NBER WORKING PAPER SERIES

FIRM R&D INVESTMENT AND EXPORT MARKET EXPOSURE

Bettina Peters
Mark J. Roberts
Van Anh Vuong

Working Paper 25228
http://www.nber.org/papers/w25228

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
November 2018

We are grateful to Pere Arque-Castells, Bronwyn Hall, Eric Bartelsman, Jordi Jaumandreu, Hans Lööf, Florin Maican, Jacques Mairesse, Marc Melitz, Pierre Mohnen, Matilda Orth, Stephen Redding, Jo Van Biesebroeck, Daniel Xu, Stephen Yeaple, and Hongsong Zhang for helpful comments and discussions. We thank the ZEW-Leibniz Centre for European Economic Research for providing data access and research support. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

Firm R&D Investment and Export Market Exposure
Bettina Peters, Mark J. Roberts, and Van Anh Vuong
NBER Working Paper No. 25228
November 2018, Revised July 2020
JEL No. F14,L25,O3

ABSTRACT

We study differences in the returns to R&D investment between German manufacturing firms that sell in international markets and firms that only sell in the domestic market. Using firm-level data for five high-tech manufacturing sectors, we 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 domestic firms and, subsequently, have higher rates of productivity growth. We use the model to simulate the introduction of export and import tariffs on German exporters, and find that a twenty-percent export tariff reduces the long-run payoff to R&D by 24.2 to 46.9 percent for the median firm across the five industries. Overall, export market participation contributes significantly to the firm's return on R&D investment, which in turn, raises long run productivity and firm value providing a source of dynamic gains from trade.

Bettina Peters
ZEW
Postfach 103443
D-68034 Mannheim
Germany
b.peters@zew.de

Mark J. Roberts
Department of Economics
513 Kern Graduate Building
Pennsylvania State University
University Park, PA 16802
and NBER
mroberts@psu.edu

Van Anh Vuong
Maastricht University
School of Business and Economics
Tongersestraat 53
Office A2.15
6211 LM Maastricht
The Netherlands
v.vuong@maastrichtuniversity.nl

Firm R&D Investment and Export Market Exposure*

Bettina Peters
ZEW-Leibniz Centre for European Economic Research
and University of Luxembourg

Mark J. Roberts
Pennsylvania State University, NBER, and ZEW

Van Anh Vuong
Maastricht University

June 2020

Abstract

We study differences in the returns to R&D investment between German manufacturing firms that sell in international markets and firms that only sell in the domestic market. Using firm-level data for five high-tech manufacturing sectors, we 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 domestic firms and, subsequently, have higher rates of productivity growth. We use the model to simulate the introduction of export and import tariffs on German exporters, and find that a twenty-percent export tariff reduces the long-run payoff to R&D by 24.2 to 46.9 percent for the median firm across the five industries. Overall, export market participation contributes significantly to the firm's return on R&D investment, which in turn, raises long run productivity and firm value providing a source of dynamic gains from trade.

1 Introduction

One source of the dynamic gains from international trade is its impact on firm innovation and long-run productivity growth. The theoretical literature on growth and trade (Grossman and Helpman 1990, 1995), has emphasized the role of international trade in affecting the speed

*We are grateful to Pere Arque-Castells, Bronwyn Hall, Eric Bartelsman, Jordi Jaumandreu, Hans Lööf, Florin Maican, Jacques Mairesse, Marc Melitz, Pierre Mohnen, Matilda Orth, Stephen Redding, Jo Van Biesebroeck, Daniel Xu, Stephen Yeaple, and Hongsong Zhang for helpful comments and discussions. We thank the ZEW-Leibniz Centre for European Economic Research for providing data access and research support. Contact information: Peters (b.peters@zew.de), Roberts (mroberts@psu.edu), Vuong (v.vuong@maastrichtuniversity.nl)

and direction of technological improvements resulting from firm investments in innovation.[1] A firm exporting to a large international market may innovate at a higher rate than a firm operating solely in a domestic market for at least three reasons. An exporter can draw on a larger knowledge base and may benefit from knowledge spillovers across countries. An exporter may be pressured to innovate more frequently to withstand the higher competition in foreign markets. Finally, it may have a larger payoff to innovation resulting from sales in a larger market. These forces, associated with exporting, elevate the firm's expected return to innovation and increase its incentive to invest in innovation activities such as R&D.

Quantifying the dynamic impact of exporting on innovation activities requires a model of firm investment in innovation. In this article, we develop and estimate a dynamic structural model of firm R&D investment that recognizes the differences in the R&D decision, innovation outcomes, productivity, and profit growth between exporting and non-exporting firms. We measure how the expected returns to R&D investment vary with the firm's trade exposure. Counterfactual analyses are used to quantify how contractions of the export market due to tariffs alter the firm's R&D investment decision and firm value, providing a measure of the dynamic losses from trade restrictions. We estimate the model using firm-level data for five high-tech German manufacturing industries.

Empirical studies using firm-level data consistently find that exporting firms, particularly high-productivity firms, are more likely to invest in innovative activities, such as R&D, patenting, and introducing new products and production processes, than their non-exporting counterparts.[2] One explanation for this positive correlation can be the causal process running from innovation to trade, because innovation can improve the firm's ability to compete in international markets. This pathway has been well documented. R&D investment causes pro-

[1] 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. Burstein and Melitz (2013) comprehensively review this literature and develop a dynamic, industry-equilibrium model to analyze how a reduction in export costs impacts industry output, firm entry, average industry productivity, export participation, and innovation investments. Akcigit, Ates, and Impullitti (2018) develop a dynamic general equilibrium model that incorporates international competition and firm investment in innovation to improve product quality.

[2] 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), Cassiman and Golvko (2011), Becker and Egger (2013), Altomonte, Aquilante, Bekes, and Ottaviano (2013), and Damijan, Kostevc, and Rojec (2017).

ductivity improvements (Cohen, 2010, and Syverson 2011) and higher productivity increases the probability of exporting.[3]

An alternative explanation, which has been less studied, is the causal chain that runs from exporting to investments in innovation. The empirical literature has utilized two approaches to quantify this linkage. The first uses exogenous export market shocks, often from a trade liberalization episode, to identify a causal effect of export activities on firm innovation.[4] Bustos (2010) shows an increase in expenditure on technology upgrading by Argentine firms facing a tariff reduction. Lileeva and Trefler (2010) find that Canadian firms, which expand their exports in response to U.S tariff reductions, increase their product innovation and technology adoption rates. Coelli, Moxnes, and Ultveit-Moe (2016) use data from 60 countries and find a positive effect of trade liberalization in the 1990s on firm patenting. Aghion, Bergeaud, Lequien, and Melitz (2017) find a mixed response: high-productivity French firms increase their patenting activity in response to positive export market shocks while low-productivity firms decrease their patenting. This pattern is the result of both the export market expansion, which differentially benefits high-productivity firms, and an increase in competition in the destination markets, which disadvantages low-productivity firms.

