Competition, Innovation, and the Sources of Product Quality and Productivity Growth*

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Abstract

This paper assesses the simultaneous impact of competition on innovative investments and achieved firm performance. I outline a structural framework to infer product quality and productivity from firm-level performance data and measure their response to changes in the competitive environment. I quantify the various channels through which competition may affect firm performance, including changing investments in R&D. Using a panel of Spanish manufacturing firms, I find that competitive pressure spurs R&D investments and performance improvements. The majority of performance gains come directly through knowledge and technology diffusion or changing managerial and worker incentives, rather than indirectly through R&D-generated innovations.

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1 Introduction

Does competitive pressure spur innovation and improve achieved economic performance? Recent work has shown that changes in the competitive environment can induce aggregate performance gains through within-firm improvements or via the reallocation of resources to those firms that can use them most effectively. In a recent survey of the evidence on competition and productivity, Holmes and Schmitz (2010) point out that the former within-firm effect is an important driver of aggregate growth in reponse to greater competitive intensity, and indeed, often times dominates the latter reallocation effect in quantitative significance. However, it is precisely the sources of within-firm growth, and hence, the impact of competitive intensity on this margin, that are still not well understood.[1]

There are several potential channels through which competitive pressure can induce performance gains within an individual firm. Changing incentives for innovative engagement may lead to increased investments in R&D in the hopes of improving future outcomes. Greater exposure to more efficient firms or higher quality products may lead to spillover effects, where the knowledge accumulated by these firms or the more efficient technologies they employ, diffuse to firms further behind the frontier. Finally, competitive intensity may improve managerial incentives and lead to more efficient work practices, garnering performance gains through the more effective use of existing assets within the firm. The quantitative magnitude of these effects is not just of intellectual curiousity, but, as shown for example by Atkeson and Burstein (2011), may have important implications for the impact of competition and innovation policies on aggregate outcomes and welfare. Thus, whether competition induces performance improvements, and if so, the relative importance of each of these channels, remain important unresolved questions.[2]

There is, of course, a vast body of work examining the impact of competitive forces on both innovative investments and achieved firm performance. In particular, two largely distinct strands of research have emerged. The first is a longstanding effort to understand the effect of competitive pressure on firm-level engagement in innovation activities. In addition to important methodological problems, a conceptual shortcoming in this line of work has been its limitation to analyzing only reported measures of innovative engagement, such as R&D expenditures or patents, and a resulting inability to address the impact of changing competitive intensity on actual performance. Second, there is a growing literature directly examining the impact of competition on achieved performance. However, this literature has been largely silent on the channels through which competitive pressure may induce performance improvements. Additionally, by focusing only on productivity growth or process innovation, this line of work has abstracted from the potential effect of competitive pressure on product quality improvements or product innovation, although this may be an important margin on which firms repond when facing intensified competition.

[1] For a recent survey on the sources of productivity growth, see Syverson (2010), who lists "which productivity drivers matter most?" as one of the outstanding "big questions" in the literature.

[2] Indeed, distinguishing the import of these channels in stimulating improved performance has long been on the research agenda, although little progress has been made. See, for example, Kortum (2004).

In this paper, I take a structural approach to empirically assess the impact of competition on innovative investments and achieved firm performance. In a departure from the existing literature, I outline a dynamic structural model of strategic competition and innovation. The economic framework explicitly incorporates the potential simultaneous effects of competitive pressure on innovative investments and achieved performance, where the latter is captured both by process efficiency and product quality. In the model, firms are characterized by two performance measures, their technological efficiency, or productivity level, and the quality of their product offering. Each firm faces a competitive state, composed of the productivity and product quality of its competitors. Firm-level productivity and product quality evolve over time as stochastic processes that can be influenced both by investments in innovation through expenditures on research and development (R&D) and by the state of competition. That the competitive state may directly influence the path of a given firm's performance captures the potential of increased competition to spur the diffusion of new knowledge and technologies, or improve managerial incentives and implemented work practices. This is what I deem the "direct effect" by which competitive pressure can induce changes in achieved performance. Additionally, the competitive state can influence firm performance through changing incentives for investments in R&D, in what I analogously call the "indirect effect."

Importantly, the competitive state is subject to an exogenous and serially correlated shock that changes the degree of competitiveness in the firm's operating market and so its future prospects. To match the empirical work, these "competitive shocks" are given the explicit interpretation of tariff reductions in the firm's output market, although they can be seen more generally as any exogenous process shifting the state of competition. By decomposing the impact of a competitive shock induced by a tariff reduction into its effect on the direct and indirect channels, the model allows for quantitative assessment of their relative importance in spurring performance gains in response to competitive pressure.

The theoretical framework lends two major advantages to my analysis. First, I use the model structure to distinguish and compute firm-level productivity and product quality based on actual firm performance. In this way, I measure the gains from innovative activity and its response to competitive pressure by the realized productive efficiency and quality offering of the firm. In contrast, previous studies of competition and innovation rely solely on reported measures of innovative output, such as patent counts, to gauge firm-level success in innovative activities and so the gains from increased competition. These measures may be poor proxies of a firm's true output of productive new knowledge. As an example, the choice of whether to patent or not might be directly related to the competitiveness of the market in which the firm operates, causing patenting activity to respond to changes in the competitive environment for reasons unrelated to greater production of new knowledge. Moreover, existing work has largely focused on the response of process efficiency to changes in competitive intensity and abstracted from product quality improvements. Indeed, to the best of my knowledge, this paper is the first to simultaneously assess the impact of competitive pressure on both process and product innovation. Second, the structural model allows me to distinguish the impact of competitive pressure along the direct and indirect margins and quantify their relative importance in influencing the path of productivity and product quality. In the absence of a structural framework, the existing literature has been largely silent as to the existence or importance of the various potential channels for performance improvements, despite their importance in determining the impact of competition and innovation policies on aggregate outcomes and welfare.

Estimation of the model's parameters is complicated by the fact that productivity and product quality levels are not directly observable and, as functions of the firm's R&D investments and the competitive state, are endogenous objects. I outline a multistage estimation algorithm to overcome these hurdles. In the first stage, I estimate a flexible demand system, derived from a standard differentiated product Logit model, enabling me to infer product quality and demand elasticities. In the second stage, I extend the methodology of the recent literature on structural estimation of the production function to my setting in order to infer the production technology parameters and recover firm-level productivity. Finally, with values of firm-level productivity and product quality in hand, I estimate the firm's R&D policy function in a final stage. Despite the complexity of the estimation, there is a certain simple symmetry by which I use information from the demand side of the market to infer product quality, its evolution and determinants, and information from the production side to infer the same about productivity. After estimating the R&D choice function, I can quantify the effect of competitive pressure on firm-level productivity and product quality and compare the relative importance of the indirect channel working through changing investments in R&D and the direct channel working through knowledge and technological diffusion or through improved managerial incentives and work practices.

I use data from a detailed panel of Spanish manufacturing firms during the 1990s and 2000s. In addition to containing standard performance variables, such as sales, capital, labor, intermediate inputs, etc., the data are particularly rich in two areas that are key to my analysis. First, the data contain measures of firm-level innovative activities. These include expenditures and employment devoted to R&D, capturing innovative investments, as well as indicators of the introduction of process and product innovations, capturing, at least to some degree, innovative outcomes. I use the variety of reported measures of innovative engagement both to estimate the structural model and to provide some motivating reduced-form evidence of the effects of competitive pressure.

Second, the data contain firm-level price deflators for both output and inputs, which is the key factor that enables me to empirically distinguish between product and process innovation. With these deflators, I am able to use the demand side of the model to infer product quality. I can also estimate the physical production function implied by the model and construct measures of pure physical productivity untainted by the presence of unobserved price variation. As is well known, absent an assumption of perfect competition, a lack of firm-level price deflators causes standard empirical methods to confound changes in physical productivity with changes in unobserved firm-specific prices. This is particularly problematic in my setting since changes in the competitive state have a significant impact on demand side factors, both directly through pressure on prices, and indirectly through price changes resulting from product innovation. Without firm-level deflators, measured productivity changes would actually reflect the net outcome of these disparate effects.

Spain's membership in the EU yields exogenous variation in the intensity of competition through changes in import tariffs. Throughout the sample period, the EU was lowering tariffs facing non-EU nations. As an EU member, Spain operates under a unique institutional structure in which it does not negotiate its own tariffs, but rather it adheres to the EU common external tariff schedule. These tariffs are negotiated and approved on behalf of all EU nations by various committees operating at the EU level and it is unlikely that they are significantly influenced by any particular firm in the Spanish manufacturing sector. Absent this particular institutional setting, endogeneity of common measures of the state of competition, including tariffs due to political economy concerns, would prevent clear interpretation of empirical results.

I find that increases in competitive pressure spur greater investments in R&D and improvements in both product quality and productive efficiency. My baseline results show that a 1 percentage point reduction in the import tariff rate generates a 3.1% increase in R&D investment for the average R&D-performing firm, and raises the hazard rate of engaging in R&D by 0.4% for the average non-performer. The direct effect implies that this 1 percentage point reduction in the tariff spurs productivity growth of 0.6% for the average R&D performer and 0.25% for the average non-performer, and product quality improvements of 0.25% and 0.3%, respectively. Because the elasticities of product quality and productivity with respect to R&D are both about 0.006, these values imply a much larger role for the direct effect of knowledge or technological spillovers or changing managerial incentives and worker practices, than for the indirect effect of R&D-generated innovation in stimulating performance improvements in reponse to greater competitive intensity. I show that these findings are robust to controlling for other potential effects of a trade liberalization and that the importance of the direct channel is likely not limited to my particular setting.

This paper relates to several strands of existing literature investigating the relationships between competition, innovation, and performance, and it would be impossible to do justice to all contributions.[3] The effect of competition on productivity has been a particular focus in the trade literature and my use of tariffs as a competitive shifter explicitly links my paper to this body of work. Beginning with Pavcnik (2002) for Chilean firms and in a more recent example, Bernard, Jensen and Schott (2006) for US firms, the trade literature has uncovered some evidence of within-firm productivity growth in response to increased exposure to foreign competition. This literature has tended to focus on increases in aggregate productivity due to the reallocation effects of competition and has not shed much light on the mechanism for within-firm gains. Moreover, there has been a general abstraction from product innovation, which I find to be an important margin in the response to competitive pressure. A particularly relevant recent contribution to this line of work is De Loecker (2010). De Loecker similarly recognizes the confounding influence of price variation when measuring productivity in the presence of imperfect competition and uses a related structural framework to distinguish the demand and production sides of the market in order to assess the productivity response of Belgian textile firms to reductions in trade barriers. In the absence of

[3] For example, the body of work on competition and innovation is widely regarded as the second largest in empirical IO, exceeded only by that examining the relationship between competition and profitability (see, e.g., Cohen and Levine [1989] and Gilbert [2006]).

firm-level price deflators, he imposes a somewhat rigid demand system to control for unobserved prices.[4] In contrast, because I observe firm-level price deflators, I am able to go one step further and use a relatively more flexible demand system to actually infer product quality and include product innovation in my analysis. Additionally, without access to R&D data, De Loecker follows the preceding literature and does not address the channels through which increased competition may affect within-firm productivity.

