Firm R&D Investment and Export Market Exposure[*]

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Abstract

In this paper we estimate a dynamic structural model of a firm's decision to invest in R&D and use it to measure the expected long-run benefit from R&D investment. We apply the model to German firms in five high-tech manufacturing industries and distinguish firms by whether they sell in just the domestic market or also export some of their production. We find that R&D investment leads to a higher rate of product and process innovation among exporting firms and these innovations have a larger impact on productivity improvement in export market sales. As a result, exporting firms have a higher payoff from R&D investment, invest in R&D more frequently than firms that only sell in the domestic market, and, subsequently, have higher rates of productivity growth. The endogenous investment in R&D is an important mechanism that leads to a divergence in the long-run performance of firms that differ in their export market exposure.

1 Introduction

The theoretical and empirical literature on international trade has emphasized the difference in performance between firms that are engaged in international markets, through either trade or investment, and ones that are not. A large empirical literature has quantified differences in productivity and growth between exporting and nonexporting firms as well as between firms that purchase inputs from foreign sources and ones that source their inputs domestically.[1] The theoretical literature, much of it based on the model by Meliz (2003), has shown how differences in underlying firm characteristics, particularly productivity, can lead to differences in the incentives to export or import and the self-selection of firms into those activities. A common starting point seen both in the theoretical and empirical literature is to identify a dimension in which firms are heterogenous, such as productivity, and study the effects of this disparity on a firm's choice to participate in international markets and the subsequent impact on performance.

In contrast, the theoretical literature on growth and trade as developed by Grossman and Helpman (1990, 1995) has emphasized the endogenous nature of technological improvements and the role that international trade can play in affecting the speed and direction of technological change.[2] For example, a firm operating in large international markets may be better able to realize profit opportunities that result from their own innovation which, in turn, increases the firm's incentive to invest in innovation activities. In this paper, we develop an empirical model to quantify two components of the endogenous growth framework. The first component accounts for the fact that innovation is expensive and that firms choose to undertake investments in R&D when the expected discounted payoff from the investment is greater than the cost. The second considers the payoff from an innovation, which may be affected by the firm's presence in international markets. For example, a firm selling in foreign markets may be better able to profit from a new product or new production process than a firm that only sells in its domestic

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[1] See Greenaway and Kneller (2007) and Keller (2010) for reviews of the empirical literature on exporting, foreign direct investment, and firm productivity. Goldberg, Khandelwal, Pavcnik, and Topalov (2010) document the importance of imported inputs as a source of firm growth.

[2] Constantini and Melitz (2008), Atkinson and Burstein (2010) and Long, Raff, and Stähler (2011) develop models of endogenous productivity growth and show that reductions in trade costs can increase firm incentives to invest in R&D or new technologies.

market. This can lead to differences in the expected return to R&D investment, which, in turn, lead to different patterns in R&D investment and alters the subsequent productivity or output growth between domestic and exporting firms.

A number of authors have found evidence that a firm's investments in R&D or technology adoption are correlated with their productivity and export market participation. Bernard and Jensen (1997), Hallward-Driemeier, Iarossi, and Sokoloff (2002), Baldwin and Gu (2004), Aw, Roberts, and Winston (2007), and Aw, Roberts, and Xu (2008) all report firm-level evidence of positive cross-section and intertemporal correlations between R&D, exporting, and productivity. Bustos (2010) and Lileeva and Trefler (2010) study environments where there were exogenous reductions in trade costs and find that these lead to increased firm innovation or technology adoption. Aw, Roberts, and Xu (2011) estimate a dynamic model of export choice and R&D investment using firm data for Taiwanese electronics producers. They find that (i) both export market sales and R&D investment generate productivity growth, (ii) firms with high productivity had higher returns to R&D and were more likely to invest in R&D and, (iii) holding productivity fixed, exporting has little direct effect on the probability of R&D investment. Together, their findings indicate that the differences in productivity between exporting and nonexporting firms are a major source of the difference in R&D investment and that, over time, this will lead to a divergence in the productivity level between the two types of firms.

In this paper, we develop and estimate a dynamic, structural model of the R&D process, including firm R&D investment, innovation outcomes, and productivity growth, and use it to quantify differences in the expected payoff to R&D between exporting and nonexporting firms. We estimate the model using firm-level data for five high-tech German manufacturing industries and use it to explain differences in the patterns of R&D investment and productivity improvement for exporting and nonexporting firms. Following the model of R&D investment by Peters, Roberts, Vuong, and Fryges (2014) (PRVF)we quantify three steps that link firm R&D investment to its expected long-run return. First, firms that invest in R&D will have different probabilities of developing new products or process innovations. Second, these innovations can improve future firm productivity and, third, the path of future firm profits. We allow each step in this process to differ between German exporting and non-exporting firms and measure

how these linkages contribute to differences in the long-run payoff to R&D.

The empirical results reveal substantial differences in the R&D process between exporting and nonexporting firms. Firms that invest in R&D are more likely to realize product and process innovations if they are exporting firms. These innovations, on average, have a larger impact on future productivity, and profits for export sales as opposed to sales in the domestic market. This leads to a higher expected benefit from R&D investment for exporting firms and a higher probability of investing. These findings are consistent with the mechanism underlying the endogenous growth models. The fact that exporters are more likely to realize innovations that have a larger impact on profits can reflect a larger set of innovative opportunities for firms that sell in international markets as opposed to those that sell solely in the domestic market. New product developments that are not profitable in the domestic market may be profitable in foreign markets. It could also reflect learning effects through technological spillovers or knowledge transmission from abroad. Overall, the empirical findings in this paper indicate a very large difference in the return to R&D and the incentives to invest in R&D between exporting and nonexporting German high-tech firms. This endogenous process of R&D investment contributes to the divergence in performance observed between exporting and nonexporting firms.

In the next section, we extend the PRVF model of R&D choice to recognize differences in the productivity process between exporting and nonexporting firms. In the third section, we discuss the German data, which is drawn from the Mannheim Innovation Panel (the German contribution to the Community Innovation Survey). In the fourth section, we briefly outline the empirical model and estimation, which follows PRVF, and then present the empirical results in the fifth section.

2   Theoretical Model

This section develops a theoretical model of a firm's dynamic decision to undertake R&D investment while accounting for their involvement in international markets. The model is structured into three stages. At the first stage, the firm makes a choice of whether or not to invest in R&D. The second stage of the model describes the effect of a firm's R&D choice on

their probability of receiving a product or process innovation. In the third stage, the realized innovations can improve the distribution of firm productivity, affecting its short-run output and profits. Moreover, if productivity improvements are long-lived, an innovation also impacts the stream of future profits.[3] A firm that invests in R&D to maximize the discounted sum of expected future profits will recognize that the expected benefits of the R&D choice made in stage one depend on the expected outcomes of the innovation realized in stage two and productivity improvement in stage three. The dynamic model of firm R&D choice developed in Peters, Roberts, Vuong and Fryges (2014) ties together all three stages of this innovation framework and measures the expected long-run benefits of R&D investment. The next section develops the theoretical model for each stage, beginning with the lindage between productivity and profits and working backward to the firm's choice of R&D. Our framework extends the model of PRVF to allow R&D to have a different impact on innovation and firm sales in the export and domestic market. This will lead to a difference in the incentive for firms to invest in R&D and their subsequent long-run performance based on their exposure to the export market.

2.1 Profits, Productivity, and Innovation

We start by defining firm productivity and linking it to the firm's profits. The firm's short-run marginal cost is represented by

$$c_{it} = \beta_t + \beta_k k_{it} - \psi_{it}, \tag{1}$$

where c_{it} is the log of marginal cost and k_{it} is the log of firm capital stock. The intercept β_t is allowed to vary over time to reflect changes in the market price of variable inputs that are assumed to be the same for all firms in period t. The firm-specific production efficiency ψ_{it} captures differences in technology or managerial ability that are known by the firm but not observable to the econometrician.[4] The capital stock is treated as a fixed factor in the

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[3]Griliches (1979) developed the "knowledge production function" framework linking R&D with firm output. In his model, R&D investment creates a stock of knowledge that enters as an input into the firm's production function. This was extended to the three-stage process which includes innovation outcomes by Crepon, Duguet, and Mairesse (1998). Their model has been widely used in empirical studies using firm data on R&D, innovation outcomes, and productivity. Recent surveys of the empirical literature are provided in Hall, Mairesse, and Mohnen (2010) and Hall (2011).