The second approach that has been used to measure the effect of exporting on investment in innovation is to model the firms' export and R&D decisions structurally. This has three key advantages. First, it can provide a measure of the expected long-run return to R&D for both exporting and non-exporting firms. Second, it can identify the pathways linking R&D investment to innovation, productivity, and long-run profits. Finally, estimates of the dynamic decision rule for R&D investment can be used to simulate the effect of trade liberalization or tariff changes on firm R&D choices and long-run firm value, a direct measure of an important

[3]A recent review of the empirical literature on productivity, exporting, and importing is given by Shu and Steinwender (2018). The theoretical literature, much of it based on the model by Melitz (2003), has shown how exogenous differences in underlying firm productivity can lead to differences in the incentives to export, import, or invest in FDI, and the self-selection of firms into these activities.

[4]A related literature has studied how exogenous import market shocks, often from China's expansion into new markets after it joined the WTO, affected innovation. Bloom, Draca, and Van Reenan(2016) find a positive effect on firm patents, IT spending, and R&D spending for 12 European countries. In contrast, Autor, Dorn, Hanson, Pisano, and Shu (2017) find a negative effect on patenting and R&D expenditure for U.S. firms. Using U.S. data, Xu and Gong (2017) find a negative effect on R&D spending for low-productivity firms but a positive impact for high-productivity firms.

source of the dynamic gains from trade. Aw, Roberts, and Xu (2011) estimate a dynamic, structural model of firm export choice and R&D investment using firm-level data for Taiwanese electronics producers. They find that, conditional on current productivity, exporters have larger productivity gains than non-exporters. An expansion of the export market leads to a substantial increase in the probability of investing in R&D. The resulting endogenous increase in R&D investment contributes to the productivity gap between exporting and pure domestic firms.[5]

Building on the dynamic, structural model of R&D investment by Peters, Roberts, Vuong, and Fryges (2017) (hereafter, PRVF), we quantify three components in the pathway linking R&D investment to the firm's expected long-run return. First, R&D investment can 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 allow each stage in this innovation process to differ between exporting and domestic firms. This flexibility is important because differences in the incentives to invest between exporting and non-exporting firms can reflect differences in innovation outcomes, the economic return to innovation, or the cost of innovation. We measure how each stage contributes to differences in the expected return to R&D investment and focus on how this affects the extensive margin of firm R&D investment. We extend the model of Aw, Roberts, and Xu (2011) by incorporating product and process innovations, allowing R&D to have completely different impacts on export and domestic productivity, and studying a range of high-tech manufacturing industries in an economy that has both high innovation rates and heavy dependence on the export market.

The empirical results reveal substantial differences in the innovation process between exporting and domestic firms. Exporting firms that invest in R&D are more likely to realize product and process innovations. This most likely reflects the learning effects through technological

[5] Lim, Trefler, and Yu (2018) use a calibrated structural model to focus on the roles of export market expansion and competition on the patterns of patenting, R&D spending, and new product sales for Chinese manufacturing firms. They find that market expansion positively impacts innovation measures while competition negatively impacts them, but firms can escape the competition effects if they are able to innovate into less competitive market niches. Using their general equilibrium model calibrated to U.S. data, Akcigit, Ates, and Impullitti (2018) find that import tariffs provide small welfare gains in the short run, but reduce the incentives to innovate resulting in large welfare losses in the long run. They also find that R&D subsidies are effective in promoting R&D investment for new and incumbent firms.

spillovers or knowledge transmissions from abroad. On average, these innovations have a larger impact on future productivity and profits from export sales compared to sales in the domestic market. The reason for this can be the larger size of international markets and/or the larger set of innovative opportunities for firms selling abroad. Both forces, a higher rate of innovation outcomes and a larger impact of the innovation outcome on future productivity, lead to higher expected benefits from R&D investment and hence a higher investment rate for exporting compared to pure domestic firms. The resulting endogenous R&D investment contributes to the divergence in performance observed between exporting and domestic firms. These micro-level findings are consistent with the mechanism underlying the endogenous growth models.

Focusing on the exporting firms, we simulate the impact of changes in export and import tariffs and subsidies to R&D costs on both the return to R&D and the probability of investing in R&D. An increase in tariffs shrinks the profitability of the export market and substantially reduces the payoff to R&D. A twenty percent tariff on German export sales, reduces the expected return to R&D by 24.2 to 46.9 percent for the median firm in these five high-tech industries. This leads to a reduction in the probability of investing in R&D by between 5.0 and 16.0 percentage points. This results in lower productivity growth, thus reducing the magnitude of the dynamic gains from exporting. Overall, the simulations show a substantial impact of tariffs on the return to R&D for the German exporters.

In the next section, we extend the PRVF model of R&D choice to recognize variations in the innovation process between exporting and domestic firms. In the third section, we discuss the data, which is drawn from the Mannheim Innovation Panel. 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 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.[6] 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 innovations 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 sales in the export and domestic market. Through its R&D investment the firm may differentially affect the future path of sales in each 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

[6] 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).

by the firm but not observable to the econometrician.[7] 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.[8]

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 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 l equal to a constant markup over

[7] 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.

[8] 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.

marginal cost: $p^l_{it} = [\eta^l/(1+\eta^l)]\exp(c_{it})$ where $l = h, f$. Given this optimal price, the log of the firm's revenue in each market $l = h, f$ is

$$r^l_{it} = (1+\eta^l)\ln\left(\frac{\eta^l}{1+\eta^l}\right) + \ln \Phi^l_t + (1+\eta^l)\left(\beta_t + \beta_k k_{it} + \beta_a a_{it} - \omega^l_{it}\right). \tag{4}$$

The term ω^l_{it} denotes the revenue productivity in market $l = h, f$. It is a combination of cost-side and demand-side shocks, defined as $\omega^l_{it} = \psi_{it} - [1/(1+\eta^l)]\phi^l_{it}$. 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^h_{it} and ω^f_{it} 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 data for high-tech manufacturing firms, virtually all of them 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.[9] Because there is virtually no entry or exit from the export market in the data, we cannot estimate the fixed or sunk costs of exporting or analyze the extensive margin of exporting 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_{it}^D, determined only by conditions in the home market, or an exporting firm whose total short-run profits Π_{it}^X 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 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 including learning effects through spillovers or knowledge transmission from abroad. It may have both the opportunity and the incentive to introduce product innovations in one of its foreign markets but not in its

[9] 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.

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:

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

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, $\partial\omega_{t+1}/\partial\omega_t$, 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 $(\varepsilon_{it+1}^h, \varepsilon_{it+1}^f)$, 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 estimate the coefficients of equations (7) and (8), 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. This allows substantial flexibility in the link between innovation and the evolution of productivities. 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 between maintaining ongoing R&D operations and starting new ones. W_{it} will include industry dummy variables and the firm's capital stock to capture variation in innovation costs with firm size.[10] 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:

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

The timing of the firm's decision problem is assumed to be the following: at the start of

[10]Peters, Roberts, and Vuong (2017) 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.

