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Abstract

In this article we study differences in the returns to R&D investment between firms that sell in international markets and firms that only sell in the domestic market. We use German firm-level data from the high-tech manufacturing sector to estimate a dynamic structural model of a firm's decision to invest in R&D and use it to measure the difference in expected long-run benefit from R&D investment for exporting and domestic firms. The results show 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. Simulating the introduction of trade tariffs we find a substantial reduction in firms' productivity growth and incentive to invest in R&D.

Keywords: R&D choice, Export, Innovation, Productivity, Dynamic structural model

JEL-Classification: F14, L25, O31, O32

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1 Introduction

The theoretical and empirical literature on international trade has emphasized the difference in performance between firms that engage in international markets, through either trade or investment activities, and those that operate in only the domestic market. A large empirical literature has quantified differences in productivity and growth between exporting and domestic 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 Melitz (2003), has shown how differences in underlying firm characteristics, particularly productivity, can lead to differences in the incentives to export or to import and the self-selection of firms into those activities. A common starting point seen in both 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 their 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, increase the firm's incentive to invest in innovation activities. In this article, we develop an empirical model built on two components of the endogenous growth framework. The first component accounts for the fact that innovation is expensive and that firms choose to undertake R&D when the expected discounted payoff from the investment outweighs the cost. The second considers that the payoff from an innovation 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 market. This can lead to differences in the expected return to R&D investment, which, in turn, leads to different patterns

[1] A recent review of the empirical literature on productivity, exporting, and importing is given by Shu and Steinwender (2018).

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

in R&D investment and alters the subsequent productivity or output growth between domestic and exporting firms.

A large empirical literature has relied on various export market shocks to study the relationship between firms' investments in R&D, technology adoption, or innovation rates and firms' productivity and export market participation. Virtually all studies find evidence of positive cross-sectional and intertemporal correlations between R&D, innovation, exporting, and productivity at the firm level.[3] An alternative approach is to estimate structural models of technology that incorporate both R&D investment and export market sales. Aw, Roberts, and Xu (2011) estimate a dynamic structural model of export choice and R&D investment using firm data for Taiwanese electronics producers. They find that export market sales increase firm productivity and the return to R&D. The resulting endogenous investment in R&D contributes to the productivity gap between exporting and domestic firms. Using a similar framework, Máñez, Rochina-Barrachina, and Sanchis-Llopis (2015) analyze Spanish firm data and find that two activity variables, exporting and R&D, increase both productivity and the probability of undertaking the complementary activity in future periods. Bøler, Moxnes, and Ulltveit-Moe (2015) find that a Norwegian R&D tax credit stimulated both R&D investment and purchases of imported intermediate inputs, which acted as complements and contributed to technological change. Bilir and Morales (2018) use data on U.S. multinational firms to measure the impact of parent and affiliate discrete R&D investment on the productivity of both the parent and affiliates. They find that parent R&D participation positively impacts affiliates' productivity while affiliate R&D participation only affects performance at that location. Overall, this empirical literature has identified positive causal linkages between foreign contacts, through either trade or foreign investment, and R&D investment or technology upgrading but, with the exception of Aw, Roberts, and Xu (2011), has not modeled the dynamic choice of R&D investment or estimated how the dynamic choice of R&D differs across firms based on their trade exposure.[4]

[3]This literature includes Bernard and Jensen (1997), Baldwin and Gu (2004), Aw, Roberts, and Winston (2007), Aw, Roberts, and Xu (2008), Van Beveren and Vandenbussche (2010), Bustos (2010), Lileeva and Trefler (2010), Cassiman and Golvko (2011), Becker and Egger (2013), Altomonte, Aquilante, Bekes, and Ottaviano (2013), Damijan, Kostevc, and Rojec (2017), and Aghion, Bergeaud, Lequien, and Melitz (2018). A robust conclusion from this literature is that firms that export, particularly high-productivity firms, are more likely to invest in R&D, report product and process innovations, or patent.

[4]An exception to the finding of a positive relationship between trade exposure and technology upgrading is

In this article, we develop and estimate a dynamic structural model of the R&D process, including firm R&D investment, innovation outcomes, and productivity growth, and measure how the expected benefits of R&D investment vary with trade exposure. We use firm-level data for five high-tech German manufacturing industries. Following the model of R&D investment by Peters, Roberts, Vuong, and Fryges (2017) (herafter, PRVF), we quantify three stages linking R&D investment and the firm's expected long-run return. First, R&D investment will change the probability of developing new products or process innovations. Second, these innovations can improve future firm productivity and, hence third, improve the path of future profits and firm value. We extend PRVF by allowing each stage in this process to differ between exporting and domestic firms and measure how they contribute to differences in the long-run payoff to R&D. We extend the model of Aw, Roberts, and Xu (2011) by incorporating product and process innovations, allowing R&D to have different effects on export and domestic productivity, and studying a range of high-tech manufacturing industries in an advanced economy.

The empirical results reveal substantial differences in the R&D process between exporting and domestic firms. Exporting firms that invest in R&D are more likely to realize product and process innovations. 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 can reflect learning effects through technological spillovers or knowledge transmissions from abroad. The fact that these innovations have a larger impact on profits can reflect the larger size of international markets as well as the larger set of innovative opportunities for firms that sell abroad. Overall, the empirical findings in this article indicate a very large difference in the return to R&D and the incentives to invest in R&D between exporting and domestic German high-tech firms. This endogenous process of R&D investment contributes to the divergence in performance observed between exporting and domestic firms. Focusing on the exporting firms, we simulate the impact of changes in tariffs and R&D subsidies. Tariff increases are found to substantially reduce the

the study by Santos (2017). He finds that reductions in trade costs increase competition among domestic firms and reduce their incentives to adopt new technologies.

payoff to R&D and result in lower R&D investment rates and productivity growth.

In the next section, we extend the PRVF model of R&D choice to recognize differences in the productivity process between exporting and domestic firms. In the third section, we discuss the data, which is drawn from the Mannheim Innovation Panel (the German contribution to the Community Innovation Surveys). In the fourth section, we present the empirical model and estimation method. Section five presents the empirical results and section six provides concluding remarks.

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. In 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.[5] 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 PRVF 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 linkage between productivity and profits and working backward to the firm's choice of R&D. Our framework extends the model of PRVF, which only treats firms as selling in a single market, to allow R&D to have a different impact on innovation and firm

[5] 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).

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. Firm i's short-run marginal production cost is represented by

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

where c_{it} is the log of marginal cost, k_{it} is the log of firm capital stock, and a_{it} is firm age. 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, time-varying production efficiency ψ_{it} captures differences in technology or managerial ability that are known by the firm but not observable to the econometrician.[6] The capital stock is treated as a fixed factor in the short-run. Thus, we allow for three sources of cost heterogeneity across firms: capital stock, firm age, and unobserved production efficiency.[7]

Each firm can sell in two markets, the home market (h) and the foreign market (f). A domestic firm i faces the demand for its product q_{it}^h in the home market 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}^h that reflects product desirability, product appeal or product quality in the domestic market. This demand

[6]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.

[7]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 three factors, the capital stock, firm age, 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.

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.

Exporting firms face a similar demand structure for their product in the home market, where the demand parameters η^h and Φ_t^h are allowed to differ between exporting and domestic firms. Exporting firms additionally face a demand curve in the foreign market given by:

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

Importantly, the firm-level demand shifter in the foreign market ϕ_{it}^f is different than the one operating on domestic sales. An exporting firm can have a product with high appeal in the home 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

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

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 $\omega_{it}^l = \psi_{it} - \frac{1}{1+\eta^l} \phi_{it}^l$. Equation (4) implies that, for a given level of capital stock and firm age, 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 that 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 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 $l = h, f$:

$$\pi^l_{it} = \pi^l_t(\omega^l_{it}, k_{it}, a_{it}) = -\frac{1}{\eta^l}\exp(r^l_{it}). \tag{5}$$

The total per-period profits of the firm depend on the markets it sells to. The profit of a firm that sells in only the domestic market will depend on only the domestic market revenue productivity (in addition to capital and age), whereas the firm that operates in both markets will have total profits that reflect productivities in both markets. The total short-run profit for a domestic market firm D and an exporting firm X is therefore defined as:

$$\begin{aligned} \Pi^D_{it} &= \Pi^D_t(\omega^h_{it}, k_{it}, a_{it}) = \pi^h_t(\omega^h_{it}, k_{it}, a_{it}) \\ \Pi^X_{it} &= \Pi^X_t(\omega^h_{it}, \omega^f_{it}, k_{it}, a_{it}) = \pi^h_t(\omega^h_{it}, k_{it}, a_{it}) + \pi^f_t(\omega^f_{it}, k_{it}, a_{it}) \end{aligned} \tag{6}$$

In our German manufacturing data, virtually all firms sell either solely in the domestic market or in both the domestic and export market in all years they are observed. None of the firms sell only in the foreign market and only very few firms move in or out of the foreign market.[8] Because there is virtually no entry or exit from the export market in our data, we cannot estimate the fixed or sunk costs of exporting or the determinants of export choice as in Das, Roberts, and Tybout (2007) or Aw, Roberts, and Xu (2011). Instead, we treat each firm as either a domestic producer with profits given by Π^D_{it}, determined only by conditions in the home market, or an exporting firm whose total short-run profits Π^X_{it} depend on conditions in both the home and foreign market.