There are a number of recent industry case-studies documenting the beneficial impact of competitive pressure on productivity. These are summarized in Holmes and Schmitz (2010) and include, for example, Holmes and Schmitz (2001) for the US shipping industry and Schmitz (2005) for the Great Lakes Iron Ore industry. These studies have shown first, that within-firm productivity growth tends to be the predominant driver of aggregate industry gains in response to increases in competition, and second, have provided some evidence on the implementation of new management and worker practices that led to these performance improvements. For example, upon the advent of railroads, longshoremen in the US shipping industry altered the rules governing the unloading of ships in such a way as to reduce time spent in port and increase labor productivity, particularly on cross-country routes that were threatened by railroad competition. Upon the introduction of competition from Brazil, the US iron ore industry changed its work practices to reduce the idle time of machines and the number of non-production repair staff, again spurring productivity gains. While informative, these studies are limited by their application to a single industry and the more anecdotal nature of their analysis. In contrast, I assess the impact of competition across a range of industries within the manufacturing sector and quantify its effects across several potential margins.

There is a recent body of work, surveyed in Syverson (2010), addressing more generally the sources of productivity growth. Recent additions include Doraszelski and Jaumandreu (2009) and Xu (2008) who investigate the impact of R&D investments on achieved productivity levels, and Bloom, Schankerman and Van Reenen (2010), who document the importance of technological spillovers from R&D investments on productivity growth. In finding an important role for the direct channel of performance improvements in reponse to competitive pressure, my results are broadly consistent with the evidence of Holmes and Schmitz (2010) and Bloom, Schankerman and Van Reenen (2010), who find that changing management and worker practices and spillovers of knowledge and technology, respectively, are sources of significant gains.

While the literature previously mentioned has investigated the impact of competitive pressure on achieved performance, there is a vast body of work focusing on the specific reponse of firm-level innovative activities to changes in the state of competition. These studies, which are comprehensively surveyed and critiqued by Cohen and Levine (1989) and Gilbert (2006), have typically been limited by a lack of adequate data in measuring both "competition" and "innovation" as well as

[4] In particular, he uses the assumption of monopolistic competition in conjunction with a CES demand system to impute firm-level prices and control for their influence in the estimation. This framework has the features that firms set a constant markup over marginal cost and products are differentiated only on the horizonal dimension. These characteristics are somewhat unattractive in my setting, where I am interested particularly in the impact of changes in competitive intensity on both process and product innovation.

by methodological problems that have proven difficult to overcome.[5] More recent additions include Aghion, Bloom, Blundell, Griffith and Howitt (2005), who present evidence of an inverted-U shaped relationship between competition and innovation in a panel of UK industries. They measure innovation by citation-weighted patent counts and competition by the Lerner index, instrumented by policy reforms. Teshima (2008) finds that tariff reductions induce increases in R&D expenditures in process innovation but not in product innovation for a panel of Mexican firms. Bloom, Draca, and Van Reenen (2009) show that increased competition from China spurred R&D investments and technology upgrading in a panel of European firms. In contrast to these studies, this paper uses a structural model to infer the effect of competitive pressure on actual performance, rather than relying only on reported measures of innovation activities, and explicitly models the choice of innovative investment as the solution to a dynamic problem, driven by firm-specific characteristics and the state of competition.

The paper is organized as follows. In the next section, I describe the firm-level microdata and the trade data. I document the competitive effects of tariff reductions on the domestic market and motivate the structural approach with preliminary evidence from simple reduced-form equations. In Section 3, I introduce the structural model. Section 4 outlines the econometric strategy. I present my results in section 5, and Section 6 concludes.

2 Data and evidence

I use firm-level data from the Encuesta Sobre Estrategias Empresariales (Survey on Business Strategies; ESEE), an annual survey of the Spanish manufacturing sector sponsored by the Spanish Ministry of Industry. The survey is an unbalanced panel of firms with 10 or more employees, covering the period 1990-2007. After eliminating observations with missing data, there are a total of 4,260 unique firms, with an annual average of about 1,800. Firms are classified into twenty three-digit industries corresponding to the NACE-93 classification. Initially, all firms with over 200 employees were asked to participate in the survey, and the response rate reached about 70 percent. Firms with between 10 and 200 employees were randomly sampled in a proportional manner by industry and size stratification, with about 5 percent of firms included in the survey. In subsequent years, the representativeness of the survey has been maintained by adding new firms with the same sampling criteria as in the initial year.

The dataset is unusually rich in information about firm-level innovative and production ac-

[5] Cohen and Levin (1989) summarize their findings concisely by stating

> Our review finds the empirical literature on Schumpeter's hypotheses pervaded by methodological difficulties. Equations have been loosely specified; the data have often been inadequate to analyze the questions at hand; and, until recently, the econometric techniques employed were rather primitive. To the extent that preoccupation with the effects of firm size and concentration on innovation encourages omission of important and potentially correlated explanatory variables, estimates of these very effects have tended to be biased. Despite some recent advances in model specification, data collection, and statistical techniques, the results of this literature must be interpreted with caution.

17 years later, Gilbert (2006) reaches a similar conclusion.

tivities. The primary measure of innovative investments reported in the ESEE is total firm-level expenditures on R&D. Additionally, the ESEE reports total employment devoted to R&D activities, with the caveat that this variable is only available every four years beginning in 1990 and ending in 2006.

The ESEE reports several direct measures of innovative outcomes, including indicators of whether the firm introduced a process or a product innovation. Process innovations are defined as "important modifications in the production process," including the introduction of new machinery or the use of new methods for organizing work. Product innovations are defined as "completely new products, or with such modifications that they are different from those produced earlier," entailing novelties such as incorporating new materials, new parts, new design or presentation, or the ability to perform new functions.

I construct the stock of net physical capital using the perpetual inventory method with industry-specific rates of depreciation and deflate the series using the investment price index.[6] Labor input is measured as average employment during the year. Intermediate inputs are defined as purchases of intermediate consumption including raw materials, services, and energy, and are deflated by a firm-specific materials price index.[7] Output is defined as sales less variation in inventories and is deflated using a firm-specific output price index.[8]

Due to its richness, the ESEE has been used in several recent papers. For example, Doraszelski and Jaumandreu (2009) use the R&D data to assess the impact of R&D investments on productivity. Ornaghi (2006) exploits the availability of firm-level price deflators to investigate the mismeasurement introduced in production function estimation by the failure to control for unobserved price variation in imperfectly competitive industries.

Tariff data come from the UNCTAD TRAINS database, a standard source in the trade literature.[9] I use EU-wide most favored nation ("MFN") tariffs aggregated to the two-digit level under the ISIC-Rev. 3 classification and weighted by the value of total EU imports. Each firm in the ESEE is placed into one of twenty industries, based upon the aggregation of NACE-93 three-digit industries. At the two-digit level, the ESEE industries are equivalent to those of the ISIC-Rev. 3 classification system. This correspondence allows me to place each firm in the ESEE into a two-digit ISIC-Rev. 3 industry and so associate it with an import tariff rate from the TRAINS database. Due to some differences in definitions between the ESEE and ISIC-Rev. 3 classifications, I aggregate several of the ESEE industries in order to properly merge the two sets of data. After the matching process is complete, I am left with 17 industries over the years 1990-2007.

I use import penetration rates to investigate the impact of tariff reductions on domestic market conditions. I collect data on imports, exports, and domestic production in each manufacturing industry from the OECD STAN STructural ANalysis database.[10] I define domestic demand for the

[6] I obtain the investment price index from the Instituto Nacional de Estadística and industry-specific deflators from Martin Marcos and Suarez (1997).

[7] This is a Paasche-type index aggregating changes in the prices of raw materials, services, and energy.

[8] Again, this is a Paasche-type index that aggregates the firm's change in price in its five largest geographic markets.

[9] The data are available at http://r0.unctad.org/trains_new/index.shtm.

[10] The data are available at http://www.oecd.org/document/62/0,3343,en_2649_34445_40696318_1_1_1_1,00.html.

output of each industry as

$$D_{jt} = Y_{jt} + IM_{jt} - EX_{jt} \tag{1}$$

where D_{jt} denotes domestic demand for industry j in time t. Y_{jt} denotes domestic production, IM_{jt} imports, and EX_{jt} exports, all denominated in current values. Import penetration rates are then constructed as

$$IMP_{jt} = \frac{IM_{jt}}{D_{jt}} \tag{2}$$

The industries reported in the STAN database are defined at the two-digit level under the ISIC-Rev. 3 system, making it straightforward to match them with the merged ESEE and tariff data.

2.1 Descriptive statistics

Table 1 contains some descriptive statistics of the ESEE firm-level data. It shows the basic characteristics of the set of firms under study from both the sample in its entirety, and conditional on reporting positive R&D expenditures. Only about one third of the firm-year observations report any formal R&D activity. There is a marked distinction in the characteristics of firms that perform R&D and those that do not. Firms that engage in R&D are much larger than the overall average in terms of sales, employment, and installed capital stock. Not surprisingly, they report higher rates of successful process and product innovations. R&D intensity, calculated as R&D expenditures divided by sales, is low at 0.7% for the firms as a whole and 2% after conditioning on firms reporting positive R&D.[11]

Table 1: ESEE Summary Statistics

	Unconditional Mean	Conditional Mean
Sales (Thousands of Euros)	43,442.75	96,718.47
Total Employment	219.76	455.50
Capital Stock (Replacement Value)	12,706.28	27,506.25
R&D Expenditures (Thousands of Euros)	632.61	1,836.88
R&D Intensity (Percent)	0.72	2.08
R&D Employment	6.02	17.45
Prob. of Engaging in R&D	0.34	1.00
Prob. of Process Innnovation	0.32	0.53
Prob. of Product Innovation	0.24	0.48
N	29,135	10,034

Table reports summary statistics from ESEE firm-level data. Only observations including all the measures reported are included, with the exception of R&D employment, which is only available every four years.

[11] For example, Doraszelski and Jaumandreu (2009) cite a recent EU report showing R&D intensities for manufacturing firms of 2.1% in France, 2.6% in Germany, and 2.2% in the UK. The same report shows that the R&D intensity of Spanish manufacturing firms is 0.69%, very close to the average of 0.7% in the ESEE data, and well below Spain's European neighbors.

The 1990s and 2000s was a period of incremental reductions in tariffs facing foreign firms seeking to export to the EU. To get a sense of how competitive pressure from abroad was evolving during this timeframe, Table 2 reports summary statistics describing the import tariff rates for the initial period in my sample 1990, the end period 2007, as well as an intermediate period, 2000. Tariffs are generally declining over the sample period, with the mean falling by over 4 percentage points, or about 50%, although the annual changes are non-monotonic. Although there is variation in the tariff movements across industries, the change in tariffs over the sample period is generally substantial.