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.[11] 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:

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

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:

$$\begin{aligned} E_t V^X(s_{it+1}^X|\omega_{it}^h, \omega_{it}^f, rd_{it}) &= \sum_{(d,z)} \int_{\omega^h,\, \omega^f} V^X(s_{it+1}^X) dG^X(\omega_{it+1}^h, \omega_{it+1}^f|\omega_{it}^h, \omega_{it}^f, d_{it+1}, z_{it+1}) \\ & \cdot F(d_{it+1}, z_{it+1}|rd_{it}, I(f_i)=1)). \end{aligned} \tag{11}$$

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 $\beta E_t V^X(s_{it+1}^X|\omega_{it}^h, \omega_{it}^f, rd_{it}=0)$. If it does invest in R&D, the discounted expected future profits are $\beta E_t V^X(s_{it+1}^X|\omega_{it}^h, \omega_{it}^f, rd_{it}=1)$ 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:

$$\Delta EV^X(\omega_{it}^h, \omega_{it}^f) \equiv \beta E_t V^X(s_{it+1}^X|\omega_{it}^h, \omega_{it}^f, rd_{it}=1) - \beta E_t V^X(s_{it+1}^X|\omega_{it}^h, \omega_{it}^f, rd_{it}=0). \tag{12}$$

[11] 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.

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: $\Delta EV^X(\omega_{it}^h, \omega_{it}^f) \geq C_{it}$. 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 an analogous value function given by:

$$V^D(s_{it}^D) = \Pi_t^D(\omega_{it}^h) + \int_C \max_{rd \in \{0,1\}} \left(\beta E_t V^D(s_{it+1}^D | \omega_{it}^h, rd_{it} = 1) - C_{it}; \beta E_t V^D(s_{it+1}^D | \omega_{it}^h, rd_{it} = 0) \right) dC, \tag{13}$$

where the expected future value is defined as:

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

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:

$$\Delta EV^D(\omega_{it}^h) \equiv \beta E_t V^D(s_{it+1}^D | \omega_{it}^h, rd_{it} = 1) - \beta E_t V^D(s_{it+1}^D | \omega_{it}^h, rd_{it} = 0). \tag{15}$$

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 and an exporting firm is the additional gain from innovation in the foreign market.[12] This difference, along with

[12] 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. Given that we do not observe export market entry in our data, we do not need to impose any restrictions on the relationship between productivity evolution in the domestic and export markets.

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 Innovation Survey which is administered in all EU countries.[13] 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 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

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

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.

The measures of both innovation inputs and innovation outputs are collected in the Community Innovation Survey. The firm's innovation input is based on 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.[14]

An important goal of this paper is to quantify how the endogenous investment in R&D contributes to the differences in performance between exporting and nonexporting firms and among exporting firms based on their exposure to the international market. Table 1 summarizes two dimensions of heterogeneity. The first two columns report the median level of firm sales per unit of capital for the domestic and exporting firms in each industry.[15] Across all the industries, the median is 5.20 for the exporting firms and 4.42 for the domestic firms. In four of the five industries, this value is larger for the exporting firms, with the ratio between exporting and domestic firms varying from 1.13 to 1.71. In one industry, electronics, the median

[14] 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).

[15] In all the industries, the mean (median) sales of the exporting firms is substantially higher than the mean (median) sales of the domestic firms. Much of this difference is due to larger capital stocks in the exporting firms. Here we are interested in the role of endogenous productivity in contributing to these differences and sales per unit of capital better reflects the potential role of productivity differences than differences in total sales.

exporting firm has a lower sales-capital ratio than the median domestic firm, but overall the two distributions are very similar for the exporting and domestic firms in this industry. This difference in sales-capital ratios suggests a role for differences in revenue-productivity between exporting and domestic firms to be part of the explanation in many of the industries. The last three columns summarize the distribution of export intensity across 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 (the median export intensity is 32.5 percent) while other firms have the export market as their main source of revenue. This heterogeneity within the group of exporting firms suggests that differences in a firm's revenue productivity between the export and domestic markets, ω^h and ω^f, may be a contributing factor to differences in export market integration.

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

	Domestic Firms	Exporting Firms			
	(Sales/K)	(Sales/K)	Export Sales/Total Sales		
	Median	Median	10th percentile	Median	90th percentile
Chemicals	2.683	4.041	0.051	0.325	0.724
Machinery	4.361	4.920	0.045	0.361	0.769
Electronics	7.105	5.873	0.033	0.278	0.643
Instruments	4.227	6.255	0.057	0.341	0.732
Vehicles	3.194	5.455	0.032	0.291	0.697
Total Sample	4.421	5.200	0.047	0.325	0.721

If productivity differences are a contributing factor to differences in firm performance, then firm's may be able to affect their performance through R&D investment and innovation. 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 $1 + (1/\eta^l)$. 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. Implementing their methodology for the exporting firms requires 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:

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

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.

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

The error term υ_{it}^{l} is a transitory shock to the firm's revenue function that 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.[16] Finally, using the estimated

[16]The revenue function for domestic firms is estimated using non-linear least squares. The domestic and foreign revenue functions for exporting firms are estimated using non-linear seemingly unrelated regressions.

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 that 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.[17]

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:

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

[17] 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

The next subsection reports 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, and the third subsection reports results of the counterfactual analysis.

5.1 R&D, Innovation, and Productivity

Table 3 summarizes the estimated probability a firm introduces successful innovations conditional on its R&D choices and export status, $F(d_{it+1}, z_{it+1}|rd_{it}, I(f_i))$. 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 period $t+1$. 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 (7) 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.[18] 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

[18]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, however, 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			
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)
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)**
$Var(\varepsilon)$	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 coefficients on d, z, and $d*z$ 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 that of 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 that of noninnovators. The coefficients on lagged productivity jointly determine the persistence of the productivity process, $\partial\omega_{it+1}/\partial\omega_{it}$. 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 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 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. The productivity process for these firms is persistent with an average persistence level of $\partial\omega_{it+1}/\partial\omega_{it} = 0.72$, which is slightly lower than that of exporters. 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 coefficient 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).