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 domestic and exporting firms. The linkage between R&D and innovation is represented by the cumulative joint distribution of product and process innovations, conditional

[8] Of the firms that export, 98.4 percent remain exporters in all years. Of the nonexporters, 95.3 percent never enter the export market. For the small number of firms that switch status, we treat them as different firms during the two periods. We have also estimated the model after dropping these firms and it has no effect on the results.

on whether or not the firm invests in R&D and whether or not it sells in foreign markets, $F(d_{it+1}, z_{it+1}|rd_{it}, I(f_i))$. In this specification, $I(f_i)$ 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 and, 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 benefit from alternative pathways for innovations. It may have both the opportunity and the incentive 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 of the domestic product but designed for consumers in the foreign market.

In the second step, firm productivity in each market is treated as a state variable that evolves over time as a Markov process, and is shifted by product or process innovations. Using the discrete innovation indicators, z_{it} and d_{it}, we model the evolution of revenue productivity in market $l = h, f$ for firms that sell in both markets as:

$$\omega^l_{it+1} = \alpha^l_0 + \alpha^l_1 \omega^l_{it} + \alpha^l_2 (\omega^l_{it})^2 + \alpha^l_3 z_{it+1} + \alpha^l_4 d_{it+1} + \alpha^l_5 z_{it+1} d_{it+1} + \varepsilon^l_{it+1}. \tag{7}$$

The parameters α_0, $\alpha_1, ...\alpha_5$ differ between the export and domestic market sales, which allows for different patterns of productivity evolution in the two markets. The parameters α_1 and α_2 capture the persistence in firm productivity over time, $\frac{\partial \omega_{t+1}}{\partial \omega_t}$, while α_3, α_4, and α_5 measure how the mean of future productivity shifts when the firm realizes one or both types of innovation. An innovation can operate through two channels, impacting productivity differentially in both the home and foreign markets. The randomness in the productivity processes is captured by $(\varepsilon^h_{it+1}, \varepsilon^f_{it+1})$ which we assume are *iid* draws across time and firms from a joint normal distribution with zero mean and variance-covariance matrix Σ. Notice that shocks to productivity are not transitory, but rather persist and affect future productivity levels through the coefficients

α_1 and α_2.

A similar parametric structure is adopted for productivity evolution for the firms that sell only in the domestic market. In this case, the firm's home market productivity evolves as:

$$\omega_{it+1}^h = \beta_0^h + \beta_1^h \omega_{it}^h + \beta_2^h (\omega_{it}^h)^2 + \beta_3^h z_{it+1} + \beta_4^h d_{it+1} + \beta_5^h z_{it+1} d_{it+1} + \varepsilon_{it+1}^h. \tag{8}$$

In the empirical model, we will estimate the coefficients of equations (7) and (8) separately, recognizing that the parameters of the productivity process can differ for sales in the home market between domestic and exporting firms and between home and foreign market sales for exporting firms. To simplify notation in the dynamic model described in the next section, we denote the domestic firms' productivity evolution process by a cdf $G^D(\omega_{it+1}^h|\omega_{it}^h, d_{it+1}, z_{it+1})$ and that of exporting firms by $G^X(\omega_{it+1}^h, \omega_{it+1}^f|\omega_{it}^h, \omega_{it}^f, d_{it+1}, z_{it+1})$, respectively.

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 firm'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 cost may vary 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, differences in the type of new products that are desirable in foreign markets versus the domestic market, as well as its prior R&D experience. The fact that some firms are better in the innovation process or have a larger set of technological opportunities for innovation is captured in this model by lower innovation costs.

To capture this heterogeneity in firms' innovation cost, we assume that firm i's cost is a random draw from an exponential distribution which has a mean that depends on the firm's export status, represented by $I(f_i)$, prior R&D experience, rd_{it-1}, and other observable firm characteristics W_{it}. The indicator variable for whether or not the firm invested in R&D in the previous year, rd_{it-1}, takes the value 1 if the firm engaged in R&D in $t-1$ and 0 otherwise.

This captures differences in the cost of innovation etween maintaining ongoing R&D operations and starting new ones. Other variables that can be included in W_{it} are industry affiliation, age, or a measure of firm size.[9] We represent the parameter of the innovation cost distribution, which is the mean of the distribution, faced by firm i as $\gamma(I(f_i), rd_{it-1}, W_{it})$. The innovation cost for firm i in year t is therefore modeled as an *iid* draw from the following exponential distribution:

$$C_{it}\tilde{}\ \exp(\gamma(I(f_i), rd_{it-1}, W_{it})). \tag{9}$$

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}^h and, if it is an exporter also the foreign sales productivity ω_{it}^f, its short-run profits Π_{it}^D or Π_{it}^X, the process for productivity evolution in each market, equation (7) or (8), and the probability of an innovation $F(d_{it+1}, z_{it+1}|rd_{it}, I(f_i))$. The state variables for a pure domestic firm are $s_{it}^D = (\omega_{it}^h, rd_{it-1})$ and for an exporting firm are $s_{it}^X = (\omega_{it}^h, \omega_{it}^f, rd_{it-1})$, and they evolve endogenously as the firm makes its decision whether or not to conduct R&D.[10] The value function differs for pure domestic firms and exporting firms.

An exporting firm chooses its R&D to maximize the sum of future discounted expected profits. Before its innovation cost is realized, its value function can be written as:

$$\begin{aligned} V^X(s_{it}^X) &= \Pi_t^X(\omega_{it}^h, \omega_{it}^f) + \\ &\int_C \max_{rd\in\{0,1\}} \Big(\beta E_t V^X(s_{it+1}^X|\omega_{it}^h, \omega_{it}^f, rd_{it}=1) - C_{it}; \beta E_t V^X(s_{it+1}^X|\omega_{it}^h, \omega_{it}^f, rd_{it}=0)\Big)\, dC. \end{aligned} \tag{10}$$

where β denotes the firm's discount factor. The exporting firm's expected future value is defined as an expectation over possible future levels of domestic and foreign market productivity and innovation outcomes:

[9] In PRVF (2017) we let the innovation cost vary with the firm's capital stock and in Peters, Roberts, and Vuong (2017) we included an indicator of the firm's financial strength measured by its credit rating. We simplify the framework here to focus on the differences between exporting and nonexporting firms by industry.

[10] Firm capital stock, age, and variables that shift the cost of innovation are exogenous state variables as well. We omit them from s_{it}^D and s_{it}^X to simplify the notation and to focus on the role of R&D, innovation, 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.

$$E_t V^X(s^X_{it+1}|\omega^h_{it},\omega^f_{it},rd_{it}) = \sum_{(d,z)} \int_{\omega^h,\ \omega^f} V^X(s^X_{it+1}) dG^X(\omega^h_{it+1},\omega^f_{it+1}|\omega^h_{it},\omega^f_{it},d_{it+1},z_{it+1}) \cdot F(d_{it+1},z_{it+1}|rd_{it},I(f_i)=1)). \tag{11}$$

Using these equations, we can characterize the exporter's optimal R&D choice rd_{it}. If it does not invest in R&D, its discounted expected future profits are $\beta E_t V^X(s^X_{it+1}|\omega^h_{it},\omega^f_{it},rd_{it}=0)$. If it does invest in R&D, the discounted expected future profits are $\beta E_t V^X(s^X_{it+1}|\omega^h_{it},\omega^f_{it},rd_{it}=1)$ and it will incur innovation cost C_{it}. The marginal benefit of investing in R&D is the difference in the two expected future profits:

$$\Delta EV^X(\omega^h_{it},\omega^f_{it}) \equiv \beta E_t V^X(s^X_{it+1}|\omega^h_{it},\omega^f_{it},rd_{it}=1) - \beta E_t V^X(s^X_{it+1}|\omega^h_{it},\omega^f_{it},rd_{it}=0). \tag{12}$$

The difference between these two measures of expected future profits is driven by the effect of R&D on the firm's future productivity in both markets. The firm will choose to make the investment if the marginal benefit of R&D is greater than or equal to its cost: $\Delta EV^X(\omega^h_{it},\omega^f_{it})$ $\geq C_{it}$. This condition will be the key to the empirical model of R&D choice developed below.