Table 2: Evolution of Import Competition

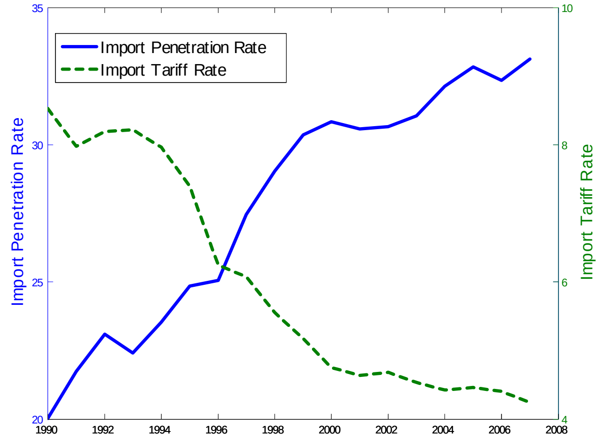
	Import Tariff Rate			Import Penetration Rate		
	1990	2000	2007	1990	2000	2007
Mean	8.53	4.76	4.24	20.02	30.84	33.13
Std. Dev.	4.90	3.36	3.37	14.31	18.60	20.65
Min	2.49	0.59	0.00	4.82	5.84	4.86
Max	18.59	10.77	10.43	63.07	70.44	80.31

2.2 The effect of tariff reductions on domestic conditions

To illustrate the impact of tariff changes on actual competitive conditions in the domestic economy, Table 2 also reports the analogous set of statistics for the import penetration rate. The reductions in import tariffs are accompanied by large increases in import penetration rates. The mean import penetration rate rises about 50% over the sample period, matching the percentage decline in the mean tariff rate. Importantly, not only the changes over the period, but also the levels of import penetration are generally substantial, reinforcing that competition from abroad should be expected to be an important determinant of domestic market conditions. By 2007, imports accounted for about one-third of domestic consumption on average, with their share ranging from 5% to over 80% across industries.

Figure 1 plots the annual mean import penetration and tariff rates across firms over the entire sample period. Again, tariffs are generally falling over the period while import penetration is rising. The largest declines in tariffs took place during the 1990s, with smaller changes occurring during the 2000s. The import penetration rate exhibits a similar pattern.

Figure 1: Import Competition 1990-2007



It is important to note that Spain was a member of the EU thoughout the sample period, meaning that while variation in tariffs comes only as a result of EU-level negotiations with third party nations, import penetration is driven both by increased exposure to third-party nations, as well as growth in intra-EU trade. The latter is not subject to any tariffs. In this light, reductions in import tariffs are not the only driver of the observed increases in import penetration.

To confirm that changes in third-party tariffs were indeed a significant factor in determining the level of import competition, I statistically analyze the relationship between import penetration and tariffs in the industries under study. The results are displayed in Table 3. Not surprisingly, the two variables exhibit a close relationship. A simple regression of the former on the latter at the industry level yields a coefficient of -0.82, implying that a 1 percentage point reduction in the tariff rate is associated with a 0.82 percentage point increase in the import penetration rate, and is significant at the 95 percent level. Adding industry fixed-effects to this regression in order to isolate within-industry variation and abstract from cross-sectional heterogeneity across industries yields a coefficient of -2.8 and is again highly significant. These coefficients suggest that reductions in the import tariff have a strong positive effect on import penetration. The R^2 of the pooled model is low at 0.018 as is standard with cross-sectional data, while the within R^2 of the fixed-effect model is much higher at 0.37, implying that within-industry tariff variations explain a substantial portion of the changes in import penetration These results confirm that tariffs are an important determinant of import competition, and so should be expected to have a significant influence on the competitive state of the domestic industry.[12]

[12] Similar results are obtained when I limit the analysis to imports from non-EU nations.

Table 3: Import Penetration and Tariffs

Coefficient	-0.8218**	-2.7722***
Standard Error	(0.3203)	(0.2137)
Industry Fixed-Effects	N	Y
R^2	0.0180	0.3688

Coefficients are from regressions of the import penetration rate on the import tariff rate across industries.

Significance: * 90%, ** 95%, *** 99%.

2.3 The effect of tariff reductions on domestic firms

Before outlining and estimating the structural model, I investigate the impact of changes in tariffs on some firm-level outcomes of interest in a reduced-form manner. First, I assess the influence of tariff changes on firm product-market performance. In particular, I regress the log of output price and quantity on the tariff rate. I include firm and time effects to control for unobserved firm-specific factors and time-varying aggregate shocks. Next, I estimate regressions of reported measures of innovative investments and outcomes on tariff rates. I use R&D expenditures and employment to measure innovative investments, and the reported indicators of successful process and product innovations to measure innovative output. The exercise here is in the spirit of the existing reduced-form literature on competition and innovation, updated to include more detailed measures of firm-level engagement in innovation. Previous studies of this kind have documented a substantial degree of persistent dispersion in firm-level innovation activities, likely driven by differences in innovative incentives and hazards of success. I include firm and time fixed-effects to control for these factors across firms as well as the influence of time-varying aggregate shocks. The results are reported in Table 4.

In Rows [1] and [2], I report the impact of tariff changes on the product-market performance of domestic firms. The positive and significant coefficient in row [1] implies that increases in import competition induced by lower tariffs puts downward pressure on domestic prices, as one would expect. Similarly, the positive coefficient in row [2] indicates that more intense competition causes losses in sales, although the effect is not significant at standard levels. A primary response to import competition seems to be a lowering of prices, confirming that changes in competition from abroad influence the product-market performance of domestic firms.

Row [3] displays the results from a Tobit regression of the log of R&D expenditures on the tariff rate. As I discuss in more detail below, a Tobit model is appropriate due to the left-censoring of the R&D variable at zero. For example, Table 1 shows that about two-thirds of firms in the sample do not engage in R&D activities. To control for permanent unobserved heterogeneity across firms, I use the random effects Tobit estimator. The assumption here is that tariff levels are uncorrelated with the specific unobserved characteristic of any individual firm.[13] The value reported in row [3] is the marginal effect of a 1 percentage point change in the tariff rate on the observed (censored) levels of R&D expenditures, evaluated at the mean tariff rate. The effect is negative and significant

[13] I discuss the exogeneity of tariffs in detail below.

at standard confidence levels, suggesting that a reduction in the tariff rate has a positive effect on R&D. The value is interpreted as a semi-elasticity and implies that a 1 percentage point reduction in the tariff is associated with a 4% increase in observed R&D expenditures.[14] Row [4] considers an analogous specification with R&D employment as the dependent variable. The coefficient is again negative and significant, and implies that at the mean tariff rate, a 1 percentage point decrease in the tariff is associated with a 1.4% increase in the observed number of employees devoted to R&D activities.

Row [5] reports the results from a regression of the process innovation indicator on the tariff. The coefficient is negative and significant, showing that reductions in the tariff correspond to an increase in the rate of process innovation. The magnitude implies that a 1 percentage point decrease in the tariff generates a 0.8 percentage point increase in the hazard of introducing a new process innovation. Row [6] shows the analogous regression for product innovations. Again, the coefficient is negative, suggesting a positive effect of tariff reductions, although not significant at standard confidence levels.[15]

Table 4: Firm Performance, R&D, Innovation, and Tariffs

Dependent Variable	Coefficient	Standard Error	N
Log Price	0.0017***	(0.0006)	30,743
Log Output	0.0034	(0.0025)	30,533
Log R&D Expenditure	-0.0400***	(0.0113)	30,515
Log R&D Employment	-0.0136***	(0.0026)	8,852
Process Innovation Indicator	-0.0083***	(0.0026)	30,730
Product Innovation Indicator	-0.0012	(0.0023)	30,729

Independent variable is import tariff rate. R&D regressions report average marginal effects from random effects Tobit. All other specifications are linear. All specifications include firm and time effects. Significance: * 90%, ** 95%, *** 99%.

The reduced-form results reported in Table 4 suggests that tariff reductions spur intensified product market competition, increased investments in R&D, and a greater rate of successful process innovation, but do not have a meaningful impact on the rate of product innovation. In the remainder of the paper, I analyze the relationships between competition, innovation, and achieved performance through the lens of a structural model.

3 A model of competition and innovation

In this section I outline a dynamic model of strategic competition and innovation. The framework explicitly incorporates the simultaneous effects of competitive pressure on innovative investments

[14] The magnitude of this result is smaller, although in the same vicinity, as previous estimates. For example, in a similar regression, Teshima (2008) finds that a 1 percentage point reduction in the tariff is associated with an 8% increase in R&D expenditures in a panel of Mexican firms.

[15] Again, this is a similar to Teshima (2008) who finds no effect of tariff reductions on R&D in product innovation.

and achieved performance, where the latter is captured both by process efficiency and product quality. The active agents in the model are heterogenous firms that differ over productivity, product quality and scale. Firms compete in the product market and choose optimal levels of investments in R&D and physical capital as a function of their own characteristics as well as those of their competitors to maximize discounted expected profits. R&D investments influence the stochastic processes governing the evolution of firm-level productivity and product quality. The aggregrate state, capturing the intensity of competition, is determined by the characteristics of the firms competing in the market and evolves in response to an aggregate shock coming through changes in tariffs as well as the idiosyncratic shocks to which firms are subject and their resulting actions. In turn, the aggregate state affects individual firm outcomes by changing the incentives for investments in R&D through expectations of future prospects and by directly influencing the path of firm product quality and productivity.

3.1 The environment

Time is discrete and indexed by t. Firms produce differentiated products and operate to maximize the PDV of expected profits. The state of a firm is summarized by a triple $(\omega, \varphi, K), \omega \in \Omega, \varphi \in \Phi, K \in \mathbb{K}$ where ω is an index of the firm's efficiency, φ the quality of its product offering, and K its level of installed physical capital.[16] The differing states of each firm form the heterogeneity in the model and will be an important driver for the large degree of persistent dispersion in firm-level R&D investment that is seen in the data. The aggregate, or competitive, state of each industry $s \in \mathbb{S}$ is then a vector listing the number of firms in the industry at each possible state of (ω, φ, K), with individual elements labeled $s(\omega, \varphi, K)$.

In each period, firms compete and earn profits on a spot product market. After maximizing over its static choices variables, the current period expected profits of firm i in industry j, $\pi\left(\omega_{ij}, \varphi_{ij}, K_{ij}, s_{-ij}\right)$, depend on its individual state $\left(\omega_{ij}, \varphi_{ij}, K_{ij}\right)$ as well as the states of its competitors within the industry s_{-ij}.

It makes sense at this point to explicitly define the notion of the competitive environment in the model. Following the original formulation of Ericson and Pakes (1995), I assume that competition in the product market generates a preorder over s, denoted by $\succeq$, which characterizes the competitive intensity of the market. For all triples (ω, φ, K), current profits are (weakly) decreasing in s in the sense of $\succeq$. An increase in competition is captured by an increase in s. Intuitively, a shift towards higher productivity, higher product quality, or larger scale of a firm's competitors generates an increase in competitive intensity. This formulation of an ordering of competitive states is convenient in its flexibility and generality in incorporating the characteristics of how "increased competition" has generally been interpreted in the literature.

Foreign firms are able to export into the domestic market subject to an import tariff rate τ, which varies over time and across industries. Tariffs are exogenous and evolve according to a

[16] I suppress subscripts wherever possible in formulating the theoretical model.

first-order Markov process.[17] By reducing the efffective marginal cost of selling in the domestic market, a reduction in tariffs should spur exporters to increase their sales volumes and new foreign firms to enter the market. Because exporters tend to be higher productivity and offer products of higher quality, the "competitive shock" induced by a tariff reduction should cause an increase in the competitive intensity of the domestic industry. Writing the competitive state as the sum of the domestic and foreign firms at each state, $s(\omega, \varphi, K) = s^d(\omega, \varphi, K) + s^f(\omega, \varphi, K)$, the immediate impact of a reduction in τ will be to increase the effective ω, φ, or K (or some combination thereof) of foreign firms with no corresponding change for domestic firms. This is the way in which, *ceteris paribus,* for any $\tau < \tau', s(\tau) \succeq s(\tau')$, that is, tariff reductions generate a more intense competitive environment. Intuitively, we can think of reductions in τ as a competition-augmenting shock, reducing domestic firm profitability by increasing the productivity, product quality, or scale of its foreign competitors, holding fixed the characteristics of its domestic competitiors. Due to the serially correlated nature of τ and the fact that changes in τ cause persistent shifts in s, τ now enters the firm's decision problem as an additional state variable, affecting current profits as well expectations of future prospects.