The two productivity levels are state variables in the firm's dynamic decision to invest in R&D. In turn, as R&D investment alters the future paths of ω^h and ω^f, it will affect the export intensity of the firm, where export intensity is defined as $\exp(r_{it}^f)/(\exp(r_{it}^h) + \exp(r_{it}^f))$. Given the specification of the log revenue function, equation (4), sales in each market are increasing in the own-market productivity and the export intensity will therefore be increasing in ω^f and decreasing in ω^h. However, since R&D will lead to increases in both ω^h and ω^f, but at different rates, the effect of R&D investment on export intensity is ambiguous. Using the productivity estimates, we can summarize which factor tends to dominate in the data. Table 5 reports the mean export intensity for each quartile of the distributions of ω^f and ω^h for the exporting firms.[19] Moving across each row, the mean export share increases with ω^f, and moving down each column the export share decreases with increases in ω^h, as expected. Since R&D generates an increase in both productivities, firms that invest will tend to move from the upper left to lower right cells in the table and this results in an increase in the export intensity. The resulting increase in ω^f will tend to outweigh the increase in ω^h and result in higher export intensity. The differences in export intensity with variation in the two productivities are substantial. For example, for firms in the lowest quartile of ω^h, increases in ω^f can account for an increase in export intensity from 0.219 to 0.862. Similarly, for firms in the highest quartile of ω^f, an

[19] Each exporting firm is assigned to a cell based on the quartiles in which its productivities fall. The quartiles are defined separately for each industry.

increase in ω^h can account for a decrease in export intensity from 0.862 to 0.487.

Table 5: Mean Export Intensity for Exporting Firms

	Quartiles of ω^f			
Quartiles of ω^h	1st	2nd	3rd	4th
1st	0.219	0.457	0.615	0.862
2nd	0.108	0.325	0.476	0.707
3rd	0.052	0.233	0.378	0.591
4th	0.026	0.113	0.260	0.487

Before summarizing the dynamic estimation, we estimate the reduced-form policy function for the discrete R&D choice. This 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 6. The coefficient estimates reflect a combination of the underlying structural components: the innovation process, productivity evolution, profit function, and innovation costs, and cannot be interpreted as structural parameters. For exporting firms, both foreign market productivity ω^f and capital are positively correlated with the firm's decision to invest in R&D while, 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, which is not consistent with the underlying structural model, but the coefficients are not statistically significant. Using the full structural model, we quantify the true causal effect of both productivities on R&D choice.

Table 6: Probit Estimates of Policy Functions for rd_{it}

	Exporting Firms	Domestic Firms
ω^h	-0.126 (0.084)	-0.056 (0.117)
ω^f	0.285 (0.060)**	
k	0.121 (0.023)**	0.179 (0.035)**
age 10-19	-0.111 (0.094)	-0.322 (0.156)*
age 20-49	-0.295 (0.092)**	-0.148 (0.160)
age >50	-0.044 (0.010)	-0.681 (0.230)**
Intercept	0.587 (0.124)**	0.139 (0.228)
Machinery	0.269 (0.089)**	-0.341 (0.183)
Electronics	0.714 (0.116)**	0.118 (0.194)
Instruments	0.895 (0.114)**	-0.232 (0.204)
Vehicles	0.009 (0.114)	-0.662 (0.240)**

All regressions include a full set of year dummies.

** significant at the 0.01 level, * significant at the 0.05 level

This section has shown that R&D investment increases the probability of innovation and innovations increase domestic and export market productivity. The next section reports estimates from the dynamic component of the model: the cost of innovation and the expected benefit of investing in R&D. 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 that cannot be inferred from the reduced-form policy function coefficients in Table 6.

5.2 Cost of Innovation and Expected Benefits of R&D

Table 7 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, with firm export status, and with an interaction term between export status and the log of the firm's capital stock k. This last term recognizes that the size differences between domestic and exporting firms may affect innovation costs. Combinations of these parameters give the mean of the untruncated distribution of innovation costs for firms with different industry, export status, firm size, and R&D history.

Table 7: Innovation Cost Parameters (standard errors)		
	Startup Cost	Maintenance Cost
Chemicals	13.942 (2.147)**	1.987 (0.338)**
Machinery	14.138 (2.209)**	4.057 (0.287)**
Electronics	3.702 (1.650)**	1.550 (0.200)**
Instruments	4.976 (1.190)**	1.401 (0.207)**
Vehicles	10.172 (0.833)**	3.238 (0.205)**
Exporting Firm	8.875 (0.884)**	1.964 (0.196)**
Domestic Firm	5.922 (1.315)**	0.517 (0.161)**
$k*$ Export Firm	3.138 (0.274)**	0.753 (0.023)**
$k*$ Domestic Firm	1.061 (0.384)**	0.338 (0.039)**
** 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 2.4 (electronics) to 7.0 (chemicals) 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 non-R&D firms will be to start investing. 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 with firm size. The interaction terms with the firm capital stock are positive, implying higher average innovation costs (and higher expected benefits of R&D) for larger firms.[20]

As part of the estimation algorithm, we solve for the value functions and construct the

[20] The estimated model predicts the R&D investment patterns observed in the data well. Overall, it predicts 84.8 percent of the observed R&D choices correctly; 86.22 percent for positive R&D investment and 79.73 for no investment.

expected payoff to R&D, $\Delta EV^D(\omega_{it}^h)$ for domestic firms and $\Delta EV^X(\omega_{it}^h, \omega_{it}^f)$ for exporting firms. Table 8 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 differences that arise solely from variation in firms' productivity levels.

Table 8 : $\Delta EV^D(\omega^h)$ 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	0.723	0.851	1.077
Machinery	0.588	0.852	1.027
Electronics	2.047	2.654	3.409
Instruments	0.283	0.414	0.561
Vehicles	0.348	0.443	0.680
Exporting Firms $\Delta EV^X(\omega^h, \omega^f)^a$			
Chemicals	11.350, 17.746	12.139, 18.459	12.855, 19.167
Machinery	15.500, 19.899	16.546, 20.916	18.007, 22.333
Electronics	9.733, 13.340	12.203, 15.674	14.591, 17.935
Instruments	8.903, 11.213	9.673, 11.952	10.580, 12.822
Vehicles	27.026, 42.365	30.299, 45.335	33.421, 48.169

[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 0.723 million euros if it invests in R&D. The expected earning rises with higher domestic sales productivity and equals 1.077 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 2.047 to 3.409 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 8 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 11.350 million euros from investing in R&D. Holding ω^h fixed, this would rise to 17.746 million if ω^f increased to the 75th percentile.

Three patterns are evident in this table. First, for any level of ω^h, 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 6.0 million euros, but an interquartile increase in ω^f results in an increase of approximately 15 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 8 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 $\Delta EV^X(\omega^h, \omega^f)$ and $\Delta EV^D(\omega^h)$ for each data point in the sample. In addition to varying with industry and firm productivity, these measures 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 and export status, industry, and capital stock, we calculate the probability of R&D investment, equations (19) and (20). Table 9 summarizes the distribution of these measures at their 25th, 50th, 75th percentiles across observations for exporting and domestic firms. In the upper panel, Table 9 reports R&D benefits measures ΔEV and $\Delta EV/V$. The lower panel reports the probability of maintaining and starting R&D activities, $Pr\left(rd_{it}=1|rd_{it-1}=1\right)$ and $Pr\left(rd_{it}=1|rd_{it-1}=0\right)$, respectively.