A firm operating in only the domestic market has a value function given by:

$$V^D(s^D_{it}) = \Pi^D_i(\omega^h_{it}) + \int_C \max_{rd\in\{0,1\}} \Big(\beta E_t V^D(s^D_{it+1}|\omega^h_{it},rd_{it}=1) - C_{it}; \beta E_t V^D(s^D_{it+1}|\omega^h_{it},rd_{it}=0)\Big)\, dC, \tag{13}$$

where the expected future value is defined as:

$$E_t V^D(s^D_{it+1}|\omega^h_{it},rd_{it}) = \sum_{(d,z)} \int_{\omega^h} V^D(s^D_{it+1}) dG^D(\omega^h_{it+1}|\omega^h_{it},d_{it+1},z_{it+1}) F(d_{it+1},z_{it+1}|rd_{it},I(f_i)=0). \tag{14}$$

The marginal benefit of investing in R&D is the difference in the expected future value when the firm invests in R&D versus when it does not:

$$\Delta EV^D(\omega^h_{it}) \equiv \beta E_t V^D(s^D_{it+1}|\omega^h_{it},rd_{it}=1) - \beta E_t V^D(s^D_{it+1}|\omega^h_{it},rd_{it}=0). \tag{15}$$

The domestic firm makes the same benefit-cost comparison as the exporting firm and will choose to invest in R&D if the expected marginal benefit is greater than or equal to the cost,

$\Delta EV^D(\omega_{it}^h) \geq C_{it}$. Compared to an exporting firm, the domestic firm can have a different probability of an innovation and its productivity in the home market can evolve in a different way, both in terms of its persistence and how it responds to product and process innovations. A key difference in the return to R&D activities between a pure domestic firm and an exporting firm is the additional gain from innovation in the foreign market.[11] This difference, along with possible differences in the cost of innovation, drives the disparity in firms' R&D choices and leads to differences in their productivity growth, sales, and profits.

Overall, this 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, equations (7) and (8), (iii) the innovation rates $F(d_{it+1}, z_{it+1}|rd_{it}, I(f_i))$, and (iv) the γ parameters describing the cost of innovation, equation (9). The complete model can be estimated with data on the firm's 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^f, the firm's capital stock and age, k and a, and other cost variables W. In the next two sections we describe the data and develop the empirical model.

3 Data

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), an annual survey collected by the Centre for European Economic Research (ZEW). This survey is the German component of the Community

[11] Though currently not exporting, domestic firms might invest in R&D to improve ω^f to be sufficiently profitable to enter the foreign market in future periods. In this case, ω^f is a state variable when the firm decides to enter the export market. The return to R&D, ΔEV^D, would also include the future gain from foreign markets rather than only the improved stream of home market profit. If we observed export market entry and exit in our data, we could measure this additional contribution of R&D. However, this requires measuring foreign market productivity for domestic firms. In their models of export market entry, Das, Roberts and Tybout (2007) and Aw, Roberts, and Xu (2011) do this by imposing structure on the relationship between the evolution of domestic and foreign market productivity. In this study, we cannot estimate the export entry decision and do not impose any restrictions on the relationship between productivity evolution in the domestic and export markets.

Innovation Survey which is administered in all EU countries.[12] We use a sample of firms from five high-tech manufacturing sectors: chemicals (NACE rev 1.1 codes 23, 24), nonelectrical machinery (29), electronics (30, 31), instruments (33), and motor vehicles (34, 35). Our sample covers the years 1994-2008 and includes 540 observations (after taking lags) from 247 domestic firms and 2590 observations from 1041 exporting firms.

For the estimation of the model, we use data on firm sales in the German domestic market and total sales in all of its export markets, variable costs, capital stock, firm age, innovation expenditures and product and process innovations. 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 constructed as the difference between total 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 article, 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 innovative activities which includes 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.[13]

[12] Details of the sampling design are discussed in PRVF and Rammer and Peters (2013).

[13] 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. Sample attrition is due to nonreporting and not due to firm death (see PRVF for a discussion).

Table 1 reports the differences in total revenue between exporting and domestic firms and the share of export sales for the exporters. Domestic firms have, on average, lower revenue than exporting firms. The difference could be due to the fact that domestic firms have, on average, less capital, lower productivity, and less investment activity. The difference in revenue between exporting and domestic firms varies substantially across industries. We observe the smallest difference in the chemical industry where exporting firms have twice as much revenue as domestic firms. In the vehicle industry this difference amounts to 27 times.

The last three columns summarize the export intensity for exporting firms. Across all industries, the export intensity ranges between 4.7 percent (10th percentile) and 72.1 percent (90th percentile) implying substantial heterogeneity across firms in the relative importance of the export market. There is a substantial number of firms that are most active in the domestic market (median of export intensity is 32.5 percent) and other firms with the export market being their main source of revenue.

Table 1: Firm Sales in Domestic and Export Markets (millions of euros)

	Domestic Firms	Exporting Firms			
	Average Firm Sales	Average Firm Sales	Export Sales/Total Sales		
			10th percentile	Median	90th percentile
Chemicals	58.905	122.034	0.051	0.325	0.724
Machinery	7.398	80.393	0.045	0.361	0.769
Electronics	17.970	114.405	0.033	0.278	0.643
Instruments	3.391	39.324	0.057	0.341	0.732
Vehicles	6.584	178.077	0.032	0.291	0.697
Total Sample	17.147	96.634	0.047	0.325	0.721

Table 2 summarizes the differences in R&D investment rates and innovation rates between domestic 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 domestic firms is 0.422, while it is substantially higher, 0.855, for exporters. This is likely to be an important source of the often-observed productivity difference between exporting and domestic firms. The fourth and fifth columns present the rates of 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 0.370 for domestic firms and 0.787 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 domestic firms, 0.309 versus 0.586. The model developed in the previous section allows innovations to occur at different rates for exporting and domestic 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 domestic firms and subsequently help explain the difference in the proportion of firms engaging in R&D.

Table 2: Firm Rates of R&D Investment and Product and Process Innovation

	R&D Investment Rate		Product Innovation		Process Innovation	
	Domestic	Exporter	Domestic	Exporter	Domestic	Exporter
Chemicals	0.596	0.800	0.472	0.726	0.449	0.577
Machinery	0.360	0.837	0.315	0.766	0.275	0.574
Electronics	0.495	0.909	0.477	0.842	0.385	0.601
Instruments	0.387	0.922	0.340	0.882	0.226	0.602
Vehicles	0.276	0.801	0.241	0.702	0.207	0.589
Average	**0.422**	**0.855**	**0.370**	**0.787**	**0.309**	**0.586**

4 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 $I(f_i) \in \{0,1\}$. The innovation probabilities are estimated separately for each industry. For exporting firms we estimate the industry elasticity of demand for home and foreign sales using the method in Das, Roberts, and Tybout (2007). We regress the firm's total variable cost (the sum of expenditure on labor, materials and energy) on the sales in each market and the coefficient on the sales variable in market l can be interpreted as $1 + \frac{1}{\eta^l}$. For domestic firms, this is equivalent to the mean of the ratio of total variable cost to total sales.

Unlike the data on firm exports, domestic sales, and capital stock, which are observable to us, firm productivity in each market is not. We use the proxy variable approach of Olley and Pakes (1996) as applied by Doraszelski and Jaumandreu (2013) and PRVF (2017) to estimate the parameters of the revenue function, equation (4), and the productivity process, equation (7), and construct estimates of productivity in each market. In order to implement their methodology for the exporting firms, 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 markup-weighted share of sales in each market. The markup-weighted share of sales in market l is equal to the physical quantity of sales in market l. Specifically, the share of material expenditure allocated to sales in market h is:

$$sm_{it}^h = \frac{\exp(r_{it}^h)(\frac{\eta^f}{1+\eta^f})}{\exp(r_{it}^h)(\frac{\eta^f}{1+\eta^f}) + \exp(r_{it}^f)(\frac{\eta^h}{1+\eta^h})}$$

and $sm_{it}^f = 1 - sm_{it}^h$. This assumption is restrictive, because it assumes that the expenditure on materials is used in fixed proportion to the quantity of output 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.

Using the structure of our model, we can solve for the demand functions for the material inputs. The factor demand equation for the log of materials used for production in each market $l = h, f$ is:

$$m_{it}^l = \beta_t^l + (1+\eta^l)\beta_k k_{it} + (1+\eta^l)\beta_a a_{it} - (1+\eta^l)\omega_{it}^l. \quad (16)$$

In this equation, the intercept β_t^l depends on the common time-varying components in the model which include the intercept of the demand function in market l and the variable input prices. The material demand depends on the observed capital stock, age, and unobserved market productivity. Solving equation (16) for productivity gives:

$$\omega_{it}^{l} = (\frac{1}{1+\eta^{l}})\beta_{t}^{l} + \beta_{k}k_{it} + \beta_{a}a_{it} - (\frac{1}{1+\eta^{l}})m_{it}^{l}. \tag{17}$$

We substitute this expression into the productivity evolution process, equation (7), lag it one period and substitute it for ω_{it}^{l} in the revenue equations (4). This allows us to express revenue in each market as a function of current and lagged capital, lagged age, lagged materials, and the product and process innovations.

$$\begin{aligned} r_{it}^{l} &= \lambda_{0}^{l} + \lambda_{t}^{l} + (1+\eta^{l})(\beta_{k}k_{it} + \beta_{a}a_{it}) \\ &\quad -\alpha_{1}\left[\beta_{t-1}^{l} + (1+\eta^{l})\beta_{k}k_{it-1} + (1+\eta^{l})\beta_{a}a_{it-1} - m_{it-1}^{l}\right] \\ &\quad -(\frac{\alpha_{2}}{1+\eta^{l}})\left[\beta_{t-1}^{l} + (1+\eta^{l})\beta_{k}k_{it-1} + (1+\eta^{l})\beta_{a}a_{it-1} - m_{it-1}^{l}\right]^{2} \\ &\quad -(1+\eta^{l})\left[\alpha_{3}^{l}z_{it} + \alpha_{4}^{l}d_{it} + \alpha_{5}^{l}z_{it}d_{it}\right] - (1+\eta^{l})\varepsilon_{it}^{l} + \upsilon_{it}^{l}. \end{aligned} \tag{18}$$