3.2 Demand

I motivate the demand system through the discrete choice literature of Berry (1994) and descendants. There is a mass of consumers each purchasing one good. Without detailed product characteristics, I model the utility to consumer c from purchasing the product of firm i in industry j at time t simply as

$$U_{cijt} = \gamma_0 + \gamma_j + \gamma_t + \gamma_{jt} + \alpha P^y_{ijt} + \varphi_{ijt} + \eta_{cijt} \tag{3}$$

where P^y_{ijt} denotes the firm's output price, γ_j a persistent industry-specific component of utility, γ_t a time-varying aggregate shock, and γ_{jt} an industry-time specific shock. η_{cijt} captures consumer-specific heterogeneity and is distributed i.i.d. type 1 extreme value. Finally, φ_{ijt} is the quality of the firm's product offering at time t as defined above, which is unobserved to the econometrician but known by all agents in the economy. This specification implies market shares of the standard form:

$$\sigma_{ijt} = \frac{e^{\gamma_0 + \gamma_j + \gamma_t + \gamma_{jt} + \alpha P^y_{ijt} + \varphi_{ijt}}}{1 + \sum_{l=1}^{I} e^{\gamma_0 + \gamma_j + \gamma_t + \gamma_{jt} + \alpha P^y_{ljt} + \varphi_{ljt}}} \tag{4}$$

The Logit demand model is appealing here for its simplicity, while still yielding the desired competitive effects. It is straightforward to derive the firm's residual demand elasticity

$$\varepsilon_d\left(\sigma_{ijt}, P^y_{ijt}\right) = \alpha P^y_{ijt}\left(1 - \sigma_{ijt}\right) \tag{5}$$

The impact of a competitive shock in the product market in the sense of inducing an $s' \succeq s$ is intuitive. As rivals become more efficient and lower their prices, or increase their product quality or capital base, they will tend to produce more and capture a greater share of the market. This

[17] I detail below how the institutional framework for the sample of Spanish firms supports the exogeneity assumption.

serves as a negative shock to the residual demand curve of a particular firm, which is forced to either reduce price or lose market share. Without imposing a particular form of equilibrium play in the product market, it is clear that firm profitability will be lessened and the market has become more cutthroat.

3.3 Production

Firms use capital, labor and intermediate inputs, or materials, to produce output according to a Cobb-Douglas production technology

$$Y_{ij} = Ae^{\omega_{ij}+\mu_{ij}} K_{ij}^{\beta_k} L_{ij}^{\beta_l} M_{ij}^{\beta_m} \tag{6}$$

where L and M denote labor and intermediate inputs, or materials. ω denotes the firm's productivity as defined above and μ an i.i.d. shock to production that captures measurement error and/or any idiosyncratic shocks that are not known when input decisions are made. It is important to make a distinction between the roles of ω and μ. The former represents an efficiency level that is correlated over time and so potentially observable or predictable to the firm when making its current period input choices, whereas the latter represents strictly exogenous and unpredictable shocks that are uncorrelated with any input choices and so captures the period-by-period uncertainty in production to which firms are inherently subject.

The firm's static problem is to choose labor L and materials M to maximize current period profits given its individual characteristics $(\omega_{ij}, \varphi_{ij}, K_{ij})$ and the aggregrate industry state s_{-ij}. Optimality entails the standard condition of choosing quantities to equate marginal revenues to marginal costs. This condition will play an important role in the econometric work below and I defer the details to that section of the paper.

3.4 State transitions

In addition to the static choices just described, the firm makes dynamic decisions over R&D investments R and physical capital I. Capital accumulates according to a standard and deterministic neoclassical law of motion

$$K'_{ij} = (1 - \delta_j) K_{ij} + I_{ij}$$

where δ_j is the industry-specific rate of depreciation. R&D investments influence the paths of productivity and product quality, which evolve according to stochastic laws of motion

$$\omega'_{ij} = f(\omega_{ij}, R_{ij}, s_{-ij}, \tau_j) + \xi'_{ij} \tag{7}$$

$$\varphi'_{ij} = g(\varphi_{ij}, R_{ij}, s_{-ij}, \tau_j) + \psi'_{ij} \tag{8}$$

The evolution of a firm's productivity and product quality are functions of several factors: ξ and ψ are i.i.d. and mean zero idiosyncratic shocks to these processes that are only realized in the following period, after all current period choices have been made. These are by construction unpredictable from the standpoint of the current period and capture the uncertainty in the path of a single firm's outcomes. The functions $f(\cdot)$ and $g(\cdot)$ represent the predictable portion of the firm's next period productivity and product quality and depend on its current levels of these characteristics, current R&D expenditures R, the competitive state of the industry s_{-ij}, and the industry tariff level τ_j. That the state of a firm's competitors and the tariff level directly affect its performance captures possible knowledge and technological diffusion from other firms in the market, whether domestic or foreign, as well as improvements in managerial incentives or work practices induced by more intense competition. That is, the inclusion of the competitive state directly in the evolution of the firm's efficiency and product quality incorporates the direct channel of competitive effects described above. These effects should be stronger when there are more efficient or higher quality firms present in the market, or when these firms are producing a greater share of industry output, i.e., when s is larger in the sense of our ordering $\succeq$.

3.5 Firm strategies

As a dynamic model of firm competition, I focus on Markov strategies. The value function for a domestic firm i in industry j can be written recursively as

$$\begin{aligned} V\left(\omega_{ij}, \varphi_{ij}, K_{ij}, s_{-ij}, \tau_j\right) &= \max_{R_{ij}, I_{ij}} \pi\left(\omega_{ij}, \varphi_{ij}, K_{ij}, s_{-ij}, \tau_j\right) - c_R\left(R_{ij}\right) - c_I\left(I_{ij}\right) \\ &\quad + \beta E\left[V\left(\omega'_{ij}, \varphi'_{ij}, K'_{ij}, s'_{-ij}, \tau'_j | \omega_{ij}, \varphi_{ij}, K_{ij}, s_{-ij}, \tau_j\right)\right] \end{aligned}$$

where $\pi(\cdot)$ is the conditional profit function, giving profits as a function of the current state conditional on the optimal static choices of the firm. $c_R(\cdot)$ is the cost function for R&D investment and $c_I(\cdot)$ for physical capital investment. β is the common rate of discount. The solution to this problem yields policy functions

$$R_{ij} = R\left(\omega_{ij}, \varphi_{ij}, K_{ij}, s_{-ij}, \tau_j\right) \quad (9)$$

$$I_{ij} = I\left(\omega_{ij}, \varphi_{ij}, K_{ij}, s_{-ij}, \tau_j\right) \quad (10)$$

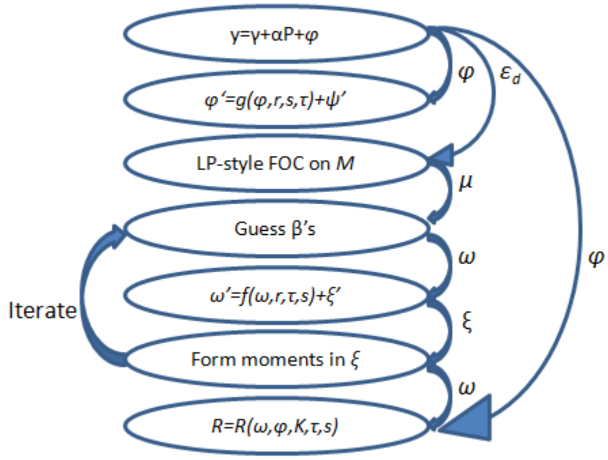
Equation (9) shows that the firm's choice of R&D investments R is the solution to a dynamic problem depending on the firm's individual characteristics and the state of competition. The impact of a shock to the competitive state on the incentives to invest in innovation is not clear. On one hand, firm profits are lower and prospects for the future more dim. On the other hand, firms may benefit through greater exposure to more advanced technology or through improved incentives in the practices of their workers and managers. Both of these channels alter innovative incentives in ways that are ambiguous. In the empirical work below, I use the data to infer whether competitive shocks increase or reduce innovative investments and quantify the effects of both the direct and indirect channels on realized outcomes.

Through the lens of the structural model, the potential impact of changes in competitive intensity on innovation and performance becomes clear. To understand how competitive pressure affects innovative investments, I will analyze how R responds to competitive shocks through reductions in τ. To assess the impact of competition on achieved outcomes and the importance of the direct and indirect channels, I will examine how the new levels of R and τ combine to influence the paths of ω and φ. Thus, equations (7), (8) and (9) are the objects that will reveal the effect of competition on innovation and realized performance. In the next section, I describe the econometric approach I take to consistently estimate these functions from the data.

4 Econometric strategy

Estimation of the model is complicated by the fact that ω, φ, and s are not directly observable in the data. In this section, I outline a multistage algorithm to recover these values. I begin by estimating the demand system. From information on the demand side of the market, I infer product quality φ and residual demand elasticities ε_d. Intuitively, identification of product quality comes from variations in market share conditional on price and other controls in the utility function. It is then straightforward to estimate the transition function of product quality. Next, I move on to estimating the production function, which itself involves a two-stage routine in the spirit of Ackerberg, Caves and Frazer (2006). In a first step, I utilize information from the firm's static profit-maximization first order condition and the demand elasticities already obtained to recover the i.i.d. shock to production μ (a modification of the procedure in Levinsohn and Petrin [2003]). Intuitively, identification of μ comes from observing deviations from optimal static choices conditional on time t information. In the second step, having purged the problem of the i.i.d. shocks, I use a GMM framework to infer the parameters of the production function and construct values of ω. Identification here comes from the timing structure of the model and essentially controlling for the endogenous shock ω in the production function. During this stage, I estimate the transition function of productivity. Finally, in a last step, I use the recovered estimates of ω and φ to consistently estimate the the R&D policy function. Following the insight of Bajari, Benkard, and Levin (2007), I take the approach of flexibly regressing observed R&D investments on the now fully observed state vector. The estimation algorithm is illustrated in Figure 2:

Figure 2: Estimation Algorithm



4.1 Demand and product quality

Recalling equation (4), the market share of firm i in industry j at time t is

$$\sigma_{ijt} = \frac{e^{\gamma_0+\gamma_j+\gamma_t+\gamma_{jt}+\alpha P^y_{ijt}+\varphi_{ijt}}}{1+\sum_{l=1}^{I} e^{\gamma_0+\gamma_j+\gamma_t+\gamma_{jt}+\alpha P^y_{ljt}+\varphi_{ljt}}}$$

Making the standard normalization of the mean utility of the outside good to zero, the share of the outside good can be expressed as

$$\sigma_{0jt} = \frac{1}{1+\sum_{l=1}^{I} e^{\gamma_0+\gamma_j+\gamma_t+\gamma_{jt}+\alpha P^y_{ljt}+\varphi_{ljt}}}$$

Combining equations gives a simple linear expression for the log ratio of market shares:

$$\ln\left(\frac{\sigma_{ijt}}{\sigma_{0jt}}\right) = \gamma_0+\gamma_j+\gamma_t+\gamma_{jt}+\alpha P^y_{ijt}+\varphi_{ijt} \tag{11}$$

Estimation of (11) requires definition of the outside good, as well as construction of its market share. This is difficult in my setting, where I have relatively aggregate industries and no well-defined outside option. By definition, the share of the outside good is the same for all firms within an industry. We can then bring this term to the right-hand side and rewrite the corresponding demand relationship as

$$y_{ijt} = \gamma_0+\gamma_j+\gamma_t+\gamma_{jt}+\alpha P^y_{ijt}+\varphi_{ijt} \tag{12}$$

where the influence of the outside good has been subsumed into the term γ_{jt} and y_{ijt} denotes the natural log of sales. Equation (12) represents the demand-side estimating equation.[18]

[18] Alternatively, we can make the somewhat unsatisfying assumption that the outside good for each industry is the remainder of the manufacturing sector excluding that industry. Because each firm represents only a very small fraction of the entire manufacturing sector, the results from this procedure are almost identical to those using (12).