Regarding R&D benefits, three patterns are evident in the data. First, there is a large difference in the expected benefits of R&D between exporting and domestic firms within the same industry. For example, in the chemical industry the median of $\Delta EV^{X}(\omega^{h},\omega^{f})$ for the exporting firms is 23.158 million euros while the median value of $\Delta EV^{D}(\omega^{h})$ for domestic chemical producers is 1.26 million. This pattern occurs for all industries. 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 14.126 million euros, while the firm at the 75th percentile has a value of 35.348 million. This within-industry heterogeneity reflects the productivity effects seen in Table 8, and also the differences in firms' size (capital stock) and age. Columns (5)-(7) of the upper panel 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. The electronics industry has slightly larger percentage gains, reaching 3.1 percent at the 75th percentile. Not only the absolute expected benefits, but also the percentage gains are substantially larger for exporting firms than for domestic firms. Across industries, the 25th percentile varies from 3.5 to 6.4 percent and at the 75th percentile varies from 5.0 to 13.0 percent. The heterogeneity in expected benefit leads to variation in firms' R&D choice, reported in the lower panel of Table 9. First, the higher expected return to R&D investment for exporting firms compared to domestic firms leads to higher probabilities of investing in R&D by the exporting firms. This holds for all industries and R&D investment mode (maintaining or starting R&D). For the median observation in the data, the startup rate of R&D for exporting firms is above 0.55 and above 0.96 for maintaining R&D, respectively. The corresponding rates for starting and maintaining are below 0.10 and 0.45 for domestic firms, with the exception of the electronic industry with higher R&D investment rate, resulting from higher return to R&D as seen in the upper panel of the table.[21] The difference in investment rate for maintaining and starting R&D results from the innovation cost differences as seen in

[21] The electronic industry consistently show higher gain in R&D for domestic and exporting firms. This results from the combination of industry specific demand elasticity and profit estimates.

Table 7. Maintaining R&D is less costly than starting R&D investment. At a given level of R&D benefits, higher innovation cost leads to lower investment rates.

Table 9: Distribution of R&D Benefits and Probability of R&D (Percentiles)

R&D Benefits	ΔEV			$\Delta EV/V$		
	25th	50th	75th	25th	50th	75th
Domestic Firms						
Chemicals	0.712	1.259	3.683	0.012	0.014	0.017
Machinery	0.818	1.757	3.753	0.008	0.009	0.011
Electronics	2.775	4.460	9.194	0.025	0.027	0.031
Instruments	0.486	0.851	1.604	0.009	0.011	0.012
Vehicles	0.936	1.620	2.777	0.012	0.014	0.018
Exporting Firms						
Chemicals	14.126	23.158	35.348	0.044	0.049	0.058
Machinery	14.049	23.477	38.022	0.035	0.042	0.050
Electronics	11.304	19.729	30.005	0.064	0.084	0.130
Instruments	7.673	12.384	21.888	0.047	0.061	0.089
Vehicles	21.769	48.396	74.141	0.048	0.063	0.107
Probability of R&D	$Pr\,(rd_{it}=1\vert rd_{it-1}=1)$			$Pr\,(rd_{it}=1\vert rd_{it-1}=0)$		
	25th	50th	75th	25th	50th	75th
Domestic Firms						
Chemicals	0.293	0.406	0.696	0.039	0.063	0.156
Machinery	0.192	0.343	0.551	0.045	0.089	0.167
Electronics	0.860	0.935	0.986	0.297	0.424	0.606
Instruments	0.353	0.448	0.583	0.057	0.086	0.137
Vehicles	0.233	0.336	0.495	0.057	0.092	0.150
Exporting Firms						
Chemicals	0.951	0.987	0.997	0.418	0.551	0.667
Machinery	0.898	0.966	0.993	0.448	0.582	0.724
Electronics	0.974	0.993	0.999	0.655	0.754	0.840
Instruments	0.937	0.971	0.993	0.492	0.578	0.703
Vehicles	0.982	0.999	1.000	0.662	0.848	0.918

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 chance of innovation success if firms engage in R&D and a larger possible impact of those innovations on firm productivity and profits. 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

An important advantage of the structural model is the ability to simulate how exporting firms would optimally respond to changes in the economic environment, including the imposition of a tariff or a subsidy to R&D. Burstein and Melitz (2013) analyze how export patterns and innovation investments are affected by a reduction in variable trade costs. Akcigit, Ates, and Impullitti (2018) simulate how import tariffs and R&D subsidies affect long-run productivity and welfare. Among other things, Lim, Trefler, and Yu (2018) and Aw, Roberts, and Xu (2013) simulate the effects of foreign market expansion on incentives to innovate. In this section we simulate how three different changes in the economic environment impact the expected benefits and probability of investing in R&D for our high-tech German manufacturing firms. The first change simulates how export and import tariffs, which both reduce the profitability of the export market sales, impact the return to R&D. This provides insights into an important source of the dynamic gains from trade. The second change simulates how a subsidy to R&D impacts investment. The final simulation alters the depreciation rate of past innovations to measure the importance of the long-lived nature of the productivity gains generated by R&D investment. As reported above, we find substantial differences in the expected return to R&D between exporting and domestic firms, and simulated changes in tariffs or R&D subsidies do little to narrow the disparity in R&D investment between the two groups. As a result, we focus our simulations on the exporting firms.

5.3.1 The Impact of Tariffs

An export tariff on German products increases their price in foreign markets and reduces German firm profits from exporting. An import tariff imposed on intermediate inputs imported to Germany raises the marginal cost of German producers and is passed on to both foreign and domestic consumers through higher prices, reducing the profits of exporters in both markets. Both of these restrictions on trade will reduce the expected benefit of investing in R&D and lead some firms to stop this investment. How much they impact the benefit of R&D depends on the firm's mix of export and domestic sales. As seen in Tables 3 and 4, product innovations are more common than process innovations among exporting firms and have a larger impact on export market productivity while process innovations have a larger impact on domestic productivity.

Table 10 reports the impact of imposing tariffs on the proportional change in the marginal benefit of R&D and the change in probability of conducting R&D, $\Delta Pr(rd = 1)$. The first measure is calculated as the percentage change in ΔEV^X moving from the no-tariff to positive tariff environment. These outcomes are calculated for four different tariff rates, 10, 15, 20, and 25 percent. In each case, the table reports the median change in the variable across all firms 5 years after the introduction of the tariffs.

The top panel simulates the effect of a permanent export tariff on German products imposed by the importing countries.[22] It is equivalent to a reduction in export market size. The second and third columns report the impact of a permanent $\tau = 10\%$ export tariff. The reduction in firms' profit in the export market translates into a substantial decrease in the benefit of investing in R&D in all five industries. The expected payoff to R&D decreases between 14.6 and 27.9 percent for the median observation, with four of the industries above 21.0 percent. This leads to a reduction in the probability of R&D between 1.0 and 5.0 percentage points. This pattern is repeated for all industries when firms face higher tariff rates and the reductions in R&D are substantial. If tariffs rose to 20 percent, the reduction in ΔEV^X for the median firm is between 24.2 and 46.9 percent across industries, and the corresponding reduction in the

[22] In our model, the export tariff increases output prices in the destination country by $1+\tau$, which 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 $1-(1+\tau)^{\eta_f}$.