The error term υ_{it}^{l} is a transitory shock to the firm's revenue function which is not observed by the firm prior to choosing its variable inputs or making its R&D decision. For estimation we utilize the moment conditions implied by the fact that the error term $-(1+\eta)\varepsilon_{it}^{l} + \upsilon_{it}^{l}$ is uncorrelated with all right-hand side variables, $a_{it-1}, k_{it}, k_{it-1}, m_{it-1}^{l}, z_{it}, d_{it}$, and $z_{it}d_{it}$. The intercept λ_{0}^{l} is a combination of the intercepts of the revenue function and the productivity evolution equation α_{0}^{l}. We can separately identify the α_{0}^{l} parameter from the revenue function intercepts using the moment condition that ε_{it}^{l} has a zero mean. The time coefficients λ_{t}^{l} and β_{t-1}^{l} are functions of the common time-varying variables including the demand intercept and factor prices. The β_{t-1}^{l} coefficients are identified, up to a base-year normalization, and can be distinguished from the λ_{t}^{l} coefficients because of the higher-order power on ω_{it-1}^{l} in equation (7). We allow the intercept λ_{0}^{l} to vary across the two-digit industries in each group, reflecting industry differences in the revenue functions and include the industry-specific estimate of the demand elasticity as data. We also allow the β_{k} and β_{a} parameters to differ in the two markets, rather than constraining them to be equal as in the theoretical model, to allow for possible differences in the marginal cost of production in each market. Finally, using the estimated residuals in the productivity evolution equations, we estimate the variance and covariance of the productivity shocks. After estimation of the revenue function parameters, firm-level productivity in each market is constructed from the inverted material demand function equation (17). The same estimation procedure is used for domestic firms except we use the total material expenditures of the firm as the control function.

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 solve for the value functions, equations (10) and (13) and, importantly, the expected payoff to each firm from investing in R&D, $\Delta EV^D(\omega_{it}^h)$ for domestic firms and $\Delta EV^X(\omega_{it}^h, \omega_{it}^f)$ for exporting firms. We use the nested fixed-point algorithm developed by Rust (1987) to estimate the structural parameters. At each iteration of the structural parameters, we approximate each of the value functions as a weighted sum of Chebyshev polynomials and include the weights as additional parameters to estimate. We use separate approximations for the domestic firms, whose state space is $s_{it}^D = (\omega_{it}^h, rd_{it-1})$ and exporting firms, which have the state space $s_{it}^X = (\omega_{it}^h, \omega_{it}^f, rd_{it-1})$. Exogenous state variables that shift the profit and cost function; age, capital stock, and industry, are treated as fixed firm characteristics in the value function calculation.[14]

The probability that a firm chooses to invest in R&D is given by the probability that its innovation cost C_{it} is less than the expected payoff. For domestic firms this is:

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

and for exporting firms it is

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

Assuming the firm's state variables s^D or s^X are independent of the cost draws and that the costs are *iid* draws from the distributions in equation (9), across all firms and time, the likelihood function for the firms' discrete R&D choice can be expressed as:

$$L(\gamma | rd, s) = \prod_{i=1}^{N} \prod_{t=1}^{T_i} Pr(rd_{it} | s_{it}; \gamma), \tag{21}$$

[14] The profit function also depends on year dummies. After estimation there is no trend in the time estimates. We treat the value functions as stationary and use the average over the time coefficients when calculating the value function.

where γ is the vector of innovation 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.

5 Empirical Results

In the next subsection we provide the estimated relationships from the first-stage model linking 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 3 summarizes the empirical relationship between firm R&D investment and innovation, $F(d_{it+1}, z_{it+1}|rd_{it}, I(f_i))$. It reports the estimated probability a firm introduces successful innovations conditional on their R&D choices and export status $I(f_i)$. If a firm does not invest in R&D in period t, columns (2) - (5) report the probability of realizing either no innovation, only product innovation, only process innovation, or both types of innovations in the next period. On average, domestic firms that do not invest in R&D report no innovation with a frequency of 0.827 and at least one type of innovation with a frequency of 0.173 (sum of columns (3) to (5)). The equivalent estimates for exporting firms are 0.736 for no innovation and 0.264 for at least one type of innovation. In addition, in every industry exporting firms have a higher frequency of innovation than domestic firms. In the case where the firm invests in R&D, the innovation probabilities are reported in columns (6) - (9). When investing, the frequency of innovation (sum of columns (6) to (9)) increases substantially to 0.768 for domestic and 0.913 for exporting firms. In every industry, exporters have a higher frequency of innovation than domestic firms.[15] This higher rate of innovation contributes to exporters having higher productivity levels and profits.

How these differences in the innovation rates affect a firm's incentive to invest in R&D depends on how ΔEV in equations (12) and (15) is affected by the difference in innovation

[15] For firms that report innovations, realizing both product and process innovations is the most common outcome for all industries. Stand alone product innovations are realized with a higher frequency than process innovations for both exporting and nonexporting firms, regardless of their R&D investments.

rates when $rd_t = 0$ versus $rd_t = 1$. In this case, there is a minor difference between exporters and domestic firms. The probability of an innovation increases, on average, by 0.595 (from 0.173 to 0.768) for domestic firms if they invest in R&D. The increase in this probability for exporters is slightly larger, 0.649 (from 0.264 to 0.913) than for domestic firms. There is a larger difference when we separate product and process innovations. In the case of product innovations ($d = 1, z = 0$ or $d = 1, z = 1$), R&D increases the probability of innovation by 0.669 for exporters but only 0.524 for domestic firms. For process innovations, the difference is modest, 0.468 for exporters and 0.421 for domestic firms. Overall, for both domestic and exporting firms, investment in R&D substantially increases the probability of innovation. The impact of R&D is larger for exporters than domestic firms, especially with respect to product innovation. However, whether this leads to a higher R&D investment rate or not will also depend on how much the realized product and process innovations impact the level of productivity.

Table 3: Probability of Innovation Conditional on Past R&D: $\Pr(d_{t+1}, z_{t+1} | \; rd_t, I(f_i))$

	$rd_t = 0$				$rd_t = 1$			
Product innovation	$d = 0$	$d = 1$	$d = 0$	$d = 1$	$d = 0$	$d = 1$	$d = 0$	$d = 1$
Process innovation	$z = 0$	$z = 0$	$z = 1$	$z = 1$	$z = 0$	$z = 0$	$z = 1$	$z = 1$
Domestic Firms								
Chemicals	0.833	0.042	0.042	0.083	0.154	0.179	0.179	0.487
Machinery	0.841	0.024	0.008	0.127	0.271	0.200	0.100	0.429
Electronics	0.786	0.089	0.000	0.125	0.153	0.186	0.051	0.610
Instruments	0.836	0.055	0.018	0.091	0.315	0.315	0.056	0.315
Vehicles	0.824	0.020	0.039	0.118	0.263	0.158	0.053	0.526
Average	**0.827**	**0.042**	**0.016**	**0.115**	**0.232**	**0.216**	**0.087**	**0.465**
Exporting Firms								
Chemicals	0.766	0.054	0.054	0.126	0.097	0.223	0.036	0.644
Machinery	0.721	0.096	0.059	0.125	0.089	0.258	0.034	0.619
Electronics	0.625	0.075	0.075	0.225	0.084	0.285	0.025	0.605
Instruments	0.821	0.026	0.000	0.154	0.059	0.301	0.007	0.633
Vehicles	0.735	0.122	0.020	0.122	0.127	0.186	0.059	0.629
Average	**0.736**	**0.077**	**0.048**	**0.139**	**0.087**	**0.258**	**0.030**	**0.625**

The next stage of the empirical model uses equation (18) to estimate the parameters of the revenue functions and the processes of productivity evolution. The estimation results, together with the estimates of the demand elasticities, are reported in Table 4.

Table 4: Productivity Evolution and Profit Function Parameters (standard errors)

	Exporting Firms		Domestic Firms
	Domestic Revenue	Export Revenue	Domestic Revenue
Productivity Evolution			
ω_{t-1}	0.761 (0.018)**	0.896 (0.023)**	0.558 (0.048)**
ω_{t-1}^2	0.087 (0.008)**	0.059 (0.006)**	0.213 (0.019)**
d	0.027 (0.011)*	0.061 (0.018)**	0.016 (0.029)
z	0.046 (0.020)*	0.012 (0.033)	0.056 (0.044)
$d * z$	-0.007 (0.022)	0.021 (0.036)	-0.049 (0.054)
$Var(\varepsilon)$	0.037	0.085	0.072
$Cov(\varepsilon^h, \varepsilon^f)$		0.016	
Revenue Function			
k	-0.065 (0.004)**	-0.065 (0.004)**	-0.102 (0.009)**
age 10-19	-0.005 (0.018)	0.013 (0.030)	0.023 (0.037)
age 20-49	-0.099 (0.027)**	-0.129 (0.050)**	-0.043 (0.046)
age >50	-0.202 (0.033)**	-0.226 (0.064)**	-0.086 (0.060)
Intercept	1.138 (0.319)**	0.760 (0.701)	0.782 (0.241)**
Chemicals	0.136 (0.044)**	-0.038 (0.066)	-0.013 (0.103)
Machinery	0.070 (0.037)	0.005 (0.060)	0.087 (0.086)
Electronics	0.099 (0.041)*	0.088 (0.068)	0.207 (0.094)*
Instruments	0.051 (0.041)	0.165 (0.067)*	0.001 (0.096)
Demand Elasticity			
Chemicals	-3.045 (0.055)**	-3.989 (0.206)**	-2.981 (0.116)**
Machinery	-4.220 (0.071)**	-4.287 (0.128)**	-4.207 (0.124)**
Electronics	-4.254 (0.091)**	-3.794 (0.186)**	-4.260 (0.181)**
Instruments	-4.235 (0.074)**	-3.506 (0.135)**	-3.480 (0.097)**
Vehicles	-4.737 (0.135)**	-4.557 (0.312)**	-4.604 (0.255)**
sample size	2,590	2,590	540

The models also include a full set of year dummies.