Because the firm observes the current level of its product quality φ_{ijt}, we would expect prices to respond to the realization of this characteristic, which is unobserved by the econometrician, introducing correlation between prices and the error term. The richness of the ESEE data present a natural instrument for output prices in the form of input prices and this is the approach I follow.

The residuals from (12) represent consistent estimates of firm product quality. Recall from equation (8) that the evolution of φ depends on its current value, R&D investments, the competitive state, the tariff level, and an unpredictable shock. To estimate this function then requires the construction of the state s_{-ij}. It is infeasible to include the entire state vector in the estimation. Instead, I assume that the relevant measure of competition influencing product quality is sufficiently captured by the sum of the product quality of each competitor in the industry weighted by its capital stock, which is a primary determinant of its size. I construct the relevant state variable accordingly as $s^{\varphi}_{-ij} = \ln\left(\sum_{l\neq i} e^{\varphi_{lj}} K_{lj}\right)$. The economic interpretation here is straightforward. The ability to imitate or learn about product quality from one's rivals, or the pressure they apply to one's own product offering, depends on the degree of exposure to high quality competitors.

To estimate the transtion function (8), I specify the function $g(\cdot)$ as an augmented AR(1) process with a full set of linear interactions. This allows for a great deal of heterogeneity in the path of product quality and in particular, in the impact of R&D investments and changes in the tariff. There are then 15 right-hand side variables, excluding the constant term. As seen in Table 1, a sizable number of firms choose the corner solution of zero R&D. In this light, I follow Doraszelski and Jaumandreu (2009) and allow for a different transition function for firms that do no R&D investment and those with positive R&D. The estimating equation takes the form

$$\begin{aligned}\varphi_{ijt+1} &= \Phi\left(R_{ijt}>0\right) g_r\left(\varphi_{ijt}, r_{ijt}, s^{\varphi}_{-ijt}, \tau_{jt}\right) \\ &\quad +\Phi\left(R_{ijt}=0\right) g_{nr}\left(\varphi_{ijt}, s^{\varphi}_{-ijt}, \tau_{jt}\right) + \psi_{ijt+1}\end{aligned} \tag{13}$$

where $\Phi(\cdot)$ is an indicator function equal to 1 if its argument is true or else is equal to zero. $g_r(\cdot)$ and $g_{nr}(\cdot)$ denote the predictable component of future product quality conditional on current conditions and choices for R&D performers and non-performers, respectively. The impact of increased competitive pressure through tariff reductions on the path of product quality is made clear in (13). The indirect channel through changing investments in innovation are captured by the effect of the marginal change in r on φ and the direct channel by the effect of τ.

4.2 Production and productivity

The estimation algorithm I develop to infer ω is an extension of that outlined by Ackerberg, Caves and Frazer (2006) to consistently estimate the production function in the presence of an unobserved and serially-correlated productivity term.[19] In particular, this methodology is meant to overcome the simulteneity bias in traditional OLS estimation due to the correlation of productivity and input choices. In my setting, the presence of differentiated products and the endogeneity of productivity

[19] Ackerberg, Caves and Frazer (2006) builds on Olley and Pakes (1996) and Levinsohn and Petrin (2003).

through R&D investments add additional layers of complication. Here, I outline a two-step method that enables estimation of the production parameters and so the computation of ω. In brief, I use the results from the demand side of the market to control for the endogeneity of price and incorporate endogenous R&D investments in a similar manner as Doraszelski and Jaumandreu (2009).

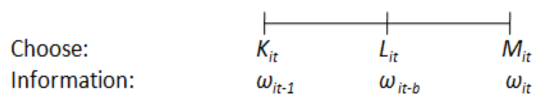
4.2.1 Stage 1

I rewrite the production function (6) in natural logs, which I denote with lower-case letters as

$$y_{ijt} = \beta_0 + \beta_k k_{ijt} + \beta_l l_{ijt} + \beta_m m_{ijt} + \omega_{ijt} + \mu_{ijt} \tag{14}$$

where $\beta_0 = \ln A$. Ackerberg, Caves and Frazer (2006) show there are collinearity problems in the standard Olley and Pakes (1996) and Levinsohn and Petrin (2003) procedures that may prevent identification of the labor coefficient in the production function. In this light, I follow their suggested alternative approach and adopt the identifying assumption that materials is the only fully flexible input in the sense of responding to the realization of ω_{ijt}. In particular, I assume that labor L_{ijt} is chosen at period $t-b, 0<b<1$, i.e., within period t, but prior to the time that materials are chosen. ω continues to evolve in the interim interval between the labor choice and the materials choice. This timing structure implies that the choice of materials M_{ijt} is a function of the firm's current productivity ω_{ijt} as well as its levels of physical capital and labor.[20] Figure 3 illustrates the timing of input choices within a single period:

Figure 3: Within-Period Timing of Inputs



With these assumptions, the firm's expected short-run conditional cost function at time t is given by

$$E\left[C\left(\cdot\right)\right] = E\left[P_{ijt}^{m}\left(\frac{Y_{ijt}}{Ae^{\omega_{ijt}}e^{\mu_{ijt}}K_{ijt}^{\beta_k}L_{ijt}^{\beta_l}}\right)^{\frac{1}{\beta_m}}\right]$$

where P_{ijt}^{m} denotes the materials price it faces at time t. The expectation is with respect to μ_{ijt}, which is only realized after all input choices have been made. Expected marginal costs can be found as

$$E\left[MC\left(\cdot\right)\right] = E\left[P_{ijt}^{m}M_{ijt}^{1-\beta_m}\frac{1}{\beta_m}\frac{1}{Ae^{\omega_{ijt}}e^{\mu_{ijt}}K_{ijt}^{\beta_k}L_{ijt}^{\beta_l}}\right] \tag{15}$$

To maximize profits, the firm's optimality condition requires that its choice of materials, which fully determines expected output, sets expected marginal cost to expected marginal revenue. This

[20] This timing assumption seems especially applicable in the case of the Spanish data used in the empirical analysis below, due to the recognized labor market rigidities prevalent in Western Europe.

latter takes the standard inverse elasticity form

$$MR(\cdot) = P_{ijt}^{y}\left(1 + \frac{1}{\varepsilon_d\left(\sigma_{ijt}, P_{ijt}^{y}\right)}\right) \tag{16}$$

Equating (15) and (16) and rearranging yields an analytic formula for the firm's productivity level. Taking natural logs gives

$$\omega_{ijt} = -\ln\beta_m + (1-\beta_m)\,m_{ijt} - \beta_0 - \mu - \beta_k k_{ijt} - \beta_l l_{ijt} - \left(p_{ijt}^{y} - p_{ijt}^{m}\right) - \ln\left(1 + \frac{1}{\varepsilon_d\left(\sigma_{ijt}, P_{ijt}^{y}\right)}\right) \tag{17}$$

where $\mu = \ln E\left[e^{\mu_{ijt}}\right]$. Substituting this expression into the production function (14) and rearranging yields

$$\left(y_{ijt} + p_{ijt}^{y}\right) - \left(m_{ijt} + p_{ijt}^{m}\right) + \ln\left(1 + \frac{1}{\varepsilon_d\left(\sigma_{ijt}, P_{ijt}^{y}\right)}\right) = -\ln\beta_m - \mu + \mu_{ijt} \tag{18}$$

which is a valid estimating equation where the left hand side consists of the log of the inverse of the materials cost share of revenues and a function of the residual demand elasticity and the right hand side simply a constant. Intuitively, the optimality condition sets the marginal revenue product of materials, which depends on the residual demand elasticity, equal to its marginal factor cost. Identification of μ_{ijt} comes through observing deviations from this rule.[21]

Equation (18) represents the first stage estimating equation. Although no production parameters are identified here, the residuals represent a consistent estimate of the firm's untransmitted shock to production $\widehat{\mu}_{ijt}$, which I will use in the next stage.

4.2.2 Stage 2

In this stage, I use GMM techniques to estimate the production function parameters and recover values for firm-level productivity ω and its transition function. Again following Ackerberg, Caves and Frazer (2006), I estimate the parameters of the value-added production function rather than of gross-output. As pointed out by Bond and Soderbom (2005), it is hard, if not impossible, to identify the coefficient on a static and perfectly variable input in the context of Cobb-Douglas production. In this light, I consider the value-added production function

$$va_{ijt} = \beta_0 + \beta_k k_{ijt} + \beta_l l_{ijt} + \omega_{ijt} + \mu_{ijt}$$

[21] Intuition for this equation is easily seen from the perfectly competitive case in which $\varepsilon_d \to \infty$. In this case, the condition collapses to $\beta_M = \frac{P_{ijt}^{m} M_{ijt}}{P_{ijt}^{y} Y_{ijt}} + \mu_{ijt}$, i.e., the firm chooses materials such that the materials expenditure share is constant and equal to its elasticity in production. Deviations are then due to the unobserved shock μ_{ijt}.

where value-added VA_{ijt} is defined as physical output less physical materials input.[22]

Given a candidate vector of the production function parameters $\{\beta_0, \beta_k, \beta_l\}$ and the first stage estimates of the i.i.d. production shock $\widehat{\mu}_{ijt}$, I can construct values for ω_{ijt} as

$$\omega_{ijt}(\beta_0, \beta_k, \beta_l) = va_{ijt} - \beta_0 - \beta_k k_{ijt} - \beta_l l_{ijt} - \widehat{\mu}_{ijt} \tag{19}$$

where I have made explicit the dependence of ω_{ijt} on the candidate parameter vector $\{\beta_0, \beta_k, \beta_l\}$. Using these values, I can estimate the productivity transition function (7). Similar to the transition of product quality, I allow for a great deal of heterogeneity in outcomes and specify the law of motion of ω as an augmented AR(1) with a full set of linear interactions, making for 15 right-hand side variables. I again allow for different functions for R&D performers and non-performers. To construct the aggregate state s_{-ij}, I assume that the potential diffusion of efficient technologies, or the improved incentives from competitive pressure, are sufficiently captured by the capital-weighted sum of rival firm efficiencies and construct the relevant state variable accordingly as $s^{\omega}_{-ij} = \ln\left(\sum_{l\neq i} e^{\omega_{lj}} K_{lj}\right)$. Intuitively, competitive market conditions and the extent to which firms can learn of new techniques from their rivals depend on the interaction of the efficiency of competitors with their scale. This yields an estimating equation of the form

$$\begin{aligned} \omega_{ijt+1}(\beta_0, \beta_k, \beta_l) \quad = \quad & \Phi(R_{ijt} > 0)\, f_r\left(\omega_{ijt}(\beta_0, \beta_k, \beta_l), r_{ijt}, s^{\omega}_{-ijt}, \tau_{jt}\right) \\ & + \Phi(R_{ijt} = 0)\, f_{nr}\left(\omega_{ijt}(\beta_0, \beta_k, \beta_l), s^{\omega}_{-ijt}, \tau_{jt}\right) + \xi_{ijt+1} \end{aligned} \tag{20}$$

where $\Phi(\cdot)$ again denotes an indicator function equal to 1 if its argument is true or else is equal to zero. $f_r(\cdot)$ and $f_{nr}(\cdot)$ denote the predictable component of future productivity conditional on current conditions and choices for R&D performers and non-performers, respectively. The effect of the competitive shock through tariff reductions is similar to that on product quality. The indirect effect will come through the marginal impact of a change in r, and the direct effect through the change in τ.

