive an equation linking the firm's observable revenue share to φ :

$$(2) \quad \theta(\varphi_t) = \ln(r(\varphi_t, s_t)/I_t) - \overline{\ln(r(\varphi_t, s_t)/I_t)} \\ = \sigma(\ln(\varphi_t) - \overline{\ln(\varphi_t)});$$

θ is the log of the firm's revenue share expressed as a deviation from the mean log market share in the industry and is proportional to the firm's value of φ . We will construct θ for each observation in our dataset and use it as a summary statistic of the firm's relative profitability.

B. Evolution of Profitability

Each firm's profitability will evolve over time with changes in productivity and capital, and the firm can affect the distribution of future profitability by its investment choices. First, the firm's productivity x_t is assumed to change over time as a result of the firm's investments in R&D, which we denote d_t , as $x_{t+1} = \rho x_t + v(d_t) + \varepsilon_t$, where ρ is the retention rate of productivity and

ε is an i.i.d. shock. Second, the firm's physical capital changes as a result of depreciation and the flow of new investment spending, as $k_{t+1} = (1 - \delta)k_t + i_t$ where δ is the depreciation rate and i_t is investment. Given these assumptions on the evolution of x_t and k_t , the evolution of firm profitability φ_t can be written

$$(3) \quad \ln(\varphi_{t+1}) = \rho \ln(\varphi_t) + v(d_t) \\ + (1 - \alpha)(1 - \rho)\gamma \ln(k_t) \\ + (1 - \alpha)\gamma \ln(1 - \delta + i_t/k_t) + \varepsilon_t,$$

or, more compactly, as $\varphi_{t+1} = g(\varphi_t, d_t, i_t, k_t, \varepsilon_t)$. This relationship can be estimated from data on firm-level revenue, R&D expenditure, physical investment, and capital stock.

C. Dynamic Decisions

The model outlined here applies to the domestic sales of the firm. By assuming a monopolistically competitive export market, similar equations for the firm's export market profits, π^f , and revenue can be derived. Assuming that the firm pays a sunk cost γ_s to enter the export market, the export decision becomes a dynamic problem for the firm and the firm's export status in year t becomes a state variable for their decision in period $t + 1$ (see Das, Roberts, and Tybout 2007). We view a firm operating in the domestic market as making three dynamic decisions in each year t . The discrete decision to export is denoted as $\chi_t = 1$ if it chooses to export, and 0 otherwise. The two continuous decisions are the level of R&D, d_t , and the investment in physical capital, i_t , and let c_d and c_i be investment cost functions. Let Φ_t capture all the aggregate states that firms take as exogenous. The firm's value function is

$$(4) \quad V(\varphi_t, \chi_{t-1}, k_t; \Phi_t) \\ = \max_{\{\chi_t, d_t, i_t\}} \left\{ \pi^d + (\chi_t = 1)(\pi^f - \gamma_f - u_1) \right. \\ \left. - c_d(d_t) - c_i(i_t, k_t) \right. \\ \left. - (\chi_t - \chi_{t-1} = 1)(\gamma_s(k_t) + u_2) \right. \\ \left. + \beta E[V(\varphi_{t+1}, \chi_{t+1}, k_{t+1}; \Phi_{t+1}) | d_t, i_t] \right\}.$$

This will result in policy functions for exporting, R&D investment, and physical investment in year $t + 1$ that are implicit functions of the state variables at the beginning of the period φ_t , k_t , and χ_{t-1} : $d_t = d(\varphi_t, k_t, \chi_{t-1})$, $i_t = i(\varphi_t, k_t, \chi_{t-1})$, and $\chi_t = \chi(\varphi_t, k_t, \chi_{t-1})$.

Slight variations in the assumptions of this model can alter the form of the policy functions and productivity evolution equation. Several of these variations have been explored in the literature. If R&D investment is treated as a sunk cost, as in Costantini and Melitz (2007), rather than a variable cost, the policy functions will depend on lagged R&D status as well. Alternatively, if R&D is an investment that creates a stock of knowledge which, in turn, affects future productivity, then the stock of knowledge will be an additional state variable in the policy functions. Finally, if exporting does not work solely through its effect on R&D or investment choice, but rather has a direct effect on productivity evolution, often labeled “learning by exporting,” then the evolution of productivity in equation (3) will also depend on past export status. Lileeva and Trefler (2007) summarize the large number of empirical studies on this topic. In their empirical study, Aw, Roberts, and Winston (2007) allow for each of these pathways, using a dummy variable to distinguish firms with past R&D expenditures from those without, as a proxy for the stock of knowledge. In the empirical results reported in Section IV, we also allow for these alternative pathways.