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

The second and third columns of Table 4 report estimates of the productivity evolution process for domestic and export market sales for the exporting firms. The first two coefficients jointly determine the persistence of the productivity process, $\frac{\partial \omega_{t+1}}{\partial \omega_t}$. Productivity persistence averages 0.79 in the domestic market and 0.86 in the export market. In both cases, productivity is highly persistent, implying a long-lived productivity impact of innovations. This further enhances the gain from investing in R&D. The coefficients on d, z, and dz measure the impact of product and process innovations on revenue productivity. For domestic sales, both innovations have a significant positive effect on productivity, increasing it by 2.7 percent for a product innovation and 4.6 percent for a process innovation. Firms that report both types of innovations have productivity that is 6.6 percent (=0.027 + 0.046 - 0.007) higher than noninnovators on average. In the export market, product innovation is particularly important, increasing productivity by 6.1 percent. Process innovations increase productivity by 1.2 percent and firms with both types of innovations have productivity levels that are 9.4 percent higher than noninnovators.

The relative importance of the domestic versus export market channel to the exporting firm's R&D choice is determined by both the productivity persistence and the impact of innovation in each market. The results in Table 4 indicate that there is both higher productivity persistence and larger impact of innovation on export market productivity, implying that R&D investment will have a larger impact on firm profits through the export channel. The impact of R&D investment on firm value will increase with the share of the firm's sales in the export market. Holding innovation costs constant, this will lead to a greater incentive to invest in R&D by exporting firms with larger export shares.

The last column of the table reports the productivity coefficients for the domestic firms. The productivity process for these firms is persistent with an average persistence level of $\frac{\partial \omega_{t+1}}{\partial \omega_t} = 0.72$ which is slightly lower than that of exporters. The productivity impact of product innovation for domestic firms is smaller than that of exporting firms while the productivity effect of process innovation is larger for the domestic firms. For a firm with both types of innovation, average productivity will be 2.3 percent higher than a firm with no innovation. However, none of the innovation coefficients are significant for the domestic firms. Overall, we find strong evidence that innovation has a significant effect on both domestic and export market productivity for exporting firms but much weaker evidence of any impact for domestic firms. This difference contributes to a widening gap between exporting and domestic firm productivity over time.

The remaining rows in Table 4 report the coefficients of the profit function, equations (4) and (5). Capital has a negative coefficent implying that firms with larger capital stocks have lower variable costs and thus higher revenues and profits. The firm age coefficients measure the deviation from the youngest group of firms, and the negative signs imply that more mature firms have, on average, lower variable production costs, hence higher profits. The highest profits will be earned by the oldest firms. The demand elasticities are reported in the bottom panel of Table 4. Profits are inversely related to the demand elasticity. Whereas the demand elasticities are fairly similar across the markets and industries, the smaller elasticities for the chemical industry imply that profits will be higher in this industry for a given level of sales. In the electronics, instruments, and vehicle industries, the smaller demand elasticity for export sales, compared to the elasticity for domestic sales, will contribute to a larger impact of export sales on profits for the exporting firms. This will increase the value of exporting in generating a larger expected benefit from R&D and increase the probability of investing in R&D. Given the parameter estimates in Table 4, we construct estimates of revenue productivity $\hat{\omega}_{it}^h$ and $\hat{\omega}_{it}^f$ for sales in each market using equation (17).

Before proceeding to the dynamic estimation, we estimate the reduced-form policy function for the discrete R&D choice. The policy function depends on the state variables ω^h and ω^f as well as the variables that define the firm types: industry, capital stock, and age. Probit estimates for the discrete R&D variable using a simple linear specification of the explanatory variables are reported in Table 5. For exporting firms, both foreign market productivity ω^f and capital are positively correlated with the firm's decision to invest in R&D and, for domestic firms, capital is positively correlated with R&D choice. These effects are statistically significant. In contrast, domestic market productivity is negatively correlated with R&D choice for both groups of firms and the coefficients are not statistically significant, suggesting a more complex relationship between the state variables and R&D choice than this specification allows.

The coefficient estimates in Table 5 reflect a combination of the underlying structural components: the innovation process, productivity evolution, profit function, and innovation costs, and cannot be interpreted as causal effects. We have already seen that R&D investment increases the probability of innovation and innovations increase domestic and export market productivity. In the next section we report estimates from the dynamic component of the model: the cost of innovation and the expected benefit of investing in R&D, $\Delta EV^X(\omega_{it}^h, \omega_{it}^f)$ for exporting firms and $\Delta EV^D(\omega_{it}^h)$ for domestic firms. These allow us to quantify how differences in domestic and foreign productivity affect the payoff to R&D and the probability of R&D investment by the firm, factors which cannot be learned from studying the reduced-form policy function coefficients in Table 5.

Table 5: Probit Estimates of Policy Functions for rd_{it}		
	Exporting Firms	Domestic Firms
ω^h	-0.127 (0.079)	-0.074 (0.118)
ω^f	0.284 (0.056)**	
k	0.120 (0.022)**	0.180 (0.034)**
age 10-19	-0.110 (0.094)	-0.319 (0.156)*
age 20-49	-0.295 (0.092)**	-0.141 (0.161)
age >50	-0.044 (0.010)	-0.678 (0.229)**
Intercept	0.587 (0.136)**	-0.519 (0.237)**
Chemicals	-0.004 (0.112)	0.651 (0.245)**
Machinery	0.263 (0.010)**	0.327 (0.210)
Electronics	0.707 (0.127)**	0.782 (0.229)**
Instruments	0.888 (0.130)**	0.423 (0.230)
All regressions include a full set of year dummies.		
** significant at the 0.01 level, * significant at the 0.05 level		

5.2 The Cost of Innovation and the Expected Benefits of R&D

Table 6 reports 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 maintenance costs to differ across industry and with firm export status. Combinations of these parameters give the mean of the untruncated distribution of innovation costs for firms with different industry, export status, and R&D history.

Table 6: Innovation Cost Parameters (standard errors)		
Industry	Startup Cost	Maintenance Cost
Chemicals	13.127 (3.203)**	3.455 (1.284)**
Machinery	10.197 (2.187)**	4.456 (1.513)**
Electronics	9.398 (2.497)**	3.180 (1.541)**
Instruments	3.443 (2.185)	0.540 (0.579)
Vehicles	17.404 (3.518)**	10.427 (1.810)**
Exporting Firms	19.904 (1.530)**	2.231 (0.638)**
Domestic Firms	1.144 (2.038)	0.370 (1.351)
** significant at the .01 level, * significant at the .05 level		

There are several clear patterns in the cost estimates. The first finding is that maintenance costs are smaller than startup costs for all industries and both export status groups. This means that, comparing two firms with the same characteristics and thus the same expected payoff to R&D, the firm that has 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 maintenance cost varies from 1.7 (vehicles) to 6.3 (instruments) across the industries. 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 than firms without prior R&D experience starting R&D investment. A second finding is that startup costs are significantly higher for exporting firms. 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 3) and the larger impact of innovation on productivity (as seen in Table 4). Due to a larger payoff to R&D, exporting firms are willing to incur higher R&D expenditures to get the expected productivity gain resulting from R&D investment. The final pattern concerns cost variation across industries. Estimated cost differences across industries reflect the difference in long-run profits that must be earned from firm's successful innovation. Firms in the vehicles industry face, on average, the highest innovation cost, whereas firms in the instrument industry have the lowest costs among the five industries. An exporting firm in the vehicles industry with no previous R&D experience faces, on average, an innovation cost of 37.31 million euros while a domestic firm with previous R&D engagement would have an innovation cost of 10.80 million euros. These costs amounts to 23.35 million and 0.91 million Euro for firms in the instrument industry, respectively.

As part of the estimation algorithm, we solve for the value functions and construct the expected payoff to R&D, $\Delta EV^D(\omega_{it}^h)$ for firms that sell only in the domestic market and $\Delta EV^X(\omega_{it}^h, \omega_{it}^f)$ for firms that sell in both markets. These payoffs are functions of the firm's respective revenue productivities. Table 7 summarizes the firm's expected payoffs to R&D at the 25th, 50th, and 75th percentiles of the productivity distributions, ω_{it}^h, and ω_{it}^f. The payoffs are reported for a firm between 10 and 19 years old with capital stock at the median level in each industry. The variations in ΔEV reflect the differences in expected benefit from R&D investment that arises solely from differences in productivity levels.