The residuals from (20) represent an estimate of the idiosyncratic and unpredictable shock in the productivity process ξ. Using these estimates, I can set up the following standard moment conditions which identify the production function parameters:

$$E\begin{bmatrix} \xi_{ijt}(\beta_0, \beta_k, \beta_l) \cdot k_{ijt} \\ \xi_{ijt}(\beta_0, \beta_k, \beta_l) \cdot l_{ijt-1} \\ \omega_{ijt} \end{bmatrix} = 0 \tag{21}$$

The production function is estimated by iterating on the initial guess of the production technology

[22] Thus, the role of materials is purely to distinguish shocks still unrealized at the time input decisions are made. Again, the intuition is that materials are the most flexible input with respect to ω and therefore should be most informative in separating out ω from μ.

parameter vector until I minimize the sample analogue to these moment conditions

$$\frac{1}{J}\frac{1}{I}\frac{1}{T}\sum_{j}\sum_{i}\sum_{t}\left[\begin{array}{c}\xi_{ijt}\left(\beta_0,\beta_k,\beta_l\right)\cdot k_{ijt}\\ \xi_{ijt}\left(\beta_0,\beta_k,\beta_l\right)\cdot l_{ijt-1}\\ \omega_{ijt}\end{array}\right] \tag{22}$$

4.3 R&D investment

I now turn to estimation of the R&D policy function (9). Here, I follow Bajari, Benkard, and Levin (2007) by flexibly regressing observed R&D choices on the state. The implicit assumption is that the data are generated by equilibrium play and so with the caveat that we observe a wide range of states, we can use the data to make inferences about the equilibrium policy functions. As seen in Table 1, about two-thirds of firms choose the corner solution of zero R&D. Thus, the distribution of R&D expenditure has positive mass at zero and is continuous over the range of positive values. The presence of this form of left-censoring renders OLS estimates inconsistent and a Tobit model, which explicitly accounts for the left-censoring of the data at zero, is appropriate.

In addition to adjusting for the censored nature of the data, the Tobit model provides a particularly useful feature in distinguishing the impact of the state variables on the R&D decisions of various subsegments of the population of firms. There are three marginal effects of interest. The first, $\frac{\partial E[r|\cdot]}{\partial \tau}$ represents the impact of the competitive shock on the conditional mean of r, the observed level of R&D spending. This is the effect not on the latent variable in the Tobit model, but on the observed censored values as reported in the data. Second, $\frac{\partial E[r|r>0,\cdot]}{\partial \tau}$ is the impact of the shock on R&D expenditures for those firms reporting a positive level of expenditure. Finally, $\frac{\partial \Pr(r>0|\cdot)}{\partial \tau}$ is the impact on the probability of being uncensored, i.e., of engaging in R&D at all. The first effect captures the overall impact of competitive intensity on engagement in R&D in the population. This can be decomposed into the latter two effects. The first of these captures the intensive margin, i.e., how do current R&D performers react to changes in the competitive environment? The second captures the extensive margin, i.e., how do changes in competitive pressure impact the probability of undertaking R&D at all?

The Tobit model takes the form

$$\begin{aligned} r^*_{ijt} &= h\left(\omega_{ijt},\varphi_{ijt},K_{ijt},s_{-ijt},\tau_{jt}\right)+\iota_{ijt}, \quad \iota_{ijt}\sim N\left(0,\sigma^2_\iota\right)\\ r_{ijt} &= \max\left(0,r^*_{ijt}\right)\end{aligned}$$

where r_{ijt} is observed R&D expenditure and r^*_{ijt} is the latent level. I specify $h(\cdot)$ as a linear function of the state variables and include interactions of τ with each of the other states. To measure s_{-ijt}, I include both s^{φ}_{-ijt} and s^{ω}_{-ijt}, for a total of 6 state variables and 11 right-hand side variables, excluding the constant. The impact of τ on r captures the response of innovative investments to shocks to the competitive environment. The combination of the effect of τ on r and in turn, r on φ and ω, together reveal the magnitude of the indirect channel of how competitive pressure affects achieved outcomes through changing engagement in innovative activities.

4.4 Tariff determination

Before moving to my results, the exogeneity of the import tariff is worth a brief comment. A particular feature of my use of Spanish data is that concerns of tariff endogeneity due to political economy issues are largely absent. As a member of the EU, Spanish external tariffs (i.e., those applicable to non-EU nations) are no longer determined by Spain itself. Rather, Spain must adhere to the EU common external tariff schedule. EU trade policies are negotiated by the European Commission on behalf of all member states, in conjunction with the "133 committee." The latter is a committee of 133 delegates from the EU member nations and the European Commission, whose agenda is the discussion and coordination of trade issues affecting the EU. It is through this body that the European Commission receives the endorsement of the member states for policy initiatives. The European Commission reports regularly to the Council of the European Union as well as to the European Parliament. The results of trade negotiations must then be approved by the Council, generally by qualifed majority voting, in order to become effective.[23] As one of the now 27 members of the EU, it is unlikely that any particular Spanish firm has a significant influence on EU-wide common external tariffs. A similar argument for the exogeneity of trade barriers in a particular European nation after integration into the EU is used by De Loecker (2010).

5 Results

In this section, I present the results from the structural estimation. I begin with the demand and production estimates. I then report the results from the R&D policy function. I assess the general reasonableness of my econometric procedure and results by examining the demand and production parameter estimates and the characteristics of the resulting φ's and ω's. Next, I show that my findings are robust to controlling for other potential effects of a trade liberalization. Finally, I summarize the effect of competitive pressure on firm performance as measured by product quality and productivity and the relative importance of the direct and indirect channels.

5.1 Demand and product quality

Table 5 presents results from the demand estimation (12). I report OLS and IV estimates of the price coefficient where the latter uses input prices as an instrument for output prices. In line with the theory outlined above, OLS results in a significant positive bias on the price coefficient. This bias translates into the elasticity estimates. The table show that with OLS, the mean elasticity is slightly less than one in absolute value, implying the unreasonable result that the average firm sets a negative markup. In contrast, the IV estimates are quite reasonable. The implied average elasticity is about -2.7.[24]

[23] See, e.g., "The European Union Trade Policy: Our Work at External Trade," Brussels, December 2008, available at http://ec.europa.eu/trade/gentools/downloads_en.htm

[24] In the IV specification, about 40 observations (less than 0.1%) have implied elasticities less than 1 in absolute value. Because these values are fed into the production function estimation, I set the elasticities of these firms equal to the average in their respective industries.

Table 5: Demand Estimates

	OLS	IV
Price Coefficient	-0.8831	-2.4066
	(0.1597)	(0.3501)
Mean (ε_d)	-0.9918	-2.7030

Both specifications include dummies for industry, time and their interaction. Standard errors are shown in parentheses and are robust to heteroskedasticity and autocorrelation at the firm level. Both coefficients are significant at the 99% level.

I use the demand estimates from Table 5 to infer the quality of the product offering of each firm. In Table 6, I assess the reasonableness of these values by examining their correlation with some of the observed firm-level characteristics. As we would expect and is predicted by theory, product quality is highly correlated with output, both in nominal and real terms, output price, and the size of the capital stock.

Table 6: Implications of Product Quality Measures

Correlation of φ with	
Nominal Output	0.88
Physical Output	0.86
Output Price	0.15
Capital	0.80

In Table 7, I present the results of the product quality transition equation (13). Recall that a separate conditional mean function was specified for R&D performers and non-performers. I report the estimates of both functions. For the sake of brevity and ease of interpretation, I report the average marginal effect of each determinant of future product quality φ'_{ij} and relegate the full set of coefficients to Table 14 at the end of the paper. Because current product quality φ_{ij}, R&D r_{ij} and the aggregate state s^{φ}_{-ij} are expressed in logs, their marginal effects represent elasticities. The marginal effect of a change in the tariff τ_j is a semi-elasticity and is interpreted as the percent change in product quality associated with a unit percentage point change in the tariff.

Not surprisingly, product quality is highly persistent across both groups of firms. R&D has a positive impact on product quality. The elasticity of product quality with respect to R&D is about 0.006. As I discuss below, this estimate in conjunction with the effect of R&D on productivity implies an elasticity of output with respect to R&D that is in line with previous findings. Clearly, however, the low elasticity of product quality with respect to R&D will limit the potential for the average firm to experience large quality gains through the indirect channel of increased R&D investments in response to competitive pressure.

The negative effect of τ implies that tariff reductions have a positive impact on product quality, with a unit percentage point decline in the tariff spurring about a 0.2%-0.3% increase in product quality. Already, we can see the relative importance of this channel, which captures the direct effect of more intense competition. The estimates imply that it would take about a 33% increase in R&D for the average firm to generate the same impact on achieved product quality that is induced through the direct channel

Finally, the negative sign on s^{φ}_{-ij} suggests that product quality worsens in reponse to increases in the quality of domestic competitors. This implies that dominating any beneficial spillovers or changing performance incentives across domestic firms is the deterioration in a firm's quality position, and hence its market share, as rivals improve or grow larger.

Table 7: The Evolution of Product Quality

	R&D Performers	Non-Performers
φ_{ij}	0.9793	0.9896
r_{ij}	0.0059	
τ_j	-0.0023	-0.0032
s^{φ}_{-ij}	-0.0112	-0.0081

Table reports average marginal effects from the transition function for product quality $g(\cdot)$. All explanatory variables are significant at the 99% level.

5.2 Production and productivity

Table 8 reports the estimated production function parameters along with the results from a standard OLS specification. The model produces results well within the standard range found in the literature with a capital elasticity about of 0.39 and labor elasticity of about 0.66. There is a small degree of returns to scale in the production technology, a common finding from firm-level data. Comparing the OLS results to those from the model, the coefficients move in the way suggested by theory and that have typically been found in the literature. The upward bias on the labor coefficient under OLS is consistent with the notion that labor is sensitive to current productivity shocks that are observed by the firm, but not by the econometrician. This same bias causes the typical decrease in returns to scale when moving from OLS to the structural estimates.