[4]Variation in input quality, which leads to variation in input prices, across firms is also captured in ψ. We model this source of quality variation as part of the unobserved firm efficiency.

short-run. Thus, we allow for two sources of cost heterogeneity across firms: the capital stock and the unobserved production efficiency.[5]

Each firm can sell in two markets, the domestic or home market and an export market. In the home market the demand for firm i's product q_{it}^h is given by

$$q_{it}^h = Q_t^h \left(\frac{p_{it}^h}{P_t^h} \right)^{\eta_h} \exp(\phi_{it}^h) = \Phi_t^h (p_{it}^h)^{\eta_h} \exp(\phi_{it}^h), \tag{2}$$

where Q_t^h is the aggregate domestic output in period t and P_t^h is the domestic price index for the industry in which the firm operates. These are combined into the industry aggregate Φ_t^h. The firm-specific variables are the domestic output price p_{it}^h and a demand shifter ϕ_{it} that reflects product desirability, product appeal or product quality. This demand shifter is known by the firm but also not observed by the econometrician. The elasticity of demand η_h is negative and assumed to be constant for all firms in the industry. Firms that sell in the export market face a similar demand structure for their product

$$q_{it}^f = Q_t^f \left(\frac{p_{it}^f}{P_t^f} \right)^{\eta_f} \exp(\phi_{it}^f) = \Phi_t^f (p_{it}^f)^{\eta_f} \exp(\phi_{it}^f), \tag{3}$$

Importantly, the firm-level demand shifter in the foreign market ϕ_{it}^f is different from the one operating on domestic sales. A firm can have a product with high appeal in the domestic market but low appeal in the export market or vice-versa.

Assuming the firm operates in a monopolistically competitive market, it maximizes its short-run profit by setting the price for its output in each market equal to a constant markup over marginal cost: $p_{it}^l = \left(\frac{\eta_l}{1+\eta_l} \right) \exp(c_{it})$ where $l = h, f$. Given this optimal price, the log of the firm's revenue in each market $l = h, f$ is

$$r_{it}^l = (1 + \eta_l)\ln \left(\frac{\eta_l}{1 + \eta_l} \right) + \ln \Phi_t^l + (1 + \eta_l) \left(\beta_t + \beta_k k_{it} - \omega_{it}^l \right). \tag{4}$$

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[5]Equation (1) implies that, in the short run, the firm can expand or contract output at constant marginal cost. This is a reasonable assumption if, along with the variable inputs, the firm can also adjust the utilization of its fixed capital stock in order to expand or contract its output in the short run. In addition, in micro panel data of the type we utilize, most of the variation in firm sales is in the across-firm rather than within-firm dimension. To account for this, our marginal cost model relies on two factors, the capital stock and production efficiency, that primarily vary across firms. Economies or diseconomies of scale are unlikely to be the source of the firm sales variation we observe in the data.

The term ω_{it}^l denotes the revenue productivity in market $l = h, f$. It is a combination of cost-side and demand-side shocks, defined as $\omega_{it}^l = \psi_{it} - \frac{1}{1+\eta}\phi_{it}^l$. Equation (4) implies that, for a given level of capital stock, heterogeneity in the firm's revenue in each market is driven by differences in production efficiency ψ and the demand shifter in that market ϕ^h or ϕ^f. We refer to the unobserved revenue productivity ω_{it}^h and ω_{it}^f simply as productivity. These will be the key state variables the firm can affect through its choice of R&D. Since revenue productivity contains demand shocks which can vary by market, the level of productivity itself and its evolution over time can be different for sales in each market. For example, a firm may have a product that is especially well-suited to domestic customers and invest in R&D to improve its product appeal at home, but does not have a product of equal attractiveness to foreign buyers.

Given the firm's pricing rule, there is a simple relationship between the firm's short-run profits and its revenue in each market $l = h, f$:

$$\pi_{it}^l = \pi_t^l(\omega_{it}^l, k_{it}) = -\frac{1}{\eta_l}\exp(r_{it}^l) \tag{5}$$

The total profits of the firm depends on the markets it sells to. In our German manufacturing data we observe that virtually all firms sell either solely in the domestic market or in both domestic and export market in all years they are observed. None of the firms sell only in foreign market and only very few firms alternate between only domestic and both markets. Due to this feature of our data, we develop the model for two types of firms: a pure domestic seller whose total short-run profits are Π_{it}^h and a mixed domestic-export market seller whose total short-run profits are denoted by Π_{it}^f. The level of Π_{it}^h is determined only by conditions in the home market. In contrast, the level of Π_{it}^f depends on conditions in both the home and foreign market.[6] In particular, a firm that sells in only the domestic market will have its profits depend on only the domestic market revenue productivity (and capital), while the firm that operates in both markets will have total profits that reflects productivities in both markets.

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[6] Aw, Roberts, and Xu (2011) also allow the firm to choose its export market participation in each year, so that firms would be choosing which markets to sell in and the productivity levels in both markets would be important to the firms's export and R&D decisions. Because we have few firms in our sample that export in only a subset of the years we do not have the information to estimate a model of export market choice. Instead, we treat export participation as a firm characteristic and estimate how the payoff to R&D differs between exporting and nonexporting firms.

The total short-run profit for each type of firm is therefore defined as:

$$
\begin{aligned}
\Pi_{it}^h(\omega_{it}^h, k_{it}) &= \pi_t^h(\omega_{it}^h, k_{it}) \\
\Pi_{it}^f(\omega_{it}^h, \omega_{it}^f, k_{it}) &= \pi_t^h(\omega_{it}^h, k_{it}) + \pi_t^f(\omega_{it}^f, k_{it})
\end{aligned}
\tag{6}
$$

We link the firm's R&D choice to domestic and export profits in two steps. In the first step, the firm makes a discrete decision to invest in R&D, $rd_{it} \in \{0, 1\}$, and this affects the probability the firm realizes a process or product innovation in year $t+1$, denoted z_{it+1} and d_{it+1}, respectively. Both are discrete variables equal to 1 if firm i realizes a process or product innovation in year $t+1$ and 0 otherwise. We allow this linkage between R&D and innovation to differ between firms that operate solely in the domestic market and firms that sell in both domestic and foreign markets. The linkage between R&D and innovation is represented by the cumulative joint distribution of product and process innovations, conditional on whether or not the firm invests in R&D and whether or not it sells in foreign markets, $F(d_{it+1}, z_{it+1}|rd_{it}, I(f_{it}))$. In this specification $I(f_{it})$ is a discrete variable equal to 1 if the firm sells in foreign markets and 0 if it is a pure domestic seller. This specification of the innovation process is simple and recognizes the key feature that R&D investment does not guarantee innovation success, furthermore, that innovations may occur even without formal R&D investment by the firm. This latter effect can result from luck, the effect of expenditures on R&D in the more distant past even if the firm is not currently investing, ideas that are brought to the firm by hiring experienced workers or other spillover channels, or changes in the production process that result from learning-by-doing without formal R&D investment. The specification also recognizes that a firm that operates in foreign markets may have both the incentive and the opportunity to introduce product innovations in one of its foreign markets but not in its domestic market. The firm's R&D investment may also result in product innovations that are variations on the domestic product but designed for consumers in the foreign market. One additional specification we will examine is the more restrictive case where there is a single innovation variable dz_{it+1}, which equals 1 if the firm has either a product or process innovation, and whose distribution depends on the firm's R&D choice $F(dz_{it+1}|rd_{it}, I(f_{it}))$.