Table 7 : $\Delta EV^D(\omega^h)$ and $\Delta EV^X(\omega^h, \omega^f)$ (millions of euros)			
	Percentile of the distribution of ω^h		
	25th percentile	50th percentile	75th percentile
Domestic firms $\Delta EV^D(\omega^h)$			
Chemicals	0.661	0.773	0.965
Machinery	0.589	0.847	1.018
Electronics	1.302	1.772	2.358
Instruments	0.300	0.446	0.618
Vehicles	0.327	0.418	0.637
Exporting firms $\Delta EV^X(\omega^h, \omega^f)^a$			
Chemicals	10.720, 17.473	11.533, 18.269	12.274, 18.990
Machinery	15.920, 20.521	17.003, 21.582	18.522, 23.065
Electronics	10.752, 15.299	13.695, 18.132	16.617, 20.926
Instruments	8.701, 11.004	9.515, 11.790	10.485, 12.725
Vehicles	22.963, 39.212	26.289 42.430	29.537, 45.534

[a] The two entries are constructed at the 25th and 75th percentile of the distribution of ω^f

The top panel summarizes the benefit for domestic firms. In the chemical industry, a firm that only sells its output on the domestic market and has a productivity level of $\omega^h = 0.46$ (25th percentile of the productivity distribution) earns an additional expected long-run profit of 0.661 million euros if it invests in R&D. The expected earning rises with higher domestic sales productivity and equals 0.965 million euros at $\omega^h = 0.95$ (75th percentile of the distribution). The expected benefit for domestic firms in the electronics industry is higher than in the remaining four industries, ranging between 1.302 to 2.358 million euros. Overall, the expected benefit roughly doubles as we move from the 25th to the 75th percentile of the productivity distribution for all industries.

The bottom panel of Table 7 summarizes the expected benefit for the exporting firms. Each cell reports two numbers, the expected benefit at the 25th and 75th percentiles of ω^f. For example, 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 10.720 million euros from investing in R&D. Holding ω^h fixed, this would rise to 17.473 million if ω^f increased to the 75th percentile.

Three patterns are evident in this table. First, the level of the expected payoff to R&D for exporting firms is substantially higher than that of domestic firms, $\Delta EV^X(\omega^h, \omega^f) > \Delta EV^D(\omega^h)$. This reflects the higher probability of successful innovations for exporting firms, their advantages in capitalizing and implementing these innovations, and also any scale advantages of serving a larger market than domestic firms. Furthermore, the productivity impacts of innovations for exporters persist longer over time, setting them on more favorable productivity paths, resulting in a higher expected benefit than that of domestic firms. Second, increases in export market productivity from the 25th to 75th percentile generate larger improvements in $\Delta EV^X(\omega^h, \omega^f)$ than comparable increases in domestic market productivity. This is particularly noticeable in the vehicle industry, where an interquartile increase in ω^h increases the expected benefit by approximately 6.5 million euros, but an interquartile increase in ω^f results in an increase of approximately 16 million euro. Third, among the exporting firms, ones with high foreign productivity will have larger expected payoffs than ones with high domestic productivity. Together, these patterns indicate that exporting firms and, in particular, those with high foreign-market productivity will have the highest expected benefits from investing in R&D.

The results in Table 7 show how the payoff to R&D varies with the key productivity state variables ω^h and ω^f. Using the model parameters, we can calculate $\Delta EV^X(\omega^h, \omega^f)$ or $\Delta EV^D(\omega^h)$ for each data point in our sample. In addition to varying with industry and firm productivity, these also vary with firm capital stock and age. Using the estimates of ΔEV and the distributions of innovation costs, which vary with the firms' prior R&D status and industry, we calculate the probability of R&D investment, equations (19) and (20).

Table 8 summarizes the distribution of ΔEV, $\Delta EV/V$ and $Pr\,(rd_{it} = 1)$ across the data observations for exporting and domestic firms. Three patterns are evident in the data. First, as was seen in Table 7, there is a large difference in the expected benefits of R&D between exporting and domestic firms in the same industry. For example, in the chemical industry the median of $\Delta EV^X(\omega^h, \omega^f)$ for the exporting firms is 23.82 million euros while the median value of $\Delta EV^D(\omega^h)$ for domestic chemical producers is 1.18 million. This pattern occurs for all industries and is reflected in the higher probabilities of investing in R&D by the exporting firms that are reported in the last three columns of the table. Second, the within-industry differences in ΔEV are substantial and much larger than the across-industry differences at a given percentile. In the case of chemicals, the firm at the 25th percentile of $\Delta EV^X(\omega^h, \omega^f)$ has an expected benefit of R&D of 13.71 million euros, while the firm at the 75th percentile has a value of 36.34 million. This within-industry heterogeneity reflects the productivity effects seen in Table 7, but also the differences due to the firm's size (capital stock) and age. Columns (5)-(7) summarize the distributions of expected benefits as a fraction of firm value $\Delta EV^X/V^X$ and $\Delta EV^D/V^D$. For most of the domestic firms, the percentage gains are between 1.0 and 2.0 percent of firm value. Only the electronics industry has slightly larger percentage gains, reaching 2.7 percent at the 75th percentile. For the exporting firms, the percentage gains are much larger. Across industries, the 25th percentile varies from 3.8 to 7.1 percent and at the 75th percentile varies from 5.5 to 17.3 percent. The heterogeneity in expected benefit leads to variation in firms' R&D probability. In our data, exporting firms have a high probability of investing in R&D, above 0.95 for the median observation in each industry. The within-industry differences in $\Delta EV^D(\omega^h)$ for domestic firms lead to substantial variation in the probability of R&D investment, from less than 0.051 at the 25th percentile to over 0.83 at the 75th percentile in some industries.

Table 8: Percentiles of the Distribution of R&D Benefits

	ΔEV			$\Delta EV/V$			$Pr\,(rd_{it}=1)$		
	25th	50th	75th	25th	50th	75th	25th	50th	75th
Domestic Firms									
Chemicals	0.66	1.18	3.41	0.013	0.014	0.016	0.069	0.242	0.450
Machinery	0.84	1.73	3.57	0.009	0.010	0.011	0.081	0.184	0.380
Electronics	1.78	3.15	7.94	0.020	0.024	0.027	0.179	0.395	0.830
Instruments	0.42	0.86	1.76	0.008	0.011	0.013	0.141	0.303	0.677
Vehicles	0.91	1.54	2.57	0.014	0.017	0.020	0.051	0.087	0.134
Exporting Firms									
Chemicals	13.71	23.82	36.40	0.043	0.052	0.061	0.663	0.963	0.997
Machinery	14.74	24.63	39.29	0.038	0.046	0.055	0.769	0.968	0.997
Electronics	13.46	22.81	33.72	0.071	0.108	0.173	0.868	0.976	0.998
Instruments	8.10	12.62	20.97	0.051	0.067	0.083	0.918	0.989	0.999
Vehicles	17.96	47.13	74.32	0.049	0.068	0.095	0.687	0.962	0.997

The clear conclusion that emerges from the estimates of the structural model is that the expected benefits from investing in R&D are higher for exporters than for domestic firms. This higher benefit is the result of both a higher probability of innovation if they do R&D and a larger impact on productivity and profits if they realize an innovation. The cost of an innovation is modestly higher for the exporting firms but, when combined with the substantially higher expected benefits, results in a greater propensity to invest in R&D. Because productivity in both the domestic and export market sales is highly persistent, the impact of R&D investment is long-lived and even more so for the export sales productivity. The higher productivity raises the incentives to invest in R&D in future periods. Because R&D investment has a larger impact on the productivity process for exporting firms and, particularly for their export sales, this will contribute to a divergence between the future productivity paths of exporting and domestic firms. In effect, firms operating in export markets realize greater returns to R&D than domestic firms leading them to invest more which further increases the productivity and profit advantage they have relative to domestic firms.

5.3 Counterfactual Analysis for Exporting Firms

In this section, we use the structural model to simulate how firms would optimally respond to changes in their economic environment. In the last section, we report substantial differences in the expected return to R&D and in the incentives to do R&D between exporting and domestic firms. Changes in the economic environment, such as the imposition of a tariff, subsidy to R&D, or change in the productivity process will impact the returns to R&D but do little to narrow the substantial differences between the two groups of firms. Instead of comparing exporting and domestic firms, in this section we focus solely on the exporting firms and report how changes in the economic environment or productivity processes impact their expected benefits and probability of investing in R&D.

How an exporting firm's R&D decision responds to changes in the economic environment depends on the mix of its export and domestic market sales and how innovation impacts each of these sales. The parameter estimates in Table 4 indicate that product innovations have a larger impact on productivity in export market sales while process innovations have a larger impact on domestic sales. Firms with both types of innovations will realize a larger productivity impact on their foreign market sales. This implies that the economic return to innovations will depend on how the firm's total sales are allocated between the two markets.