Table 10: Change in Outcomes Due to Tariffs (Median)

	10%		15%		20%		25%	
Industry	$\%\Delta EV^X$	$\Delta Pr(rd=1)$	$\%\Delta EV^X$	$\Delta Pr(rd=1)$	$\%\Delta EV^X$	$\Delta Pr(rd=1)$	$\%\Delta EV^X$	$\Delta Pr(rd=1)$
Export Tariff								
Chemicals	-0.279	-0.050	-0.378	-0.100	-0.469	-0.160	-0.545	-0.230
Machinery	-0.225	-0.040	-0.301	-0.070	-0.367	-0.100	-0.422	-0.140
Electronics	-0.146	-0.010	-0.190	-0.020	-0.242	-0.050	-0.292	-0.090
Instruments	-0.216	-0.030	-0.308	-0.070	-0.381	-0.110	-0.463	-0.170
Vehicles	-0.272	-0.010	-0.340	-0.020	-0.422	-0.050	-0.491	-0.115
Export and Import Tariffs								
Chemicals	-0.399	-0.110	-0.535	-0.220	-0.647	-0.360	-0.729	-0.525
Machinery	-0.356	-0.090	-0.472	-0.175	-0.566	-0.265	-0.637	-0.370
Electronics	-0.221	-0.020	-0.297	-0.060	-0.385	-0.150	-0.485	-0.280
Instruments	-0.367	-0.080	-0.459	-0.170	-0.573	-0.260	-0.655	-0.390
Vehicles	-0.398	-0.020	-0.488	-0.080	-0.611	-0.230	-0.728	-0.395

probability of conducting R&D decreases between 5.0 and 16.0 percentage points.

It is important to note that, even though the tariff impacts export market profits, the impact through the domestic market sales is not zero. The resulting decline in the R&D investment rate, impacts the growth in domestic productivity ω^h and profits as well, further reducing the payoff to R&D.

The second 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. The impact depends on the fraction of inputs that are imported ρ. In our data, we do not observe this fraction at the firm level so, in this simulation, we calculate the effect of this tariff increase using the industry-specific fraction of imported inputs which is $\rho = 0.260$, 0.301, 0.197, 0.244, and 0.249 for the five industries.[23] The impact of export and import tariffs on firms' profits are different. Under the export tariff τ, the firm charges the price $p^f = (1+\tau)[\eta^f/(1+\eta^f)]\exp(c)$ and receives the lower price $p^f = [\eta^f/(1+\eta^f)]\exp(c)$ with a lower quantity sold than without the tariff. Under an import tariff λ, the increase in production cost is passed on to consumers through higher domestic and export prices. Firms charge and receive the price $p^l = [\eta^l/(1+\eta^l)]\exp(c)(1+\lambda\rho)$ for $l = h, f$ in this case. The increase in prices partially offsets the revenue loss from the lower quantity sold which mitigates the profit loss compared to the export tariff case.[24]

When both export and import tariffs are imposed at $\lambda = \tau = 10$ percent, the expected long-run benefit of R&D decreases between 22.1 and 39.9 percent for the median firm across the five industries, and the probability of investing in R&D falls between 2.0 and 11.0 percentage points. This loss is magnified as the tariff rates rise to 25 percent. When both tariffs are set at 25 percent, the probability of investing in R&D is reduced by 28.0 to 52.5 percentage points for the median exporting firm.

While the impacts of the trade restrictions at the median are substantial, the impact at

[23] Statisches Bundesamt (2018), Input-Output Tabelle (Revision 2011) - Inländische Produktion (Herstellungspreise): Deutschland 2008, accessed online 08.10.2018. Calculation of ρ as (inputs from abroad/(inputs from domestic production + inputs from abroad).

[24] Assuming firms import a fraction ρ of their inputs, an import tariff λ 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.

the firm level depends on the firm's initial export share. To measure the differential impact, we divide firms in each industry into quartiles based on their export share. Table 11 reports the impact of a 20 percent export tariff on the median firm in each quartile. The percentage reduction in ΔEV^X does not vary substantially across firms with different export shares. The only industry with a differential effect across firms is vehicles. The firms with the smallest export shares had a larger percentage reduction in ΔEV^X, -56.7 percent, than firms in the remaining three quartiles. In contrast, the last four columns of the table show that there is a systematic impact on the probability of investing in R&D depending on the firm's export share. Firms with the smallest export shares see a reduction in the probability of doing R&D between 8.0 and 24.0 percentage points. The impact decreases monotonically as the firm's export share increases, so that the reduction in the probability of investing in R&D varies from 2.0 to 11.0 percentage points for firms in the quartile with the largest export shares. For the firm's that have a smaller share of their sales in the export market, the export tariff reduces the payoff to R&D sufficiently that it is no longer profitable for them to invest in R&D.

Table 11: Impact of a 20% Export Tariff by Quartile of the Export Share

	$\%\Delta EV^X$				$\Delta \Pr(rd=1)$			
Quartiles	1st	2nd	3rd	4th	1st	2nd	3rd	4th
Industry								
Chemicals	-0.483	-0.459	-0.474	-0.456	-0.240	-0.160	-0.145	-0.110
Machinery	-0.380	-0.367	-0.361	-0.362	-0.175	-0.110	-0.080	-0.040
Electronics	-0.242	-0.242	-0.239	-0.249	-0.080	-0.045	-0.040	-0.030
Instruments	-0.385	-0.376	-0.382	-0.380	-0.145	-0.090	-0.100	-0.080
Vehicles	-0.567	-0.394	-0.405	-0.419	-0.415	-0.050	-0.030	-0.020

Overall, the tariff simulations indicate substantial reductions in the expected payoff to R&D and, as a result, a reduction in the extensive margin of R&D investment. 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. Trade restrictions act to substantially reduce one of the major sources of the dynamic gains from trade by reducing firm incentives to invest in R&D.

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 exporting firms to invest.

The top panel in Table 12 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 face 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 2.0 percentage points. This increase seems 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 initial higher innovation cost regime. The third column shows the median value of the percentage change in firm long-run value from investing in R&D. Across industries, this change varies between 3.1 (vehicles) and 6.5 (electronics) percent.