In the second step, firm productivity in each market is treated as a state variable that

evolves persistently over time, and is shifted by product or process innovations and a stochastic shock that the firm cannot control. Specifically, the evolution of productivity in each market is modeled as a Markov process. Denoting z_{it} as the discrete indicator equal to one if the firm reports a new process innovation and d_{it} as the discrete indicator if the firm reports a new product innovation, we model the evolution of revenue productivity in market $l = h, f$ as:

$$\omega_{it+1}^l = \alpha_0^l + \alpha_1^l \omega_{it}^l + \alpha_2^l (\omega_{it}^l)^2 + \alpha_3^l (\omega_{it}^l)^3 + \alpha_4^l z_{it+1} + \alpha_5^l d_{it+1} + \alpha_6^l z_{it+1} d_{it+1} + \varepsilon_{it+1}^l. \qquad (7)$$

The parameters $\alpha_0, \alpha_1, ...\alpha_6$ differ between the export and domestic market sales, which allows for different patterns of productivity evolution in the two markets. The parameters α_1, α_2, and α_3 capture the persistence in firm productivity over time while α_4, α_5, and α_6 capture how the mean of future productivity shifts when the firm realizes an innovation. The randomness in the productivity process is captured by ε_{it+1} which we assume are *iid* draws across time and firms from a normal distribution with zero mean and variance σ_ε^2. Notice that shocks to productivity are not transitory, but rather persist and affect future productivity levels through the coefficients α_1, α_2, and α_3. We will also estimate the specification where the productivity process depends on a single innovation varible dz_{it+1}. This specification does not attempt to estimate separate productivity effects for the product and process innovations, but rather allows any innovation to have the same effect on the mean of future productivity. To simplify notation in the dynamic model described in the next section, we denote the productivity evolution process by a cdf $G^l(\omega_{it+1}^l | \omega_{it}^l, d_{it+1}, z_{it+1})$.

2.2 The Firm's Dynamic Decision to Invest in R&D

This section develops the firm's decision rule for whether or not to invest in R&D. In contrast to the majority of the empirical innovation literature that aims at measuring the correlation between R&D investment and observed firm and industry characteristics, we structurally model the firm's optimal R&D choice. The firm's investment choice depends on both the effect of R&D on the firms's expected future profits and the cost the firm has to incur for the productivity improvement. In this model, the firm's cost is the expenditure it must make to generate a process or product innovation. This varies across firms for many reasons such as the nature of

the investment project, the firm's expertise in creating innovation, its ability to access capital as well as its prior R&D experience. The fact that some firm's are good in the innovation process or have a large set of technological opportunities for innovation is captured in this model by lower innovation costs. To capture this heterogeneity in firm's innovation cost, we assume that the firm's cost is a random draw from an exponential distribution, with mean $\gamma I(rd_{it-1}) + \gamma_x X_{it}$. The mean of the cost distribution depends on the firm's previous R&D choice $I(rd_{it-1})$, a set of observable exogenous variables X_{it}, and a parameter vector (γ, γ_x). The indicator variable for whether or not the firm invested in R&D in the previous year, $I(rd_{it-1})$, takes the value 1 if the firm was engaged in R&D in $t-1$ and 0 otherwise. The coefficient γ captures differences in fixed costs of maintaining ongoing R&D operations versus the start-up costs of beginning to invest in R&D. Other variables that can be included in X_{it} are a measure of firm size and an indicator of foreign market participation. With the exception of the lagged R&D status variable $I(rd_{it-1})$, we will treat the other variables in X_{it} as exogenous firm characteristics. The firm's innovation cost is therefore modeled as *iid* draws from the following exponential distribution:

$$C_{it} \tilde{\ } \exp(\gamma I(rd_{it-1}) + \gamma_x X_{it}). \tag{8}$$

The timing of the firm's decision problem is assumed to be the following: at the start of period t, the firm observes its current domestic sales productivity ω_{it}^d and, if it is an exporter, the foreign sales productivity ω_{it}^f, as well as its short-run profit function, the process for productivity evolution in each market, equation (7), and the probability of an innovation $F(d_{it+1}, z_{it+1} | rd_{it}, I(f_{it}))$. The state variables for a pure domestic firm are $s_{it}^h = (\omega_{it}^h, rd_{it-1})$ and for an exporting firm are $s_{it}^f = (\omega_{it}^h, \omega_{it}^f, rd_{it-1})$. The state variables evolve endogenously as the firm makes its decision whether or not to conduct R&D, $rd_{it} \in \{0, 1\}$. The value function differs for pure domestic firms and firms that sell in both home and foreign markets. Before the firm observes its innovation cost realization, the value function for a domestic producer, can be written as:

$$
\begin{aligned}
V^h(s_{it}^h) &= \pi(\omega_{it}^h) + \\
&\int_{C_{it}} \max_{rd \in \{0,1\}} \left(\beta E_t V^h(s_{it+1}^h | \omega_{it}^h, rd_{it} = 1) - C_{it}; \beta E_t V^h(s_{it+1}^h | \omega_{it}^h, rd_{it} = 0) \right) dC
\end{aligned} \tag{9}
$$

The firms's expected future value is defined as an expectation over possible future levels of domestic productivity and innovation outcomes:

$$E_t V^h(s_{it+1}^h | \omega_{it}^h, rd_{it}) = \sum_{(d,z)} \int_{\omega^h} V^h(s_{it+1}^h) dG^h(\omega_{it+1}^h | \omega_{it}^h, d_{it+1}, z_{it+1}) dF(d_{it+1}, z_{it+1} | rd_{it}). \quad (10)$$

Using these equations we can characterize the firm' optimal R&D choice rd_{it}. If they do not invest in R&D, their expected future profits are $\beta E_t V^h(s_{it+1}^h | \omega_{it}^h, rd_{it} = 0)$. If they do invest in R&D the expected future profits are $\beta E_t V^h(s_{it+1}^h | \omega_{it}^h, rd_{it} = 1)$ and they will incur cost C_{it}. The marginal benefit of investing in R&D is the difference in the two expected future profits:

$$\Delta EV^h(\omega_{it}^h) \equiv \beta E_t V^h(s_{it+1}^h | \omega_{it}^h, rd_{it} = 1) - \beta E_t V^h(s_{it+1}^h | \omega_{it}^h, rd_{it} = 0). \quad (11)$$

The difference between these two measures of expected future profits is driven by the effect of R&D on the firm's future productivity. The firm selling only in the domestic market will choose to make the investment if the marginal benefit of R&D is larger than its cost $\Delta EV^h(\omega_{it}^h)$ $\geq C_{it}$.[7]

A firm that sells in both the home and foreign market faces a similar problem except their firm value and the expected marginal benefit of conducting R&D now depend on the evolution of productivities in both markets. The value function for this firm is given by:

$$V^f(s_{it}^f) = \pi(\omega_{it}^h, \omega_{it}^f) + \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad (12)$$
$$\int_{C_{it}} \max_{rd \in \{0,1\}} \left(\beta E_t V^f(s_{it+1}^f | \omega_{it}^h, \omega_{it}^f, rd_{it} = 1) - C_{it}; \beta E_t V^f(s_{it+1}^f | \omega_{it}^h, \omega_{it}^f, rd_{it} = 0) \right) dC.$$

The firm's expected future value becomes:

$$E_t V^f(s_{it+1}^f | \omega_{it}^h, \omega_{it}^f, rd_{it}) = \sum_{(d,z)} \int_{\omega^h, \omega^f} V^f(s_{it+1}^f) dG^h(\omega_{it+1}^h | \omega_{it}^h, d_{it+1}, z_{it+1}) \cdot \qquad (13)$$
$$dG^f(\omega_{it+1}^f | \omega_{it}^f, d_{it+1}, z_{it+1}) dF(d_{it+1}, z_{it+1} | rd_{it}, I(f_{it})).$$

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[7]The profit function $\pi(\omega_{it})$ and value function $V(s_{it})$ also depend on the exogenous variables in the firm's environment including the capital stock, variable input prices, aggregate demand shock, industry demand elasticity and variables that shift the cost of innovation X. We have suppressed notation for these to highlight the role of R&D, process and product innovations, and productivity. In the empirical model, we define different firm types based on the exogenous variables and calculate the profit and value functions separately for each type.