We simulate three categories of changes in the economic environment. The first two, changes in trade tariffs and subsidies to R&D expenditures, simulate changes in the environment that can result from policy choices. The third category simulates the impact from modifications in the productivity process. The result from this exercise measures the overall contribution of R&D to the firm's value and measures the importance of the long-lived nature of the productivity gains generated by R&D investment. We simulate the effect of these changes in the environment on the firms' optimal R&D decisions and firm value and report these values after a five-year period.

5.3.1 The Impact of Tariffs

The first exercise examines the impact of an export tariff which increases the firm's output price in the foreign market and hence reduces its profit in that market. The second exercise simulates the impact of an import tariff imposed by the German government on imported products that are used as intermediate inputs in production by German firms. The import tariff increases marginal production cost, which is passed on to consumers through higher prices and reduces profits in both foreign and domestic markets. The third exercise combines these two tariff changes.

Table 9 reports the impact of imposing tariffs on seven outcomes: the probability the firm conducts R&D, the long-run payoff to R&D investment ΔEV^X, the proportional change in ΔEV^X, the change in firm per-period profit, the fraction of the change in the total period profits accounted for by the change in export profits, and the changes in sales productivity in home and foreign markets . In each case, the table reports the median change in the variable across all observations.

The top panel simulates the effect of a permanent 10 percent export tariff on German products imposed by the importing countries. In our model, this raises the price of German goods in the destination country by $(1+\tau)$, where τ is the tariff rate, and reduces firm's demand and profit in the foreign market.[16] It is equivalent to a reduction in market size. The second column shows that an export tariff of $\tau = 0.10$ reduces the probability of investing in R&D between 2.0 (instruments) and 7.5 (chemicals) percentage points due to the reduced profitability in the export market. This occurs because of a substantial decrease in the marginal benefit of

[16]Increasing output prices in the destination country by $1 + \tau$ is equivalent to shifting the intercept in the foreign demand curve equation (3) to $\Phi_t^f (1 + \tau)^{\eta_f}$. This reduces export profits by a factor of $1 - (1 + \tau)^{\eta_f}$.

investing in R&D in all five industries. The results in the third column show that firms in the instrument industry will have the expected marginal benefit of R&D reduced by 2.536 million euros. The vehicle industry is more vulnerable to an export tariff, with the median expected payoff to R&D investment falling by 14.727 million euros. These reductions are a substantial proportion of the value of doing R&D. Column (4) shows that the proportional reduction in ΔEV^X due to the tariff increase amounts to between 17.3 and 36.1 percent for the median observation. Lower R&D investment results in a decline in firm's productivity as reported in the last two columns. Home market productivity declines range from 0.3 percent (instruments and electronics) to 1.1 percent (chemical). The decline in foreign productivity is larger than in the home market and ranges between 0.5 and 1.7 percent for the instruments, electronics and chemical industry, respectively. Imposing an output tariff of 10 percent significantly reduces the firm's incentive to invest in R&D and their productivity growth.

The main source of this reduction is the reduction in the payoff from the export market. Column (5) shows that the reduction in firms' profit varies from 0.327 million euros in the instrument industry to 2.595 million euros in the vehicle industry. Overall, this loss in period profit amounts to approximately 16 percent of the reduction in the long-run return for each industry. Column (6) of the table shows that virtually all of the reduction in short-run profits comes from the reduction in export market profits. In every industry the contraction in the export market accounts for over 95 percent of the total reduction in period profit. It is interesting to note that even though the main source of the reduction in firm value due to the tariff arises from the loss of profit in the export market, the impact from the domestic market is not zero. In the presence of a tariff and the resulting lower R&D investment rate, domestic productivity ω^h is also put on a less favorable path. This further reduces the incentive to invest in R&D in the future relative to a no-tariff environment.

The second panel of the table simulates the effect of an import tariff of $\lambda = 10\%$ on products imported by Germany. Assuming firms import a fraction ρ of their inputs, an import tariff increases firm's production cost and lowers its profit in both export and domestic markets by a factor of $1 - (1 + \lambda\rho)^{(\eta^f+1)}$ and $1 - (1 + \lambda\rho)^{(\eta^h+1)}$, respectively. In our data, we do not observe the fraction of firms' intermediate inputs that are imported, therefore in the exercise we calculate the effect of this tariff if $\rho = 0.50$ of firm's material input is affected. The results in the second column show that the probability of investing in R&D falls by 1 percentage point, much less than in the export tariff case. The loss in the long-run expected gain to R&D is also smaller than in the case of an export tariff. Firm's long-run expected gain from R&D falls between 1.027 million euros in the instrument industry to 4.236 million euros in vehicles. This is between 7.0 and 10.0 percent of the expected gain from R&D without the tariff. The smaller loss in period profit and ΔEV^X, relative to the export tariff, occurs because the higher prices the firm receives in this case partially offset the revenue loss from the lower quantity sold. In this case, the higher prices the firm receives for its product are: $p^l = \frac{\eta^l}{1+\eta^l}\exp(c)(1+\lambda\rho)$ for $l = h, f$. In contrast, in the case of the export tariff, the exporting firm sells a lower quantity and receives only $p^f = \frac{\eta^f}{1+\eta^f}\exp(c)$. Column (6) shows that the change in export profits as a fraction of the change in total profit varies between 30.9 and 55.2 percent. The losses are more evenly divided between the domestic and export market sales than under the scenario of an export tariff. The last two columns report the loss in firm productivity in both markets. Across industries, the loss in home market productivity is small, 0.1 percent, and slightly larger, 0.2 percent, in the foreign market. Overall, both reductions are smaller than those of an export tariff.

The third panel summarizes the effect when both export and import tariffs are imposed, as would be the case if Germany retaliated with an import tariff when an export tariff is imposed on its foreign sales. A clear pattern arises. There is a substantial reduction in the probability of investing in R&D, between 5.0 and 15.0 percentage points, and the expected long-run benefit of R&D falls between 4.069 and 21.756 million euros across industries. The decrease in ΔEV^X amounts to between 27.5 and 49.6 percent of the initial value across all industries. These are the largest effects of all three trade tariff scenarios. For each industry, a majority of the profit loss is due to the profit reduction in the export market. This fraction varies from 0.687 in instruments to 0.834 in chemicals. The large reduction in ΔEV^X results from lower period profit but also from lower R&D investment and therefore the forgone productivity improvement in the long run. Productivity losses in this scenario are larger than in the previous two, whereas productivity losses in the foreign market dominate those in the home market. Due to less R&D

activity, home market productivity decreases between 0.6 and 1.8 percent for the electronics and chemical industry, respectively. Foreign productivity decreases by 1.1 to 2.9 percent for the electronic and chemical industry compared to the pre-tariff situation.

Overall, the simulations indicate fairly substantial reductions in the incentive to invest in R&D as a result of the introduction of tariffs. The reduction in export sales or the increase in production costs reduces the long-run expected payoff to R&D and makes it more likely that the firm will not find it profitable to bear the costs of innovation. This negatively impacts the future path of productivity in both the export and domestic markets and reduces firm value. Consistent with the mechanisms hypothesized in the endogenous growth and trade literature, operating in the export market provides benefits to the firm that increase the incentives to invest in innovation with positive long-run effects.

Table 9: Change in Outcomes Due to Tariffs (Median)

Industry	$Pr(rd=1)$	ΔEV^X	Prop. Change ΔEV^X	Π^X	$\frac{\pi^f}{\Pi^X}$	ω^h	ω^f
			Export tariff 10%				
Chemical	-0.075	- 7.401	-0.298	-1.065	0.950	-0.011	-0.017
Machinery	-0.040	- 6.966	-0.231	-1.220	0.977	-0.004	-0.007
Electronics	-0.040	- 4.145	-0.211	-0.777	0.979	-0.003	-0.005
Instruments	-0.020	- 2.536	-0.173	-0.327	0.965	-0.003	-0.005
Vehicles	-0.070	-14.727	-0.361	-2.595	0.971	-0.006	-0.010
			Import tariff 10%				
Chemical	-0.010	-1.782	-0.074	-0.422	0.552	-0.001	-0.002
Machinery	-0.010	-2.378	-0.081	-0.587	0.503	-0.001	-0.002
Electronics	-0.010	-1.839	-0.080	-0.484	0.360	-0.001	-0.002
Instruments	0.000	-1.027	-0.070	-0.240	0.309	-0.001	-0.001
Vehicles	-0.010	-4.236	-0.100	-1.233	0.494	-0.001	-0.002
			Export and Import tariffs 10%				
Chemical	-0.150	-10.524	-0.414	-1.722	0.834	-0.018	-0.029
Machinery	-0.080	-10.362	-0.343	-1.975	0.820	-0.009	-0.015
Electronics	-0.090	- 7.110	-0.333	-1.363	0.737	-0.006	-0.011
Instruments	-0.050	- 4.069	-0.275	-0.661	0.687	-0.008	-0.012
Vehicles	-0.140	-21.756	-0.496	-4.141	0.819	-0.011	-0.019

5.3.2 The Impact of R&D Subsidies

Policies designed to subsidize R&D expenditures, either directly or through preferential tax treatment, are used in many countries. Using the estimated structural model, we simulate the effect of R&D subsidies, which are equivalent to reducing the cost of innovation in our framework, on the incentives of firms to invest.