Columns (4) and (5) in Table 12 simulate the effect of a 20% subsidy to the startup cost of innovation for firms in their first year of R&D investment. While this reduction makes it less costly for firms to begin investing in R&D it also makes it less costly for firms to disrupt their R&D and restart at another time. Reducing startup costs thus encourages both entry and exit into R&D activities. Column (4) shows that there is no net effect on the participation rate from these two opposing forces. The results on the percentage change in ΔEV are reported in column (5) and indicate that the long-run payoff to R&D falls as a result of the reduced innovation cost. The reduction varies between 6.7 and 8.0 percent of the long-run return. This happens because the expected value of not doing R&D $E_tV^X(s^X_{it+1}|\omega^h_{it}, \omega^f_{it}, rd_{it} = 0)$ 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 12: Change in Outcomes Due to R&D Subsidies and Productivity Process (Median Across Firms)

	20% Reduction in Maintenance Cost		20% Reduction in Startup Cost		No Persistence in Productivity	
Industry	$\%\Delta EV^X$	$\Delta Pr(rd=1)$	$\%\Delta EV^X$	$\Delta Pr(rd=1)$	$\%\Delta EV^X$	$\Delta Pr(rd=1)$
Chemicals	0.062	0.02	-0.079	0.00	-0.913	-0.83
Machinery	0.061	0.01	-0.073	0.00	-0.893	-0.79
Electronics	0.065	0.01	-0.067	0.00	-0.891	-0.78
Instruments	0.055	0.01	-0.080	0.00	-0.913	-0.84
Vehicles	0.031	0.00	-0.067	0.00	-0.898	-0.71

5.3.3 Change in Productivity Persistence

The final counterfactual focuses on the importance of persistence in the productivity processes for the firm's long run profit and probability of R&D investment. By removing all persistence in the productivity processes, so that $\partial\omega^f_{t+1}/\partial\omega^f_t = \partial\omega^h_{t+1}/\partial\omega^h_t = 0$, we restrict the impact of innovation on productivity to last for only one period and turns the R&D decision into a static choice. This allows us to measure how much of the incentive to invest in R&D comes from the long lasting impact of R&D on future productivity. The final two columns in Table 12 report the results of this restriction. Immediate depreciation of the productivity gains results in a substantial reduction in the average long-run return to R&D, amounting to between 89.1 and 91.3 percent of the long-run return for the median firm in each industry. This reduction in the benefits of innovation leads to a reduction in the R&D participation rate of between 71 and 84 percentage points. It is not just the fact that R&D improves productivity, but also that the improvement depreciates slowly, that generates the incentives to invest in R&D.

6 Conclusion

A large empirical literature in international trade has documented substantial and persistent differences in firm performance between firms that export 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 and is an important source of dynamic gains from trade.

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 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 firm's 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 0.85 million euros in the instruments industry and 4.46 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 from 0.9 to 2.7 percent across industries. The corresponding expected payoff for a median exporting firm is much higher, and varies between 12.38 million euros in instruments and 48.40 in vehicles. As a percentage of firm value, these expected gains vary from 4.2 to 8.4 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 20 percent, which effectively reduces the size and profitability of the foreign market, lowers the long-run return to R&D investment for the median firm by more than 24.2 to 46.9 percent across the five industries and reduces R&D participation by between 5.0 and 16.0 percentage points across industries. This causes a decline in productivity and slows growth. 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 between 3.1 and 6.5 across industries and induces higher R&D participation rates by between 1.0 and 2.0 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 in R&D activities. This is reflected, on average, in a 6.7 to 8.0 percent reduction in the expected return to R&D across industries. The effects of entry and exit offset each other resulting in an R&D participation rate that is unchanged in this case. Finally, we find that over 90 percent of the return to R&D is due to the slow depreciation of the impact of innovations on future productivity in both the domestic and export market. It is critical to recognize this dynamic aspect of the R&D process when assessing the impact of trade restrictions on the incentives to invest in innovation.

Overall, these 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. Tariff restrictions significantly reduce the payoff to R&D investment among exporting firms. In summary, our findings are consistent with the ideas underlying models of endogenous growth and trade that 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.

References

[1] Aghion, Philippe, Antonin Bergeaud, Matthieu Lequien, and Marc J. Melitz (2018), "The Impact of Exports on Innovation: Theory and Evidence," NBER Working Paper 24600.

[2] Akcigit, Ufuk, Sina T. Ates, and Giammario Impullitti (2018), "Innovation and Trade Policy in a Globalized World)," NBER Working Paper 24542.

[3] Altomonte, Carlo, Tommas Aquilante, Gabor Bekes, and Gianmarco Ottaviano (2013), "Internationalization and Innovation of Firms: Evidence and Policy," *Economic Policy*, Vol. 28, No. 76, pp. 663-700.

[4] Atkeson, Andrew and Ariel Burstein (2010), "Innovation, Firm Dynamics, and International Trade," *Journal of Political Economy*, Vol. 118, No. 3, pp. 433-484.

[5] Autor, David, David Dorn, Gordon H. Hanson, Gary Pisano, and Pian Shu (2017), "Foreign Competition and Domestic Innovation: Evidence From U.S. Patents." NBER Working Paper 22879.

[6] Aw, Bee Yan, Mark J. Roberts, and Tor Winston (2007), "Export Market Participation, Investments in R&D and Worker Training, and the Evolution of Firm Productivity," *The World Economy*, Vol. 14, No. 1, pp. 83-104.

[7] Aw, Bee Yan, Mark J. Roberts, and Daniel Yi Xu (2008), "R&D Investments, Exporting, and the Evolution of Firm Productivity," *American Economic Review, Papers and Proceedings*, Vol. 98, No.2 (May), pp. 451-456.

[8] Aw, Bee Yan, Mark J. Roberts, and Daniel Yi Xu (2011), "R&D Investment, Exporting and Productivity Dynamics," *The American Economic Review*, Vol. 101, No. 4 (June), pp. 1312-1344.

[9] Baldwin, John R. and Wulong Gu (2004), "Export Market Participation and Productivity Performance in Canadian Manufacturing," *Canadian Journal of Economics*, Vol. 36, pp. 634-657.

[10] Becker, Sascha O. and Peter H. Egger (2013), "Endogenous Product vs Process Innovation and a Firm's Propensity to Export," *Empirical Economics*, Vol. 44, No. 1, pp. 329-354.

[11] Bernard, Andrew B. and J. Bradford Jensen (1997), "Exporters, Skill Upgrading, and the Wage Gap," *Journal of International Economics*, Vol. 42, pp. 3-31.

[12] Bloom, Nicholas, Mirko Draca, and John Van Reenen (2016), "Trade Induced Technical Change? The Impact of Chinese Imports on Innovation, IT, and Productivity," The Review of Economic Studies, Vol. 83, No. 1, pp 1347-1393.

[13] Burstein, Ariel and Marc Melitz (2013), "Trade Liberalization and Firm Dynamics," in *Advances in Economics and Econometrics Tenth World Congress. Applied Economics, Econometric Society Monographs. Vol 2.* Cambridge U.K.: Cambridge University Press.