For a firm selling in both markets, productivity in each market evolves in a different way and may respond differently to product and process innovations. This is one of the conditions used in the empirical model to explain the differences in the R&D choice of exporting and nonexporting firms.

A firm operating in both markets makes the same comparison as the pure domestic seller and will choose to invest in R&D if the expected marginal benefit is greater than the cost, $\Delta EV^f(\omega_{it}^h, \omega_{it}^f) \geq C_{it}$, where the expected benefit is defined as:

$$\Delta EV^f(\omega_{it}^h, \omega_{it}^f) \equiv \beta E_t V^f(s_{it+1}^f | \omega_{it}^h, \omega_{it}^f, rd_{it} = 1) - \beta E_t V^f(s_{it+1}^f | \omega_{it}^h, \omega_{it}^f, rd_{it} = 0). \qquad (14)$$

The key difference in the return to R&D activities between a pure domestic firm and a firm that sells in both markets is the additional gain from innovation in the foreign market. This difference drives the disparity in firms' R&D choices and lead to variations in their productivity growth, size, and profits.

Overall, our model endogenizes the firm's choice to undertake R&D investments allowing it to depend on the net expected gain in long-run profits of each option. This model places structure on the firm's decision rule and ties the firm's choice to invest in R&D explicitly to the resulting expected innovation and productivity outcomes. The key structural components that we estimate from the data are (i) the firm revenue functions in both markets, equation (4), (ii) the process for productivity evolution in each market, equation (7), (iii) the innovation rates $F(d_{it+1}, z_{it+1} | rd_{it}, I(f_{it}))$, and (iv) the γ parameters describing the cost of innovation, equation (8). The complete model can be estimated with data on the firms discrete decision to invest in R&D, rd, discrete indicators of innovation, d and z, sales in the home and foreign markets, r^h and r^d, the firm's capital stock, k, and other cost shift variables in X. In the next two sections we describe the data and develop the empirical model.

3 Data

3.1 Firm Sample

The data we use to analyze the role of R&D in the productivity evolution of German firms are *taken from* the Mannheim Innovation Panel (MIP) survey collected by the Centre for European Economic Research (ZEW)**.** The survey is conducted every year for firms in the manufacturing, mining, energy, water, construction, and service sectors. Firm samples are drawn from the Creditreform database according to the stratifying variables firm size, region, and industry.[8] These are representative of firms with German headquarters and at least 5 employees.

The manufacturing survey begins in 1993 and follows the form of the Community Innovation Surveys (CIS) that are administered in many OECD countries. The survey adheres to the Oslo Manual, which provides guidelines for the definition, classification, and measurement of innovation (OECD (1992, 1997, 2005)). Every year, the same set of firms are asked to participate in the survey and to complete the questionnaire sent to them via mail. The sample is updated every two years to account for exiting firms and newly- founded firms. Additionally, a non-response analysis is performed via phone to check and correct for non-response bias. Every firm remains in the panel, on average, for 2 to 3 years. Due to cost reasons, starting in 1998, the full questionnaire was only sent out every other year to all firms in the full sample. Information on variables of interest, however, are asked retrospectively for the previous year to ensure the annual coverage. In odd years, only short questionnaires with core questions are sent to a subset of firms resulting in a significantly lower number of firms in odd than in even years in the panel. This limits the ability to follow individual firms over time. Participation in the survey is voluntary and the average response rate is about 25 percent. Each year approximately 5000 firms answer the questionnaires across all industries (see Rammer and Peters, 2013).[9]

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[8]The Creditreform database is the largest credit rating agency in Germany and maintains a comprehensive database of approximately 3.3 million German firms.

[9]The sample attrition that occurs is virtually *completely* due to nonreporting and not to the death of the firm. Beginning in 1999, we can use codes in both the Creditreform data set and the MIP questionaire to identify firms that are likely deaths. Depending on the stringency of our death criteria, we find that between 1.77 and 5.20 percent of the observations that disappear from our sample are true or likely firm deaths. We also find that comparing the firms that remain in the sample and those that exit the sample, there is no significant difference in firm characteristics, particularly productivity, in their last year of observation. The sample attrition in our data set is *therefore* not due to the death of low productivity firms and is not likely to affect estimates of the model parameters.

For the empirical analysis, we focus on five high-tech (HT) industry groups, each of them is an aggregate of two-digit manufacturing industries (NACE codes): chemicals (23, 24), non-electrical machinery (29), electrical machinery (30, 31, 32), instruments (33), and motor vehicles (34, 35). Our data covers the period 1993-2008.

3.2 Variable Measurement

For the estimation, we use data on firm sales in the German domestic market and total sales in all of its export markets, variable costs, capital stock, innovation expenditures as well as product and process innovations.[10] The firm's total revenue is the sum of domestic and export sales. Total variable cost is defined as the sum of expenditure on labor, materials and energy. The firm's short-run profit is the difference between revenue and total variable cost. The firm's value is the discounted sum of the future short-run profits and thus measures the long-run resources available to pay its capital expenses plus the economic profits.

In this paper, we use the measures of both innovation inputs and innovation outputs collected in the Community Innovation Surveys. The firm's innovation input is measured by the firm's expenditure on R&D plus spending on worker training, acquisition of external knowledge and capital, marketing, and design expenditures for producing a new product or introducing a new production process. The discrete R&D variable that we analyze in the empirical model (rd_{it}) takes the value one if the firm reports a positive level of spending on innovation activities and zero otherwise. We also utilize two discrete variables for innovation output. In the survey in year t, the firms are asked whether they introduced new or significantly improved products or services during the years $(t-2)$, $(t-1)$, or t. The discrete variable product innovation d_{it} takes the value one if the firm reports yes to the question. The discrete variable for process innovation z_{it} equals one if the firm reports new or significantly improved internal processes during the years $(t-2)$ to t.[11]

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[10]For 1999 and 2000, the panel does not contain information on the firms' capital stock. We impute these missing years using linear interpolation.

[11] In the empirical model, this outcome is related to R&D spending in the previous year $(t-1)$, so there is not a perfect match between the timing of the R&D and the realization of the innovations. This may lead us to overestimate the effect of R&D on innovation since the innovation variable could be capturing outcomes from two years earlier. Attempting to use more distant lags of R&D spending exaggerates the problems caused by sample attrition and reduces the number of observations containing the necessary current and lagged variables.

4 Empirical Model

The empirical model is based on the framework developed by Peters, Roberts, Vuong, and Fryges (2014). In this section we briefly summarize its key steps and describe how it is affected by categorizing firms based on their export status. We refer to Peters, Roberts, Vuong, and Fryges (2014) for detailed discussion on the development of the empirical model.

4.1 Productivity Evolution

We estimate the probability of innovation directly from the data as the fraction of observations reporting each of the four combinations of d_{it+1} and z_{it+1} conditioning on previous R&D choices $rd_{it} \in \{0,1\}$ and the firm's export status $I(f_{it}) \in \{0,1\}$. The innovation probabilities are estimated separately for each industry. We follow the method in Das, Roberts and Tybout (2007) and estimate the elasticity of demand for home and foreign sales by regressing the firm's total variable cost, which equals the expenditure on labor, materials, and energy, on the sales in each market. The coefficients on the sales variable in market l can be interpreted as $1 - \frac{1}{\eta^l}$.