The top panel in Table 10 reports the impact of reductions in maintenance costs and startup costs of innovation on the probability of investing and the long-run payoff to R&D. In each case we reduce the mean of the innovation cost distribution by 20 percent, so that, on average, firms are facing lower costs of realizing a product or process innovation. The second and third columns report the impact of a reduction in the maintenance cost, which reduces the barrier for firms to continue their R&D activities. This change generates an increase in the R&D participation rate of between 1.0 and 3.0 percentage points. This increase may seem small but the R&D participation rate for exporting firms in our sample is already high, averaging 0.855 across all industries (Table 2). The change in R&D rate reported here captures, in particular, the participation decision of firms that would have stopped their R&D activity under the higher innovation cost regime. The third column shows that the median value of the long-run increase in firm value from investing in R&D is between 1.043 (instrument) and 3.151 (vehicles) million euros. Across industries, the percentage change in ΔEV^X varies between 7.8 percent (machinery) and 10.7 percent (vehicles).

Columns (5) to (7) in Table 10 report the results from a 20 percent reduction in the cost of innovation in the first year the firm invests in R&D, which simulates a subsidy to R&D expenditure for firms that are just starting their R&D investment. This reduction makes it less costly for firms with no R&D experience to realize innovations and this will increase the participation rate. However, an offsetting effect is that a lower startup cost "encourages" firms to disrupt their R&D and restart at another time. Reducing startup costs thus encourages both entry and exit. Column (5) shows that there is no net effect on the participation rate from these two opposing forces. The results on the change in ΔEV are reported in column (6) and indicate that the long-run payoff to R&D falls as a result of the reduced innovation cost. The reduction varies between 1.327 (instruments) and 3.392 (vehicles) million euro across industries, which equals between 5.4 and 8.0 percent of the long-run return. This happens because the expected value of not doing R&D $E_t V^X(s_{it+1}^X | \omega_{it}^h, \omega_{it}^f, rd_{it} = 0)$ in equation (12) rises, reducing the gain from investing in the current period. These countervailing effects are not present when subsidies are directed at continuous R&D operations. The comparison of the two innovation cost subsidies emphasizes that subsidies to induce participation can have subtle effects on the incentive to make ongoing investments. In particular, the effectiveness of a subsidy directed at starting R&D will depend on the proportion of firms that are inactive and can be induced to start versus the proportion that are active and will be induced to stop.

Table 10: Change in Outcomes Due to R&D Subsidies and Productivity Process (Median)

Reduction in Innovation Maintenance and Startup Costs by 20%						
	Maintenance Cost			Startup Cost		
Industry	$Pr(rd = 1)$	ΔEV^X	Prop. Ch ΔEV^X	$Pr(rd = 1)$	ΔEV^X	Prop. Ch ΔEV^X
Chemical	0.020	1.855	0.096	0.000	-2.080	-0.072
Machinery	0.010	1.926	0.078	0.000	-2.413	-0.071
Electronics	0.010	1.739	0.094	0.000	-2.000	-0.070
Instruments	0.010	1.043	0.083	0.000	-1.327	-0.080
Vehicles	0.030	3.151	0.107	0.000	-3.392	-0.054
Changes in Productivity Processes						
	No Productivity Persistence			No Innovation Impact		
Industry	$Pr(rd = 1)$	ΔEV^X	Prop. Ch ΔEV^X	$Pr(rd = 1)$	ΔEV^X	Prop. Ch ΔEV^X
Chemical	-0.820	-23.545	-0.916	-0.960	-25.442	-1.0
Machinery	-0.760	-28.190	-0.892	-0.980	-31.283	-1.0
Electronics	-0.800	-22.754	-0.900	-0.980	-24.997	-1.0
Instruments	-0.840	-14.222	-0.902	-0.990	-15.720	-1.0
Vehicles	-0.730	-44.014	-0.881	-0.950	-48.569	-1.0

5.3.3 Changes in the Productivity Process

The final two simulations focus on the role of the productivity processes for the firm's long run profit and probability R&D investment. First, we remove all persistence in the productivity processes so that $\partial\omega_{t+1}^f / \partial\omega_t^f = \partial\omega_{t+1}^h / \partial\omega_t^h = 0$. This setting implies that the impact of innovation on productivity only lasts for one period and the R&D choice becomes a static decision because R&D only affects one period's profit. This allows us to measure how much of the incentive to invest in R&D comes from the dynamic impact of R&D on future productivity. Second, we remove the impact of innovation on productivity. Thus, R&D does not create any additional productivity improvement and productivity becomes an exogenous process. This provides insights into the overall contribution of the endogenous productivity process.

The second panel in Table 10 reports the results when simulating changes to the productivity processes. Columns (2) to (4) show the importance of the dynamic impact of R&D by removing the persistence in the productivity process. This immediate depreciation of the productivity gains reduces the benefit from innovation, leading to a reduction in the R&D participation rate of between 73 and 84 percentage points. The results also show a dramatic reduction in the average firm return to R&D of between 14.222 to 44.014 million euros. This represents, on average, 90 percent of the long-run return to R&D in the estimated model. This illustrates the importance of the long-run component of the gains to innovation. While innovation is crucial to the improvement of productivity, the long-lasting nature of these productivity gains contributes substantially to the payoff of R&D investment as well.
The last three columns in Table 10 report the contribution of endogenous innovation on the value of the firm. In this exercise we remove any impact that innovation has on future productivity by treating the productivity process as exogenous $\omega_t^l = g(\omega_{t-1}^l) + \epsilon_t^l$. This removes the firm's incentive to undertake R&D, and we observe that the R&D participation rates drop to zero and is reflected in a reduction of more than 95 percentage points compared to the base case. The reduction in ΔEV^X reflects the value of conducting R&D and ranges between 15.72 and 48.57 million euros. Overall, R&D investment generates a substantial increase in the value of the exporting firms.

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 international firms may reflect the endogenous decisions of these firms to invest in R&D that generates 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 article, 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 productivity and future profits of the firm. The investment and innovation process is allowed to differ between exporting and domestic firms. In addition, for exporting firms we allow the impact of innovations on productivity to differ between their domestic and export market sales. These factors generate incentives to invest in R&D that vary with the firms' export intensity. Using the model estimates, we construct a measure of the firm's expected long-run payoff to R&D investment that differs by firm characteristics and, most importantly, by the firm's export market participation.

The empirical results show that exporting firms are more likely to introduce product and process innovations than domestic firms. R&D investment increases the probability of innovation for exporting firms by 65 percent and by 59.5 percent for domestic firms. Even without R&D investment, exporting firms have an innovation rate that is 9.1 percentage points higher than their domestic counterparts. The average productivity impact of these innovations and their persistence is larger for exporting firms leading to a higher expected return to R&D for exporting firms. The median firm that sells its output only in the domestic market expects an average long-run payoff from R&D investment between 0.86 million euros in the instruments industry and 3.15 million euros in the electronics industry. When expressed as a percentage of firm value, the increase in value resulting from R&D for the median firm varies 1.0 to 2.4 percent across industries. The corresponding expected payoff for a median exporting firm is much higher, and varies between 12.62 million euros in instruments and 47.13 in vehicles. As a percentage of firm value, these expected gains vary from 4.6 to 10.8 percent across industries. This difference in expected payoff to R&D is reflected in the higher R&D investment rate for exporting firms compared with domestic firms.

Using the model estimates, we simulate the effect of exogenous changes in the economic environment, including an export tariff and R&D subsidy, on an exporting firm's expected return to R&D and R&D choice. An export tariff of 10 percent, which effectively reduces the size and profitability of the foreign market, lowers the long-run return to R&D investment by at least 20 percent in all industries, reduces R&D participation by between 2.0 and 7.5 percentage points across industries, and slows growth, causing a decline in productivity between 0.3 and 1.7 percent. An R&D subsidy that reduces the cost of innovation by 20 percent for ongoing R&D investment increases the median firm's long-run return by approximately 9.0 percent in all industries and induces higher R&D participation rates by between 1.0 and 3.0 percentage points. In contrast, a 20 percent reduction in innovation costs for R&D startups reduces the incentives for firms to continue R&D and encourages both entry and exit. This is reflected, on average, in a 5.4 to 8.0 percent reduction in the expected return to R&D across industries. The offsetting effects result in an R&D participation rate that is unchanged in this case. Finally, we assess how much of the payoff to R&D investment is captured by the impact on current profits versus the long-run impact on firm value. Over 90 percent of the return to R&D is due to the long-lasting impact of innovations on future productivity.

Overall, our findings provide evidence that firms that participate in the export market have a greater incentive to invest in R&D for several reasons. Their investment is more likely to generate product and process innovations and these innovations have a larger effect on future productivity. This difference in R&D investment incentives between exporting and domestic firms reinforces any initial differences in productivity between the two groups and contributes to a greater divergence in performance between them over time. Among the exporting firms, R&D investment has a greater impact on the future profits from export sales than domestic sales. This provides greater incentives for export intensive firms to invest in R&D. In summary, our findings are consistent with the ideas underlying models of endogenous growth and trade which emphasize that participation in international markets can affect the speed and direction of technological improvements because of the incentives it creates for firms to invest in R&D.

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