[14] Bustos, Paula (2010), "Multilateral Trade Liberalization, Exports and Technology Upgrading: Evidence on the Impact of MERCOSUR on Argentinean Firms," *American Economic Review*. Vol 101, No. 1, pp. 304-340.

[15] Cassiman, Bruno and Elena Golvko (2011), "Innovations and Internationalization Through Exports," *Journal of International Business Studies*, Vol 42, No. 1, pp. 56-75.

[16] Coelli, Federica, Andreas Moxnes, and Karen Helene Ulltveit-Moe (2016), "Better, Faster, Stronger: Global Innovation and Trade Liberalization," NBER Working Paper 22647.

[17] Cohen, Wesley M. (2010), "Fifty Years of Empirical Studies of Innovative Activity and Performance," in *Handbook of the Economics of Innovation, Vol 1*, B. Hall and N. Rosenberg (eds), North-Holland, pp. 129-213.

[18] Constantini, James A., and Marc J. Melitz (2008), "The Dynamics of Firm-Level Adjustment to Trade Liberalization," in *The Organization of Firms in a Global Economy*, E. Helpman, D. Marin, and T. Verdier (eds.), Cambridge: Harvard University Press.

[19] Crépon, Bruno, Emmanuel Duguet, and Jacques Mairesse (1998), "Research Innovation and Productivity: An Econometric Analysis at the Firm Level," *Economics of Innovation and New Technology*, Vol. 7, No. 2, pp. 115-158.

[20] Damijan, Jože, Črt Kostevc, and Matija Rojec (2017), "Exporting Status and Success in Innovation: Evidence from CIS Micro Data for EU Countries," *The Journal Of International Trade & Economic Development*, Vol. 26, No. 5, pp. 585-611.

[21] Das, Sanghamitra, Mark J. Roberts, and James R. Tybout (2007), "Market Entry Costs, Producer Heterogeneity, and Export Dynamics," *Econometrica*, Vol. 75, No. 3, pp. 837-873.

[22] Doraszelski, Ulrich and Jordi Jaumandreu (2013), "R&D and Productivity: Estimating Endogenous Productivity," *Review of Economic Studies*, Vol. 80, No. 4, pp. 1338-1383.

[23] Griliches, Zvi (1979), "Issues in Assessing the Contribution of Research and Development to Productivity Growth," *Bell Journal of Economics*, Vol. 10, No. 1 (Spring), pp. 92-116.

[24] Grossman, Gene M. and Elhanan Helpman (1990), "Trade Innovation, and Growth," *American Economic Review, Papers and Proceedings,* Vol. 80, No. 2, pp. 86-91.

[25] Grossman, Gene M. and Elhanan Helpman (1995), "Technology and Trade," in *Handbook of International Economics,Vol. III*, G Grossman and K. Rogoff (eds.), Elsevier Science B.V., pp. 1279-1337.

[26] Hall, Bronwyn H. (2011), "Innovation and Productivity," NBER Working Paper No. 17178.

[27] Hall, Bronwyn H., Jacques Mairesse, and Pierre Mohnen (2010), "Measuring the Returns to R&D," in *Handbook of the Economics of Innovation, Vol 1*, B. Hall and N. Rosenberg (eds), North-Holland, pp. 1033-1082.

[28] Hallward-Driemeier, Mary, Giuseppe Iarossi, and Kenneth L. Sokoloff (2002), "Exports and Manufacturing Productivity in East Asia: A Comparative Analysis with Firm-Level Data," NBER Working Paper No. 8894.

[29] Lileeva, Alla and Daniel Trefler (2010), "Improved Access to Foreign Markets Raises Plant-Level Productivity...For Some Plants," *Quarterly Journal of Economics*, Vol. 125, No. 3, 1051-1099.

[30] Lim, Kevin, Daniel Trefler, and Miaojie Yu, (2018), "Trade and Innovation: The Role of Scale and Competition Effects," Working Paper, Rottman School of Management, University of Toronto.

[31] Máñez, Juan A., Maria Rochina-Barrachina, and Juan A. Sanchis-Llopis (2015), "The Dynamic Linkages Among Exports, R&D, and Productivity," *The World Economy*, Vol. 38, No. 4, pp. 583-612.

[32] Melitz, Marc J. (2003), "The Impact of Trade on Aggregate Industry Productivity and Intra-Industry Reallocations," *Econometrica*, Vol. 71, No. 6, pp. 1695-1725.

[33] Olley, G. Steven and Ariel Pakes (1996), "The Dynamics of Productivity in the Telecommunications Equipment Industry," *Econometrica,* Vol. 64, No. 6 (November), pp. 1263-1297.

[34] Peters, Bettina, Mark J. Roberts, Van Anh Vuong and Helmut Fryges (2017), "Estimating Dynamic R&D Demand. An Analysis of Costs and Long-run Benefits," *Rand Journal of Economics*, Vol. 48, No. 2, pp. 409-437.

[35] Peters, Bettina, Mark J. Roberts, and Van Anh Vuong (2017), "Dynamic R&D Choice and the Firm's Financial Strength," *Economics of Innovation and New Technology*, Vol. 26, No. 1-2, pp. 134-149.

[36] Rammer, Christian and Bettina Peters (2013), "Innovation Panel Surveys in Germany," in *Handbook of Innovation Indicators and Measurement,* Fred Gault (ed.), Edward Elgar: Cheltenham, UK and Northampton, MA, USA, pp. 135-177.

[37] Roberts, Mark J. and James R. Tybout (1997), "The Decision to Export in Colombia: An Empirical Model of Entry with Sunk Costs," *American Economic Review,* Vol. 87, No. 4 (September), pp. 545-564.

[38] Santos, Carlos Daniel (2017), "Sunk Costs of R&D, Trade, and Productivity: The Moulds Industry Case," *Economic Journal,* Vol. 127, No. 63, pp. 1626-1664.

[39] Rust, John (1987), "Optimal Replacement of GMC Bus Engines: An Empirical Model of Harold Zurcher," *Econometrica*, Vol. 55, No. 5 (September), pp. 999-1033.

[40] Shu, Pian and Claudia Steinwender (2018), "The Impact of Trade Liberalization on Firm Productivity and Innovation," NBER Working Paper 24715.

[41] Syverson, Chad (2011), "What Determines Productivity," *Journal of Economic Literature*, Vol. 49, No. 2, pp. 326-365.

[42] Van Beveren, Ilke and Hylke Vandenbussche (2010), "Product and Process Innovation and Firms' Decision to Export," *Journal of Economic Policy Reform*, Vol. 13, pp. 3-24.

[43] Van Long, Ngo, Horst Raff, and Frank Stähler (2011), "Innovation and Trade with Heterogenous Firms," *Journal of International Economics*, Vol. 84, pp. 149-159.

[44] Xu, Rui, and Kaiji Gong (2017), "Does Import Competition Induce R&D Reallocations? Evidence from the U.S.," International Monetary Fund Working Papers 17/253.