Parameters of the revenue function, equation (4) and the productivity process, equation (7), are estimated for each market using the proxy variable approach of Olley and Pakes (1996). To estimate productivity evolution in each market and construct estimates of domestic and foreign productivity for each firm's sales we need a control variable for each market that will depend on firm productivity. In general, firms with high productivity in the domestic market will have large output and thus large material expenditures for domestic production m_{it}^h. Similarly, high productivity in foreign market sales will result in large production for the export market and large expenditures on materials for export production m_{it}^f. We do not directly observe m_{it}^h and m_{it}^f but construct them by dividing total material expenditures, which we observe, into these two components using the share of sales in each market. This assumption is restrictive, because it assumes that material expenditure is used in fixed proportions to sales in each market, but it is *a* practical way to incorporate information on the firm's relative size in the domestic and export market. Our constructed *material* variables will contain information on both the firm's total size and its relative size in each market. Given our constructed variables m_{it}^h and m_{it}^f we replace the unobserved productivity in each revenue function with a polynomial function of

the firm's capital stock and material expenditure in that market and estimate the first stage regression using the revenue data from market $l = h, f$:

$$r_{it}^l = \delta_0^l + \sum \delta_t^l D_t + \phi^l(k_{it}, m_{it}^l) + v_{it}^l \tag{15}$$

The time dummies D_t control for the factor prices and aggregate demand shock, and the intercept contains the demand elasticity. The function $\phi^l(k_{it}, m_{it}^l)$ is a third-order polynomial in the firm's capital stock and materials expenditure in market l and is used to control for the joint effect of productivity and capital stock on the firm's revenue $(1 + \eta_l)[\beta_k k_{it} - \omega_{it}^l]$. Using the fitted value $\widehat{\phi_{it}^l}$ from equation (15) and substituting it into equation (7), we can recover the remaining structural parameters for sales in market l by estimating:

$$\begin{aligned}
\widehat{\phi_{it}^l} &= \beta_k^l k_{it} - \alpha_0^l + \alpha_1^l(\widehat{\phi_{it-1}^l} - \beta_k^l k_{it-1}) - \alpha_2^l(\widehat{\phi_{it-1}^l} - \beta_k^l k_{it-1})^2 + \\
&\quad \alpha_3^l(\widehat{\phi_{it-1}^l} - \beta_k^l k_{it-1})^3 - \alpha_4^l z_{it} - \alpha_5^l d_{it} - \alpha_6^l d_{it} z_{it} - \varepsilon_{it}^l.
\end{aligned} \tag{16}$$

This equation is estimated separately for domestic market sales and for foreign markets sales and the parameters describing the evolution of productivity $\alpha_0, \alpha_1, ...\alpha_6$ are allowed to differ for each market.[12] Given estimates of the structural parameters in equation (16), an estimate of revenue productivity can be constructed for the firm's sales in each market. Firm productivity in domestic sales is constructed as:

$$\hat{\omega}_{it}^h = -\frac{1}{1 + \hat{\eta}_h} \widehat{\phi_{it}^h} + \hat{\beta}_k^h k_{it}. \tag{17}$$

Similarly, revenue productivity for foreign market sales is estimated as:

$$\hat{\omega}_{it}^f = -\frac{1}{1 + \hat{\eta}_f} \widehat{\phi_{it}^f} + \hat{\beta}_k^f k_{it}. \tag{18}$$

Using this method we recoveryep the unobserved productivity state variables ω_{it}^h and ω_{it}^f for each firm as well as their transition process. Productivity in the foreign sales can only be constructed for the firms that export. This is not a problem, however, because it is only relevant as a state variable for these firms.

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[12] The parameters in equation (16) are scaled by the demand elasticity in the market. See PRVF (2014), equation (11) for the exact formula. We also do not constrain the capital coefficient β_k to be the same for domestic and export sales.

4.2   Value Function and the Dynamic Choice of R&D

Given estimates of the state variables and structural parameters described in the last section we can construct estimates of the value functions, equations (12) and (9) and, importantly, the expected payoff to each firm from investing in R&D, $\Delta EV^h(\omega_{it}^h)$ if the firm only sells in the domestic market and $\Delta EV^f(\omega_{it}^h, \omega_{it}^f)$ if it sells in both markets.   We use Rust's (1987) nested fixed point algorithm to estimate the model. We discretize the state space $s_{it}^h = (\omega_{it}^h, rd_{it-1})$ for domestic firms and $s_{it}^f = (\omega_{it}^h, \omega_{it}^f, rd_{it-1})$ for exporting firms into 100 grid points for each type of productivity and two values for lagged R&D choice and use value function iteration to solve for the value function at each element of this discretized state space.   In addition, firms are divided into discrete firm types based on the value of their capital stock, using 100 grid points, and 12 industries, and the value function is estimated at each discrete state point for each of these firm types. We use a cubic spline to interpolate across the productivity and capital grid points for each industry and impute the firm's value function and expected payoff to R&D at each data point in the sample.

The probability that a firm chooses to invest in R&D is given by the probability that its innovation cost $C_{it}(I(rd_{it-1}), X_{it})$ is less than the expected payoff.   For pure domestic firms this is:

$$Pr\left(rd_{it} = 1 | s_{it}^h\right) = Pr\left[C_{it}(I(rd_{it-1}), X_{it}) \leq \Delta EV^h(\omega_{it}^h)\right] \tag{19}$$

and for firms in both markets is

$$Pr\left(rd_{it} = 1 | s_{it}^f\right) = Pr\left[C_{it}(I(rd_{it-1}), X_{it}) \leq \Delta EV^f(\omega_{it}^h, \omega_{it}^f)\right] \tag{20}$$

Assuming the firm's state variables are independent of the cost draws and that the costs are *iid* across all periods and all firms, conditional on the observable characteristics X, the likelihood function for the firms' R&D choice data can be expressed as

$$L(\gamma|rd, s) = \prod_i^N \prod_t^{T_i} \Pr(rd_{it}|s_{it}; \gamma), \tag{21}$$

where γ is the vector of cost function parameters. The vectors rd and s contain every firm's R&D choice and state variables for each period, respectively. The total number of firms is

denoted by N, and T_i is the number of observations for firm i. We estimate the parameters of the cost distribution using the firms' discrete choices on R&D.

5   Empirical Results

In the next subsection we provide descriptive statistics on innovation rates and R&D investment rates for exporters and nonexporters and the estimated relationships from the first-stage model between R&D, innovation, and productivity. The second subsection reports results from the dynamic model for the cost and the long-run expected benefits of R&D.

5.1   R&D, Innovation, and Productivity

Table 1 summarizes the differences in R&D investment rates and innovation rates between nonexporting and exporting firms for each industry. Overall, there is a very clear and robust pattern between the two groups across all five industries: exporters are more likely to invest in R&D and have higher realization rates for innovations. We focus on the average across all industries reported in the final row. The second and third columns give the fraction of firm-year observations that report positive spending on R&D and other innovation inputs. The rate for nonexporters is 0.494, while it is substantially higher, 0.852, for exporters. This is likely to be an important source of the often observed productivity difference between exporting and nonexporting firms. The fourth and fifth columns present the rates of new product innovation for the two groups of firms and there is a substantial difference here as well. On average, the proportion of firm-year observations with product innovations is 0.423 for nonexporters and 0.793 for exporters. Finally, the rates of process innovation, while lower than the rates of product innovation, show a similar pattern, with the rate for exporters being much larger than the rate for nonexporters, 0.343 versus 0.604. The model developed in the previous section allows innovations to occur at different rates for exporting and nonexporting firms. Moreover, it allows innovation to have different impacts on the future productivity of domestic and export sales. These two features contribute to the differences in the expected benefits of R&D between exporting and nonexporting firms and subsequently help explain the difference in the proportion of firms engaging in R&D.