II. Data for Taiwanese Electronics Producers

As part of our research program, we are applying this structural model to data on the investment, exporting, and productivity patterns of Taiwanese electronics producers. The dataset consists of firm-level observations for Taiwanese firms in four 3-digit electronics industries: consumer electronics, telecommunications equipment, computers and storage equipment, and electronics parts and components. Data are collected by the Ministry of Economic Affairs and, while not a complete census of all firms in the industry, cover more than 92 percent of manufacturing employment in each year. The survey is conducted in non-census years between 1987 and 2004 but the exporting and capital stock data that we utilize are not collected every year. The years in which all variables that we need to

estimate our model are reported are 2000, 2002, 2003, and 2004. The regressions are estimated using the observations for 2002–2004, with only 2000 data used to provide the necessary lagged profitability, exporting, and R&D control variables. There is a total of 7,772 observations used in the empirical work.

III. Empirical Results

A. Policy Functions

A useful first step is the estimation of the policy functions and productivity evolution process. The policy function estimates are reported in Table 1. The first three columns are the revenue share (the proxy for φ), prior export status, and the capital stock. Two additional variables, a lagged R&D dummy variable and an interaction term between the export and R&D dummy, are also included in the equations in order to allow for the possibility that R&D investment incurs a sunk start-up cost. While the inclusion of R&D is not directly implied by the model developed in Section I, these two variables are implied by the model developed by Constantini and Melitz (2007). We include them to allow for some flexibility in the specification of the way that R&D expenditure enters the firm’s objective function.

Table 1 reports probit estimates for the export, R&D, and investment equations. It also reports tobit estimates for the R&D and investment variables. In the export probit model, reported in the first row of the table, the revenue share and export dummy are positive and significant as expected. This is consistent with the findings in virtually every study of the export decision. The estimation also shows a negative effect of the capital stock on the probability of exporting, which could reflect a dependence of the sunk cost of exporting on firm size.

The patterns in the two R&D equations, rows 2 and 3, show evidence of significant, positive effects of all the state variables. The qualitative effects are the same regardless of whether R&D is modeled as a discrete or continuous variable. In particular, prior exporting is positively correlated with current investments in R&D, which is consistent with the larger export market providing higher returns to R&D as modeled by Lileeva and Trefler (2007) and Constantini and Melitz (2007). We also find a significant role for past R&D, which is consistent with either

TABLE 1—EXPORT, R&D, AND INVESTMENT POLICY FUNCTIONS

Policy function year t	Log revenue share (θ_t)	Export dummy (χ_{t-1})	Capital stock ($\ln k_t$)	R&D dummy ($I(d_{t-1}>0)$)	R&D-export interaction ($I(d_{t-1}>0)(\chi_{t-1})$)
Export probit	0.181*	1.545*	-0.060*	0.199*	-0.078
χ_t	(0.014)	(0.042)	(.013)	(0.075)	(0.082)
R&D probit	0.240*	0.204*	0.130*	1.856*	-0.048
$I(d_t>0)$	(0.019)	(0.062)	(.019)	(0.080)	(0.097)
R&D tobit ^a	1.332*	1.563*	0.531*	10.467*	-0.936*
$\ln(d_t)$	(0.066)	(0.279)	(0.061)	(0.347)	(0.383)
Invest probit	0.291*	-0.161*	0.120*	0.170*	-0.020
$I(i_t)$	(0.014)	(0.040)	(0.012)	(0.072)	(0.083)
Invest tobit	1.682*	-0.800*	0.719*	0.584	0.147
$\ln(i_t)$	(0.062)	(0.202)	(0.057)	(0.328)	(0.364)

Note: All regressions include year and three-digit industry dummies; * indicates statistically significant at 0.01 level.

^a In this regression the lagged R&D variables are measured as continuous variables equal to 0 if the firm does no R&D and $\ln(\text{R\&D})$ if it does.

adjustment costs or sunk start-up costs for the R&D process, which prevent it from being a fully variable input in each year.