Table 8: Production Function Parameters

	OLS	Model
Capital	0.2954	0.3940
	(0.0103)	(0.0470)
Labor	0.7716	0.6554
	(0.0161)	(0.0844)
RTS	1.0670	1.0494

Estimates are all significant at the 99% confidence level. Model standard errors are block-bootstrapped at the firm level with 500 replications.

To investigate the implications of the productivity estimates, I assess their correlations with other observable firm-level characteristics. Table 9 shows that productive efficiency is highly correlated with both nominal and physical output, and importantly, highly negatively correlated with output price. These relationships are in line with the theory. The correlation with physical capital is quite low, substantiating the fixed nature of capital investment. Foster, Haltiwanger and Syverson (2008; "FHS"), one of the few studies I am aware of with access to firm-level price deflators, report a similar set of statistics which I include in the table for purposes of comparison. The two sets of estimates are strikingly similar.

Table 9: Implications of Productivity Measures

Correlation of ω with	Model	FHS (2008)
Nominal Output	0.28	0.17
Physical Output	0.32	0.28
Output Price	-0.46	-0.54
Capital	0.05	0.03

In Table 10, I present the results of the productivity transition equation (20). Again, for brevity and ease of interpretation, I report average marginal effects for each right-hand side variable and leave a listing of all coefficients for Table 15 at the end of the paper. We see that firm efficiency is highly persistent both for R&D performers and non-performers. R&D expenditures have a positive impact on productivity.[25] The elasticity of productivity with respect to R&D is almost identical to the product quality elasticity at 0.006.

The effect of τ is again negative, implying that increased competitive pressure has a positive direct impact on realized productivity. The effect is present for both R&D performers and non-performers, although the magnitudes are fairly different. The values imply that a 1 percentage point reduction in the tariff induces a 0.6% increase in productivity among R&D performers and 0.24% among non-performers. There are several reasons why the productivity response of R&D-performing firms may be more susceptible to competitive shocks. First, there is evidence that in addition to its role in stimulating new innovation, R&D investment also enhances the capacity of firms to absorb and integrate new technologies. For example, Griffith, Redding and Van Reenen (2004) document this phenomenon across a panel of OECD countries during the 1970s and 1980s. Another possible explanation is that R&D performers are generally operating in more innovative and dynamic industries, where maintaining efficiency is of utmost importance to remain competitive. In this case, marginal changes in the competitive environment may have greater impact through changing managerial incentives and the implementation of productivity-enhancing work practices. Finally, as I explore in more detail below, this difference may be an artifact of a correlation between import and export tariffs, where the latter have a disproportionate effect on large, more productive firms, which are also those engaged in R&D. Table 10 reveals the weight of the direct channel in the response of productivity to competitive pressure. The average R&D performer would have to almost double its level of R&D investment to garner the same productivity gains it obtains through the direct effect of technology transmission or changing manager and worker incentives.

[25] The effect of R&D is significant at the 92% level, which is a common finding, and is simply indicative of the large degree of uncertainty in the path of firm efficiency. For example, Xu (2008) finds a similar degree of statistical significance in the effect of R&D on productivity.

The aggregate state s^{ω}_{-ij} has a positive impact on productivity growth, in contrast to the negative impact of the analogous measure on product quality. This confirms that the positive effect of potential knowledge or technology transfers from domestic competitors or the continued pressure on manager and worker incentives from facing more efficient competitors plays a significant role in stimulating firm-level productivity growth.

Table 10: The Evolution of Productivity

	R&D Performers	Non-Performers
ω_{ij}	0.9009	0.9040
r_{ij}	0.0059	
τ_j	-0.0058	-0.0024
s^{ω}_{-ij}	0.0227	0.0138

Table reports average marginal effects from the transition function for productivity $f(\cdot)$. All explanatory variables are significant at the 99% level except for r which is significant at 90%.

5.3 R&D investments

Table 11 displays results from the firm's R&D policy function. I report the average marginal effect of each state variable on the three subsegments of the firm population described above, that is, on the conditional mean of observed R&D expenditures, R&D expenditures for firms reporting positive R&D, and on the probability of engaging in R&D. Table 16 at the end of paper reports the full set of Tobit coefficients. The impact of the explanatory variables on R&D expenditures can be interpreted as elasticities for ω, k, and s, since they are already expressed in log form and as a semi-elasticity for the tariff rate τ. On the extensive margin, the impact of the explanatory variables are interpreted as the percentage point change in the probability of undertaking R&D for the average non-performer.

As we would expect, the amount of installed capital k, productive efficiency ω, and product quality φ each have a large and positive impact on R&D investments. The negative sign on τ implies that more intense import competition induced through reductions in the tariff generate higher levels of engagement in R&D. A 1 percentage point decrease in the tariff rate corresponds to a 3.8% increase in average observed R&D expenditures across all firms. This is composed of a 3.1% increase among current R&D performers and a 0.4% increase in the hazard of undertaking R&D. Clearly, changes in competitive pressure have a significant impact on firms' innovative investments, both on the discrete choice of whether to perform R&D and on the level of investment for firms that choose to do so. The positive coefficient on s^{ω} and the negative coefficent on s^{φ} are consistent with the results found in the transition functions for ω and φ. Firms tend to increase their R&D investments in response to efficiency gains by their competitors, seeking to maintain their proximity to the technological frontier, perhaps by successful imitation or absorption of the more efficient technologies of their rivals. In contrast, the dominant effect of product quality gains by competitors is to cut into the firm's market share, likely reducing the incentives to invest in R&D.

Table 11: The Determinants of R&D Investments

	$E[r\|\cdot]$	$E[r\|r>0,\cdot]$	$\Pr(r>0\|\cdot)$
k_{ij}	0.7408	0.6055	0.0734
ω_{ij}	0.3448	0.2817	0.0342
φ_{ij}	0.6728	0.5450	0.0666
τ_j	-0.0376	-0.0307	-0.0037
s^{ω}_{-ij}	0.6403	0.5234	0.0634
s^{φ}_{-ij}	-0.4457	-0.3643	-0.0441

Table reports average marginal effects from R&D policy function $h(\cdot)$. All explanatory variables are significant at the 99% level.

5.4 Additional effects of trade liberalization

In Section 2, I presented evidence linking tariff reductions to increases in the competitiveness of the domestic market as seen through the rising market share of foreign firms and the lowering of prices by domestic firms. I use this as motivation for the intuitive notion that competitive pressure induced through such trade shocks underlies my empirical results. However, the literature has posited several additional mechanisms through which a trade liberalization may lead to gains in firm-level performance. In this section, I address the robustness of my findings to the inclusion of these channels and corroborate that the "competitive" channel of tariff reductions is the primary driver of my empirical results.

What other effects of a trade liberalization may lead to domestic performance improvements? First, if tariff reductions are bilateral, there may be a learning-by-exporting phenomenon by which domestic firms experience performance gains not through increased exposure to foreign competitors in the home market as I model above, but rather via entry into the foreign market. De Loecker (2007) and Van Biesebroeck (2005) document the potential importance of this channel. Moreover, increased access to foreign markets through tariff reductions may change the incentives of domestic firms to engage in performance-enhancing R&D. Atkeson and Burstein (2010) and Aw, Roberts and Xu (2009) investigate the link between trade costs, exporting, and engagement in R&D. Another potential channel for performance improvements and changing R&D investments lies in the impact of a trade liberalization on the cost of inputs, and in particular, the cost of R&D investments.

To investigate whether my results are robust to allowing for these alternative vehicles for performance gains, I collect data on the tariff levels facing Spanish firms exporting to the rest of the world. As with import tariffs, the data are from the UNCTAD TRAINS database. I again use the MFN tariffs aggregated to the same industry level, weighted by the value of Spanish exports of each product to each country. Not surprisingly, there is a relatively high correlation of export and import tariffs across industry-time cells of about 0.68, suggesting a bilateral nature of trade negotiations, although the relationship is far from perfect. I re-estimate the model with the explicit inclusion of export tariffs in order to control for the potential impact on domestic outcomes caused by a greater ease of access to foreign markets. Additionally, to control for the possible effect of trade liberalization on the cost of R&D investment, I include a vector of time effects in the R&D policy function, under the assumption that the cost of innovative investment is common across firms. To limit the complexity of the estimation and focus on the first-order changes resulting from the inclusion of the additional variables, I employ linear specifications to model the transitions of product quality and productivity as well as the R&D policy function $h(\cdot)$ within the Tobit model.

The main results are consolidated in Tables 12 and 13 and the full set of results are presented in Tables 17 and 18 at the end of the paper. Table 12 displays the transition functions for product quality and productivity after the inclusion of the export tariffs. The import tariff is denoted by τ_j^{im} and the export tariff that Spanish firms face abroad by τ_j^{ex}. The foreign tariff is generally negative and significant, suggesting that access to markets abroad may have an effect on the performance of domestic firms. Despite this, the negative and significant coefficient on the import tariff across both performance measures and both groups of firms imply that the beneficial effect of increased competition through tariff reductions continues to hold. The qualitative impact of reductions in τ_j^{im} are similar to those found above, where the lowering of import tariffs spurs gains in both product quality and productivity, independent of expenditures on R&D. Clearly, the competitive effects of reductions in the import tariff found above are not driven by changes in the tariffs faced abroad.

Quantitatively, most effects are similar to those in the baseline model above. There are, however, several interesting exceptions. First, there is an increase in the impact of R&D on product quality as well as in the magnitude of the direct effect of import tariff reductions on product quality. Second, there is a fall in the size of the direct effect on productivity only for R&D performers, and where in the absence of the export tariff, this effect was much larger for performers than non-performers, the two effects are now approximately equal. A fall in export tariffs, which eases access to foreign markets and may facilitate learning-by-exporting, would be expected to predominantly impact exporting firms, which are typically larger and more productive, precisely those that tend to engage in R&D. This suggests that the disproportionately large direct effect of import tariff reductions on the productivity of R&D performers found above may be partially due to a corresponding fall in foreign tariffs.

Table 12: The Evolution of Product Quality and Productivity

	φ'_{ij}		ω'_{ij}	
	R&D Performers	Non-performers	R&D Performers	Non-Performers
φ_{ij}/ω_{ij}	0.9832***	0.9907***	0.9025***	0.9071***
r_{ij}	0.0095***		0.0051**	
τ_j^{im}	-0.0040***	-0.0045***	-0.0033**	-0.0028**
τ_j^{ex}	0.0052***	0.0035***	-0.0042***	-0.0009
$s^{\varphi}_{-ij}/s^{\omega}_{-ij}$	-0.0054**	-0.0017	0.0203***	0.0126***

Table reports coefficients from linear specification of transition functions for productivity and product quality with the inclusion of foreign tariffs. Significance: * 90%, ** 95%, *** 99%.

In Table 13, I report average marginal effects from the R&D policy function with the addition of the export tariff and time effects to control for possible changes in the cost of R&D investment.