Table 1: Rates of R&D Investment and Product and Process Innovation

	R&D Investment Rate		Product Innovation		Process Innovation	
	Nonexporter	Exporter	Nonexporter	Exporter	Nonexporter	Exporter
Chemicals	0.619	0.812	0.489	0.741	0.443	0.598
Machinery	0.453	0.835	0.373	0.785	0.317	0.595
Electronics	0.528	0.897	0.466	0.828	0.378	0.626
Instruments	0.492	0.911	0.451	0.863	0.308	0.589
Vehicles	0.437	0.818	0.374	0.734	0.320	0.631
Average	**0.494**	**0.852**	**0.423**	**0.793**	**0.343**	**0.604**

The relation between firm R&D investment and innovation, $F(d_{it+1}, z_{it+1}|rd_{it}, I(f_{it}))$, is summarized in Table 2. These numbers are estimates of the probability of a product or process innovation for exporting and non-exporting firms. The table shows that, on average in every industry, exporting firms are more likely to have an innovation than nonexporting firms. The second and third column in table 2 report the probability of receiving no innovation (column 2) or some type of innovation (column 3) in $t+1$ when the firm does not invest in R&D in t. On average across the five industries, the probability of an innovation for a nonexporting firm is 0.188 but 0.285 for an exporting firm. If the firms do invest in R&D, the probability of innovation (column 5) increases substantially and the probability of no innovation (column 4) drops correspondingly. The difference between exporting and nonexporting firms persists: Nonexporting firms have a probability of innovation, averaged across industries, of 0.786 while the probability for exporting firms is 0.905. This difference holds for every industry. The first comparison reveals that exporting firms are more likely to have innovations than nonexporting firms and this will lead them to have higher productivity and profit levels. However, the effect of exporting on the incentive to invest in R&D will depend on how the probability of innovation differs when $rd_t = 0$ versus $rd_t = 1$. In this case, there is only a minor difference between exporters and nonexporters. For non-exporters, the probability of an innovation increases from 0.188 to 0.786 if they invest in R&D. The increase in this probability for exporters is very similar, from 0.285 to 0.905. In both cases, firms that invest in R&D have a probability of innovation that is approximately 60 percentage points higher than firms that do not invest.

Table 2: Probability of Innovation Conditional on Past R&D: $\Pr(d_{t+1}, z_{t+1}| \, rd_t, I(f_{it}))$				
	$rd_t = 0$		$rd_t = 1$	
	$d = z = 0$	$d = 1$ or $z = 1$	$d = z = 0$	$d = 1$ or $z = 1$
Nonexporting Firms				
Chemicals	0.828	0.172	0.184	0.816
Machinery	0.853	0.147	0.235	0.765
Electronics	0.767	0.233	0.146	0.854
Instruments	0.778	0.222	0.279	0.721
Vehicles	0.836	0.164	0.229	0.771
Average	**0.812**	**0.188**	**0.214**	**0.786**
Exporting Firms				
Chemicals	0.772	0.228	0.103	0.897
Machinery	0.716	0.284	0.086	0.914
Electronics	0.585	0.415	0.094	0.906
Instruments	0.771	0.229	0.068	0.932
Vehicles	0.732	0.268	0.125	0.875
Average	**0.715**	**0.285**	**0.095**	**0.905**

The next stage of the empirical model estimates the impact of innovations on revenue productivity in each market. Table 3 reports the parameter estimates for the productivity

evolution equation (7).

Table 3: Productivity Evolution Parameters for High-Tech Industries (standard errors)					
	Domestic Sales	Export Sales	Domestic Sales	Export Sales	Domestic Sales	Export Sales
k	-0.041***	-0.049 ***	-0.041***	-0.049 ***	-0.041 ***	-0.049***
	(0.002)	(0.007)	(0.002)	(0.007)	(0.002)	(0.007)
ω_{t-1}	0.937***	0.937***	0.936***	0.936***	0.936***	0.937***
	(0.007)	(0.008)	(0.007)	(0.008)	(0.007)	(0.008)
ω_{t-1}^2	0.081***	0.024***	0.080***	0.024***	0.080***	0.024***
	(0.016)	(0.003)	(0.016)	(0.003)	(0.016)	(0.003)
ω_{t-1}^3	-0.028***	-0.002***	-0.028***	-0.002***	-0.028***	-0.002***
	(0.008)	(0.001)	(0.008)	(0.001)	(0.008)	(0.001)
d			0.006	0.023*		
			(0.004)	(0.014)		
z			0.010	0.006		
			(0.008)	(0.024)		
$d*z$			-0.006	0.002		
			(0.009)	(0.027)		
dz	0.009***	0.027**				
	(0.003)	(0.011)				
rd_{t-1}					0.012***	0.024**
					(0.004)	(0.012)
$intercept$	0.005*	0.001	0.005*	0.001	0.003	0.003
	(0.003)	(0.010)	(0.003)	(0.010)	(0.003)	(0.011)
$SE(\varepsilon)$	0.092	0.468	0.092	0.468	0.092	0.468
sample size	3211	2616	3211	2616	3211	2616

*** significant at the .01 level, ** significant at the .05 level, * significant at the .10 level

The second and third columns of the table report the productivity evolution process for domestic and export sales using a single indicator $dz = 1$ if the firm reported either a product or process innovation. The coefficients on this variable are 0.009 for domestic sales and 0.027 for export sales and both are statistically significant. The latter coefficient implies that, on average, export sales productivity ω_{it}^f is 2.7 percent larger for firms that reported an innovation in year t. Domestic sales for the same firms are 0.9 percent higher. Innovation has a substantially larger effect on revenue productivity in the export market. This may reflect a greater range of opportunities to capitalize on innovations in the export market. Firms that are exporters may receive a larger payoff from R&D investment, causing them to be more likely to invest in R&D, other things equal. The coefficients on the past productivity level indicate high persistence

in the productivity process: the coefficient on ω_{t-1} is 0.937 in both the domestic and export market. There is also more randomness in the evolution of export productivity. The standard error of the shocks to the productivity evolution equations $SE(\varepsilon)$ is 0.468 in the export market and 0.09 in the domestic market. Transitions across productivity levels, both up and down, are more common for export market sales.

The fourth and fifth columns of the table disaggregate the innovation indicator into separate indicators for product, process, and both types of innovation. For domestic sales, firms that report a product innovation havean average productivity growth that is 0.006, six-tenths of one percent, higher than for firms with no innovation. Firms that report a process innovation, or both types of innovations have an average productivity growth that is 1.0 percent higher. None of the individual parameters, however, are statistically significant. For export sales, firms with product innovations have productivity growth that is 2.3 percent higher than firms without innovations. Process innovations raise productivity growth by 0.6 percent and both innovations increase productivity by 3.1 percent, however, only the direct product innovation coefficient is significant at the 0.10 level. While the magnitude of the innovation coefficients in columns 1 and 2 indicate a more substantial impact of innovation on productivity in the export market than in the domestic market, the fact that the coefficients are virtually all statistically insignificant, is a reflection of the high correlation between the separate innovation variables. This makes it difficult to measure separate productivity impacts of product and process innovations.

One additional specification we estimate replaces the innovation variable with the lagged indicator for whether or not the firm invested in R&D. These results are reported in the last two columns of Table 3. The results are similar to the ones using the single innovation variable. In this case, firms that invested in R&D in the previous period had productivity increases in the domestic and export markets, respectively, that were 1.2 and 2.4 percent higher than firms that did not invest. The use of either the lagged R&D indicator or the current innovation indicator suggests a very different impact of R&D investment on revenue productivity in each market and thus leads to differences in the expected benefit of R&D between exporting and nonexporting firms. When estimating the dynamic model of R&D choice, we rely on the productivity specification that uses a single innovation indicator dz.

Given the estimates of equation (7) reported in the second and third column of Table 3, we construct estimates of revenue productivity $\hat{\omega}_{it}^h$ and $\hat{\omega}_{it}^f$ for sales in each market using equations (17) and (18). Table 4 summarizes the median and interquartile range of the productivity estimates across firms in each market and industry. For the exporting firms, the productivity estimates are reported separately for the two markets.

In all five industries, the median domestic sales productivity ω^h is substantially higher for the exporting firms than for the nonexporters and the interquartile range is slightly larger in all but the chemical industry. For example, in chemicals, the median ω^h is 0.596 for exporters and 0.161 for nonexporters. If we look at additional percentiles of the domestic productivity distribution we see that the distribution for exporting firms stochastically dominates the distribution for nonexporters. This results in higher domestic profits for the exporting firms which is then reinforced by the productivity in the export market sales ω^f. Together, these productivity estimates imply that exporting firms will have higher profits than domestic firms.