The final choice variable for the firm is the level of investment, and here the results indicate a positive, significant effect from firm profitability, measured by the revenue share and firm capital stock. By itself, the negative and significant correlation of past exporting with physical investment is surprising. When combined with the positive correlation of exporting and R&D, however, it may suggest that R&D and physical investment are substitute pathways for investment spending, and that exporting firms channel their investment spending into R&D, possibly to raise product quality, rather than the physical plant. Investment in physical capital may be viewed as a process that is more closely tied to the efficiency and size of the firm, rather than to the investments in R&D or exposure to export markets.

Overall, the correlation patterns in the policy functions suggest some avenues that the full structural model should incorporate. Interdependence between the R&D and exporting choice is important, particular in explaining the current R&D decision. This interdependence is a focus of the recent literature on exporting, and appears useful for understanding the Taiwanese electronics industry data. Although we cannot distinguish heterogeneity in profitability arising from productivity, capital, or differences in markups, it is clear that differences in profitability are an important determinant of

all three choice variables. Finally, differences in capital stocks are also an important source of heterogeneity, which may be overlooked in empirical models that focus only on the export and/or R&D decision.

B. The Evolution of Profitability

The second component of our empirical results is the relationship between the investment and exporting decisions of the firm and their future profitability. These results are reported in Table 2. The first column shows results using a dummy variable for R&D as the control. The second column uses a continuous variable to measure and control for the level of R&D chosen by the firm. The variable equals zero if the firm does not have any R&D expenditure, and equals the log of the expenditure when it does.

The quantitative results for the non-R&D variables are virtually identical across both specifications, and all have the expected sign. The profitability measure has a coefficient of 0.777 in the first specification. Using the profitability process derived in equation (3) above, this coefficient is an estimate of ρ , the annual retention rate of past productivity in the process for productivity change. Past R&D has a positive, significant effect in the equation, as does past investment and the capital stock. All these effects are consistent with equation (3).

In addition to the variables implied by the theoretical model above, we include lagged exporting status in the profitability equation.

TABLE 2—EVOLUTION OF FIRM PROFITABILITY φ_{t+1}

Explanatory variables	R&D dummy $I(d_t)$	Continuous R&D $\ln(d_t)$
Revenue share (φ_t)	0.777* (0.011)	0.768* (0.012)
R&D variable	0.312* (0.048)	0.041* (0.005)
Export dummy (χ_t)	0.173* (0.024)	0.181* (0.024)
R&D*export dummy	-0.108* (0.050)	-0.015* (0.005)
Investment ($\ln i_t$)	0.023* (0.003)	0.022* (0.003)
Capital stock ($\ln k_t$)	0.102* (0.009)	0.098* (0.009)

Note: All regressions include year and three-digit industry dummies; * indicates statistically significant at 0.01 level.

This would be appropriate if there were a direct effect of exporting on productivity as discussed in the learning-by-exporting literature. We find that there is a positive, significant effect of exporting on future profitability. One explanation for this is that exporting provides a channel for knowledge acquisition by the firm which allows it to incorporate better production techniques or upgrade product quality. A further extension of this pathway would allow for the effect of exporting experience to vary with the firm's R&D expenditure. Wesley M. Cohen and Daniel A. Levinthal (1989), and a number of authors since these studies, have argued that R&D has two roles: directly affecting productivity, but also allowing the firm to assimilate knowledge or expertise from external sources. In our application, R&D could allow the firm to assimilate expertise from its export market contacts. To see if this pathway is important, we include an interaction term between R&D and the exporting dummy, but find that the coefficient is negative and statistically significant. This is not consistent with the argument that a firm's own R&D is necessary for it to benefit from its external contacts. This finding is not consistent with the patterns reported in Aw, Roberts, and Winston (2007). Using a longer time series of data, but with less firm coverage, they find a significant positive coefficient on the interaction term. Overall, the role of exporting in the evolution of profitability is still unclear in these estimating equations and requires further analysis.

IV. Conclusions

The analysis of the micro data for Taiwanese electronics producers indicates that firm heterogeneity in productivity or profitability and capital stocks is crucial to explaining differences in exporting choice. This has been a common theme in the recent trade literature recognizing heterogeneous producers. More interestingly, the data also show that there is interdependence in the firm's choice of export status and R&D investment, and that the probability of investing in R&D is increased by prior export market activity. This is consistent with arguments that the larger export market provides higher returns to R&D investment. Finally, the evolution of firm profitability is improved by investments in both R&D and physical capital. We also find evidence of a direct positive effect of exporting on future profitability, which is not incorporated in all recent models, and a negative interaction term between R&D and exporting. The source of this latter effect requires further exploration.

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