Table 4 Distribution of Revenue Productivity ω^h and ω^f		
	Median	p75 - p25
Chemicals		
Nonexporters: Domestic Sales	0.161	0.968
Exporter: Domestic Sales	0.596	0.681
Exporter: Export Sales	0.291	0.825
Machinery		
Nonexporters: Domestic Sales	0.003	0.281
Exporter: Domestic Sales	0.183	0.300
Exporter: Export Sales	0.190	0.960
Electronics		
Nonexporters: Domestic Sales	0.019	0.285
Exporter: Domestic Sales	0.221	0.444
Exporter: Export Sales	0.326	3.855
Instruments		
Nonexporters: Domestic Sales	-0.168	0.356
Exporter: Domestic Sales	0.123	0.410
Exporter: Export Sales	-0.043	1.523
Vehicles		
Nonexporters: Domestic Sales	0.038	0.226
Exporter: Domestic Sales	0.292	0.352
Exporter: Export Sales	0.159	0.428

Being a state variable in the dynamic model, ω^h is expected to affect the incentives to

invest in R&D for nonexporting firms, while both ω^h and ω^f should affect the decision to invest in R&D for exporting firms. To verify this, we construct the fraction of firms investing in R&D for different percentiles of the ω^f and ω^h distribution and report them in Table 5. The second column show that firms in the chemical industry that fall into the lowest quartile of the domestic sales productivity distribution have an R&D investment rate of .694. The chemical producers that fall into the lowest quartile of the export sales productivity distribution have an investment rate of .842. Two clear patterns emerge in the table. First, as we move from low to high quartiles for both ω^f and ω^h, the proportion of firms that invest in R&D increases in all industries, except for the chemical industry with respect to export market productivity. This is consistent with the argument that high productivity firms have a higher net payoff from investing in R&D. Second, comparing domestic and export market productivity we observe that R&D investment rates are higher for the firms with export market exposure, again with the exception of the chemical industry. Together these two patterns suggest that the model we developed, in which productivity and export market exposure are two determinants of the firm's incentive to invest in R&D, delivers consistent results that match the R&D patterns we observe in these industries.

Table 5: R&D Investment Rates by Productivity Quartiles

	Chemicals	Machinery	Electronics	Instruments	Vehicles
Quartiles of ω^h					
Lowest	.694	.546	.755	.684	.433
Second	.779	.735	.778	.823	.678
Third	.792	.830	.875	.850	.833
Highest	.792	.897	.902	.961	.900
# observations	578	1086	575	611	361
Quartiles of ω^f					
Lowest	.842	.707	.893	.832	.569
Second	.767	.781	.903	.920	.836
Third	.758	.883	.938	.944	.863
Highest	.743	.977	.902	.992	.958
# observations	480	891	453	501	291

5.2 The Cost and Expected Benefits of R&D

Table 6 reprots the final set of parameter estimates: the dynamic costs of innovation. These are estimated by maximizing the likelihood function in equation (21) with respect to the parameter vector γ. We allow the distribution of startup and fixed costs to differ across industry and with firm export status. Each parameter is the mean of the untruncated distribution of costs that firms face when investing to develop a product or process innovation.

Table 6: Innovation Cost Parameters (standard errors)				
	Nonexporting Firms		Exporting Firms	
Industry	Startup Cost	Fixed Cost	Startup Cost	Fixed Cost
Chemical	11.74	2.34	154.93	19.79
	(0.92)	(0.18)	(1.03)	(0.35)
Machinery	13.18	1.91	27.98	5.73
	(1.10)	(0.22)	(4.88)	(0.30)
Electronics	11.03	2.05	26.20	2.70
	(1.55)	(0.15)	(0.41)	(0.05)
Instruments	2.25	0.48	8.89	1.26
	(0.54)	(0.10)	(1.59)	(0.15)
Vehicles	47.08	4.10	31.85	9.80
	(5.12)	(0.67)	(4.48)	(0.80)

There are several clear patterns in the cost estimates. The first finding is that fixed costs are smaller than startup costs for all industries and export status groups. This means that, comparing two firms with the same productivity, capital stock, industry, and export status and, therefore, the same expected payoff to R&D, the firm that was previously engaged in R&D will, on average, find it less expensive to develop an innovation than a firm with no prior R&D experience. The cost differential is substantial. The ratio of the mean startup cost to fixed cost varies from 4.7 (instruments) to 11.5 (vehicles) among the nonexporters and 3.25 (vehicles) to 9.7 (electronics) among the exporters. Prior R&D experience induces a cost saving in the innovation process so that firms with prior experience will be more likely to continue investing in R&D. A second finding is that, within an industry, both costs are higher for exporting firms. This holds for all industries except vehicles. In the estimated model, the payoff to conducting R&D is going to be larger for exporting firms because of the larger impact of R&D on innovation (as seen in Table 2) and the larger impact of innovation on productivity (as seen

in Table 3). This larger payoff will make exporting firms willing to incur greater R&D costs in order to get the expected productivity gain that it will generate. The final pattern concerns variation across industries. This difference reflects the difference in long-run profits that will be earned from an innovation which, in turn, depends on the magnitude of the firm's revenue in each market. Vehicles and chemicals are the largest industries in terms of median firm sales and instruments is the smallest and this reflects the differences in R&D investments that firms are willing to make.

As part of the estimation algorithm, we solve for the value functions and construct the expected payoff to R&D, $\Delta EV^h(\omega_{it}^h)$ for firms that sell only in the domestic market and $\Delta EV^f(\omega_{it}^h, \omega_{it}^f)$ for firms that sell in both markets. These payoffs are functions of the firm's revenue productivity in the markets in which it sells. Table 7 summarizes the expected payoffs at three different percentiles of the productivity distribution for ω_{it}^h and ω_{it}^f, the 25th, 50th, and 75th. The capital stock is held fixed at the median value and so the variation reflects differences arising solely from differences in productivity levels.

Table 7 : $\Delta EV^h(\omega^h)$ and $\Delta EV^f(\omega^h, \omega^f)$ (millions of euros, evaluated at the median capital stock)		
	Percentile of the distribution of ω^h	
$\Delta EV^h(\omega^h)$ 25th percentile	50th percentile	75th percentile
Chemicals 0.89	5.19	14.41
Machinery 4.96	8.51	14.20
Electronics 6.87	12.03	26.90
Instruments 0.67	1.34	2.89
Vehicles 21.53	37.28	66.05
$\Delta EV^f(\omega^h, \omega^f)$		
Chemicals 63.67-126.62[a]	69.43-131.30	82.06-141.45
Machinery 14.54-25.22	18.13-28.32	24.49-33.90
Electronics 9.48-32.31	15.40-36.03	31.61-48.63
Instruments 4.66-10.11	5.73-10.92	8.29-12.97
Vehicles 29.11-37.47	40.76-48.78	65.34-72.91
[a] The two entries are constructed at the 25th and 75th percentile of the distribution of ω^f		

The entries are the expected benefit of investing in R&D, in millions of euros, by a firm with different combinations of ω^h and ω^f. For example, for a pure domestic firm in the chemical industry with ω^h equal to the 25th percentile of the productivity distribution, the gain in long-run expected profits if they invest in R&D is 0.89 million euros. This will rise with productivity

and increase to 14.41 million euros if ω^h is at the 75th percentile of the distribution. In contrast, an exporting chemical firm with ω^h at the 25th percentile and a level of ω^f equal to the 25th percentile of that distribution would earn 63.67 million euros from R&D investment. Holding ω^h fixed, this would rise to 126.62 million if ω^f increased to the 75th percentile. For this industry, there are substantial differences in the expected benefit of conducting R&D between nonexporting and exporting firms.

In the table, four patterns are evident. First, holding ω^h fixed, the level of the expected payoff to R&D for exporting firms is generally much higher than for nonexporting firms, $\Delta EV^f(\omega^h, \omega^f) > \Delta EV^h(\omega^h)$. This reflects the higher probability of realizing an innovation, the larger impact of innovations on the export revenue function, and the larger variance in the exogenous shocks to productivity. The latter can result in large improvements in productivity over time and, because of the convexity of the profit function in productivity, increases in mean expected profits. Second, with the exception of the vehicle industry, increases in export market productivity from the 25th to 75th percentile generate larger improvements in $\Delta EV^f(\omega^h, \omega^f)$ than comparable increases in domestic market productivity. Third, related to the last point, if we vary both productivity measures we see that an exporting firm with low domestic productivity (ω^h at the 25th percentile) but high export productivity (ω^f at the 75th percentile) will have a higher expected benefit than a pure domestic firm with high productivity. Again, the vehicle industry is an exception. Together, these patterns all indicate that exporting firms and, in particular, high productivity exporting firms will tend to have the highest expected benefits from investing in R&D. Finally, the payoff to R&D varies substantially across industries. It is lowest for domestic producers in the chemical, machinery, and instrument instruments and highest for chemical, electronics, and vehicle firms that export.

Table 7 summarizes how the benefit of R&D varies with values of the state variables ω^h and ω^f but does not capture the actual distribution of firms across the states. In the next table we summarize the net returns to R&D across the actual firm observations in each industry. We calculate the net return for a firm that faces the mean fixed or startup cost for exporting and nonexporting firms in their industry, respectively (see Table 6). We express this net benefit relative to the value of the firm. We define the expected net benefit of investing in R&D by

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an exporting firm as:

$$NB_{it}^f = \frac{\Delta EV^f(\omega_{it}^h, \omega_{it}^f) - E(C_{it}^f)}{V^f(s_{it}^f)}.$$

It measures the proportional change in the value of an exporting firm if it goes from not investing in R&D to investing. Similarly we can define the net benefit for a firm that does not export as:

$$NB_{it}^h = \frac{\Delta EV^h(\omega_{it}^h) - E(C_{it}^h)}{V^h(s_{it}^h)}.$$

Table 8 reports the 25th , 50th, and 75th percentiles of the distribution of net returns across all observations. The percentiles are reported by industry, by export status, and by whether the firm must pay a fixed or startup cost when investing in R&D. Focus first on the columns for firms that had prior R&D experience and are thus paying a fixed cost to maintain R&D investment. The first row shows that in the chemical industry, nonexporting firms at the 25th percentile of NB_{it}^h will have a negative expected payoff to R&D of -7.2 percent of firm value. This occurs because, given the firms productivity and capital stock, the net benefits from investing in R&D are quite small relative to the mean fixed cost expenditure in that industry. In this case the firm would choose not to invest in R&D, even though it only had to pay the costs of maintining an R&D program. At the 75th percentile this return becomes positive and equals 1.3 percent of firm value. A firm with this combination of state variables would have an expected increase of 1.3 percent of firm value if they invested in R&D, relative to an identical firm that did not invest. The second row of the table summarizes the distribution of net returns, NB_{it}^f, for firms that are in the export market. Even at the 25th percentile of the distribution the exporting firm has positive expected benefits. The value rises from .5 percent of firm value to 1.6 percent as we move to the 75th percentile. In this case, all of these exporting firms would find it profitable to invest in R&D.

A clear pattern that is evident in Table 8 is that a larger fraction of the exporting firms will have a positive expected return from R&D. In all five industries the 25th percentile of of NB_{it}^h is negative and in two of the industries the median is negative, implying the firm would not find it optimal to invest in R&D. In contrast those values are always positive for NB_{it}^f, implying that these firms would find it profitable to invest in R&D. This will lead to a higher R&D investment rate among the exporting firms.

The last three columns of the table report the same statistics for firms that face the higher startup cost for R&D rather than the fixed cost. The same difference between nonexporting and exporting firms is observed but now a larger percentage of both groups of firms have negative expected returns. For two of the industries, the 75th percentile is negative for both nonexporting and exporting firms. There will be a much lower R&D investment rate for the firms that have to pay startup costs but there will still be a higher investment rate for the exporting firms in the three industries where the upper tail of the distribution of NB_{it}^{f} is positive. .

Table 8: Long-Run Expected Net Return to R&D, NB_{it}^{h} and NB_{it}^{f}		Continuing R&D Firms			Startup R&D Firms		
Percentile of distribution		25th	50th	75th	25th	50th	75th
Chemicals	Nonexport	-.072	-.037	.013	-.391	-.235	-.004
	Export	.005	.014	.016	-.045	-.020	-.006
Machinery	Nonexport	-.019	.001	.015	-.194	-.107	-.054
	Export	.006	.012	.015	-.022	-.006	.003
Electronics	Nonexport	-.009	.004	.015	-.097	-.056	-.022
	Export	.007	.014	.017	-.047	-.013	-.007
Instruments	Nonexport	-.012	-.005	.007	-.078	-.051	-.020
	Export	.010	.015	.017	-.019	-.003	.007
Vehicles	Nonexport	-.010	.005	.023	-.281	-.184	-.106
	Export	.001	.007	.011	-.015	-.000	.007

6 Conclusion

A large empirical literature in international trade has documented substantial and persistent differences in firm performance between firms that engage in international markets, through either sales, input purchases or capital investment, and those that limit their business activities to the domestic market. The theoretical literature on growth and trade has emphasized that the superior performance of firms that participate in international markets may reflect the endogenous decisions of these firms to invest in R&D and other activities that lead to innovations and productivity improvements. Firms engaging in international markets may have better opportunities to realize profits that become available as a result of their endogenous innovative activities and this, in turn, creates greater incentives for them to invest in R&D. The superior

long-run performance of these firms is the result of greater endogenous investment in innovative activities.

In this paper we provide empirical evidence on this endogenous investment mechanism and measure how it differs for two groups of German high-tech manufacturing firms, one that exports and one that does not. In our empirical model, firm R&D investment generates new product and process innovations which then improve the long-run expected profits of the firm. We use the model estimates to measure the expected payoff to the firm from investing in R&D. We allow the entire investment process to differ for domestic and export sales.

The empirical results indicate that exporting firms are more likely to realize product and process innovations from their R&D investments than pure domestic firms. On average, across the five high-tech industries, the probability of an innovation for an exporting firm is 0.905 if they invest in R&D and 0.285 if they do not. Nonexporting firms have lower probabilities of innovation, 0.786 and 0.188 depending on whether or not they invested in R&D. These realized innovations have larger impacts on firm productivity and profits for sales in the export market than for domestic sales. Innovation raises productivity in the export market by 2.7 percent but only 0.9 percent in the domestic market. The higher propensity to innovate combined with the larger impact of innovation on productivity, implies a larger expected benefit of R&D investment for exporting firms. For a firm selling only in the domestic market and with the median level of industry productivity and capital stock, the expected payoff to R&D investment varies from 1.3 million euros in the instruments industry to 37.3 million euros in the vehicle industry. The expected payoff for an exporting firm will depend on both their domestic and export market productivity. At the median export productivity, the payoff to R&D is approximately 20 percent higher in the vehicle industry, two to three times as large in machinery and electronics, and higher than this in chemicals and instruments. We also estimate the costs of innovation to calculate an expected net return to the firm from investing in R&D. We find that the net benefit is positive for exporting firms with prior R&D experience while it is often negative for nonexporting firms. The magnitude of the net benefit is the main driving force that leads to a higher rate of R&D investment for exporters.

Overall, our findings provide evidence for greater incentives to invest in R&D by firms that

participate in the export market. This endogenous difference in R&D investment between the two groups of firms reinforces any initial differences in productivity between the two groups and contributes to a greater divergence in performance between exporting and nonexporting firms over time. Our findings are consistent with the idea underlying models of endogenous growth and trade which emphasize that participation in international markets can affect the speed and direction of technological improvements.

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