Again, the import tariff continues to have a negative and significant effect, implying that competitive pressure through reductions in the import tariff spur greater innovative investments. Here, the effects of changes in the export tariff are of an order of magnitude smaller than those of changes in the import tariff and the export tariff is not significantly different from zero at standard confidence levels. This suggests that access to foreign markets may not be an important determinant of R&D investments for this group of firms. Additionally, that the import tariff continues to have a significant effect on R&D expenditures after the inclusion of time effects indicates that the impact of import tariff reductions is not driven by a lowering of the cost of R&D investment, and hence is likely the result of increases in competitive pressure, corroborating the main results above.

Table 13: The Determinants of R&D Investments

	$E[r\|\cdot]$	$E[r\|r>0,\cdot]$	$\Pr(r>0\|\cdot)$
k_{ij}	0.7352	0.6006	0.0728
ω_{ij}	0.4171	0.3407	0.0413
φ_{ij}	0.6779	0.5538	0.0672
τ_j^{im}	-0.0711	-0.0581	-0.0070
τ_j^{ex}	-0.0096	-0.0078	-0.0009
s_{-ij}^{ω}	0.9239	0.7547	0.0915
s_{-ij}^{φ}	-0.6315	-0.5158	-0.0626

Table reports average marginal effects from linear specification of the R&D policy function $h(\cdot)$ with the inclusion of foreign tariffs and time effects. All explanatory variables are significant at the 99% level with the exception of foreign tariffs, which are not significant at 90%.

5.5 Quantifying the effect of competition

What is the immediate effect of an increase in competitive pressure on firm-level performance? The baseline results imply that in response to a 1 percentage point reduction in the tariff, R&D expenditures for the average R&D performer increase by about 3.1%. Using the parameters from the transition functions, this increase in R&D investments should garner one-period growth in both product quality and productivity of only about 0.02%. Clearly, the response to competitive pressure operating through greater engagement in R&D has only a small incremental effect on performance, whether measured by productivity growth or improvements in product quality. From the transition functions, we see that the direct effect is an order of magnitude greater than the indirect. Through the direct channel, the same 1 percentage point reduction in the tariff spurs product quality growth of 0.23% and 0.32% for R&D performers and non-performers, respectively, and productivity growth of 0.6% and 0.24%.

These values are for the average firm only and the econometric specifications allow for a great deal of heterogeneity in outcomes underlying this average. For some firms, the indirect effect will carry more weight and the direct effect less. Some firms may come upon important new innovations through R&D investments that have large effects on product quality or productivity.

It would seem, however, that such breakthroughs are the exceptions rather than rule. The average marginal effect of R&D is fairly small. In reponse to competitive pressure, the vast majority of incremental performance improvements come via the transfer of new technology or ideas, or the beneficial impact on managerial incentives and worker practices, rather than through major new R&D-generated innovations.

These results are robust to additional possible effects of a trade liberalization. After explicitly controlling for associated changes in foreign tariffs and the cost of R&D investment in order to further isolate the "competitive" channel, a 1 percentage point reduction in the import tariff generates about a 5.8% increase in R&D expenditures among R&D performers. Using the new transition function estimates, this translates into a 0.05% increase in product quality and a 0.03% increase in productivity. In contrast, the direct channel spurs about a 0.4% increase in product quality and a 0.3% increase in productivity, again an order of magnitude greater than the indirect.

The relative importance of the direct channel is likely not limited to the specific sample of firms used here. For example, Hall, Mairesse and Mohnen (2009) survey a wide array of studies of the returns to R&D and report that the average study finds an elasticity of output with respect to R&D of about 0.08. In my setting, R&D-generated innovations increase output both through product quality improvements, enhancing the demand for the firm's product offering and through efficiency gains, reducing the firm's marginal costs and spurring increased output. Summing these effects gives an elasticity of output with respect to R&D of above 0.012, well in line with previous estimates, and indeed, slightly above the average. In this light, the importance of the direct channel is likely to be a more general result, rather than simply attributable to any lack of "R&D efficiency" in Spanish manufacturing firms. Moreover, the predominance of the direct channel is in line with the case-study evidence reviewed in Holmes and Schmitz (2010), who find that productivity improvements in response to competitive pressure come primarily through changing management and worker practices.

6 Conclusions

In this paper, I take a structural approach to empirically assess the impact of competition on innovative investments and achieved firm performance. I outline a structural model of strategic competition and innovation, explicitly incorporating the simultaneous effects of competitive pressure on investments in innovation and realized outcomes. I use the structural framework to infer both product quality and productive efficiency from firm-level performance data and measure their response to changes in the competitive environment, that is, to jointly assess the effect of competitive pressure on product and process innovation. Additionally, I use the model structure to distinguish and quantify the relative importance of various channels through which increased competition may spur improvements in firm performance. I estimate the model on a detailed panel of Spanish manufacturing firms during the 1990s and 2000s, when reductions in tariffs facing non-EU nations led to intensified competition for domestic firms.

I find that competitive pressure spurs greater investments in innovation and performance improvements. On average, a 1 percentage point reduction in the tariff induces a 3.8% increase in R&D expenditures and product quality and productivity gains ranging from 0.25% to 0.6%. The majority of these gains come through the direct effect of knowledge and technology diffusion or changing managerial incentives and worker practices, rather than indirectly through R&D-generated innovation. I show that these findings are robust to controlling for other potential effects of a trade liberalization and that the importance of the direct effect is likely not limited to my particular setting. Moreover, the notion that it is the direct effect of competition that stimulates performance gains rather than new innovations through R&D investments is consistent with existing case-study evidence of various industries and their response to competitive shocks.

In carefully assessing the effect of competition on innovation and realized performance in an explicit economic environment, my paper sheds renewed light on these relationships, and in particular, the relative importance of the potential channels for within-firm performance gains resulting from increased competitive intensity. My findings call for a better understanding of the transmission mechanism throuch which knowledge and technology are diffused throughout the economy. Moreover, if competitive pressure stimulates growth through changing managerial incentives and work practices, we run into the often-asked question of why these changes were not implemented prior to the period of intensified competition. With a better grasp of the microstructure underlying these channels, we can begin to consider the implications of policies meant to stimulate competition and innovative investments, their welfare effects, and their potential impact on economic growth and development.

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Table 14: The Evolution of Product Quality

	R&D Performers			Non-Performers		
	Coefficient	Standard Error	P-Value	Coefficient	Standard Error	P-Value
φ_{ij}	1.6873	(0.4586)	<0.01	0.7254	(0.0701)	<0.01
r_{ij}	0.3616	(0.1023)	<0.01			
τ_j	0.2998	(0.1517)	<0.01	-0.0702	(0.0149)	<0.01
s^{φ}_{-ij}	0.1307	(0.0486)	<0.01	-0.0228	(0.0051)	<0.01
$\varphi_{ij} \cdot \tau_j$	-0.0453	(0.0653)		0.0244	(0.0089)	
$\varphi_{ij} \cdot r_{ij}$	-0.0721	(0.0375)				
$\tau_j \cdot r_{ij}$	-0.0335	(0.0138)				
$\varphi_{ij} \cdot \tau_j \cdot r_{ij}$	0.0038	(0.0055)				
$s^{\varphi}_{-ij} \cdot \varphi_{ij}$	-0.0281	(0.0192)		0.0112	(0.0029)	
$s^{\varphi}_{-ij} \cdot r_{ij}$	-0.0147	(0.0043)				
$s^{\varphi}_{-ij} \cdot \tau_j$	-0.0125	(0.0062)		0.0028	(0.0006)	
$s^{\varphi}_{-ij} \cdot \varphi_{ij} \cdot \tau_j$	0.0018	(0.0027)		-0.0010	(0.0004)	
$s^{\varphi}_{-ij} \cdot \varphi_{ij} \cdot r_{ij}$	0.0029	(0.0016)				
$s^{\varphi}_{-ij} \cdot \tau_j \cdot r_{ij}$	0.0014	(0.0006)				
$s^{\varphi}_{-ij} \cdot \varphi_{ij} \cdot \tau_j \cdot r_{ij}$	-0.0002	(0.0002)				
N	8,841			16,317		
R^2	0.9639			0.9552		

Table reports all coefficients from the transition function for product quality $g(\cdot)$. P-values are from joint test of significance for all terms involving each explanatory variable.

Table 15: The Evolution of Productivity

	R&D Performers			Non-Performers		
	Coefficient	Standard Error	P-Value	Coefficient	Standard Error	P-Value
ω_{ij}	0.9098	(0.9498)	<0.01	0.2812	(0.1343)	<0.01
r_{ij}	0.0846	(0.0747)	0.0807			
τ_j	0.0835	(0.1335)	<0.01	0.0470	(0.0157)	<0.01
s^{ω}_{-ij}	0.0822	(0.0448)	<0.01	0.0305	(0.0060)	<0.01
$\omega_{ij}{\cdot}\tau_j$	0.0918	(0.1534)		0.0137	(0.0167)	
$\omega_{ij}{\cdot}r_{ij}$	-0.0523	(0.0731)				
$\tau_j{\cdot}r_{ij}$	-0.0026	(0.0112)				
$\omega_{ij}{\cdot}\tau_j{\cdot}r_{ij}$	-0.0066	(0.0128)				
$s^{\omega}_{-ij}{\cdot}\omega_{ij}$	-0.0007	(0.0454)		0.0307	(0.0065)	
$s^{\omega}_{-ij}{\cdot}r_{ij}$	-0.0039	(0.0036)				
$s^{\omega}_{-ij}{\cdot}\tau_j$	-0.0045	(0.0063)		-0.0024	(0.0008)	
$s^{\omega}_{-ij}{\cdot}\omega_{ij}{\cdot}\tau_j$	-0.0043	(0.0072)		-0.0007	(0.0008)	
$s^{\omega}_{-ij}{\cdot}\omega_{ij}{\cdot}r_{ij}$	0.0026	(0.0035)				
$s^{\omega}_{-ij}{\cdot}\tau_j{\cdot}r_{ij}$	0.0001	(0.0005)				
$s^{\omega}_{-ij}{\cdot}\omega_{ij}{\cdot}\tau_j{\cdot}r_{ij}$	0.0003	(0.0006)				
N	8,394			15,663		
R^2	0.7628			0.7881		

Table reports all coefficients from the transition function for productivity $f(\cdot)$. P-values are from joint test of significance for all terms involving each explanatory variable.

Table 16: The Determinants of R&D Investments

	Coefficient	Standard Error
k_{ij}	1.1726***	(0.1283)
ω_{ij}	0.6025***	(0.1805)
φ_{ij}	2.6870***	(0.1549)
τ_j	2.9340***	(0.4763)
s^{ω}_{-ij}	4.5705***	(0.1861)
s^{φ}_{-ij}	-2.3666***	(0.1781)
$\tau_j{\cdot}k_{ij}$	0.1526***	(0.0187)
$\tau_j{\cdot}\omega_{ij}$	0.0616**	(0.0255)
$\tau_j{\cdot}\varphi_{ij}$	-0.1322***	(0.0222)
$\tau_j{\cdot}s^{\omega}_{-ij}$	-0.4618***	(0.0296)
$\tau_j{\cdot}s^{\varphi}_{-ij}$	0.1854***	(0.0253)
N	28,213	
Pseudo R^2	0.1050	

Table reports Tobit coefficients from R&D policy function $h(\cdot)$. Significance: * 90%, ** 95%, *** 99%.

Table 17: The Evolution of Product Quality and Productivity

	φ'_{ij}		ω'_{ij}	
	R&D Performers	Non-performers	R&D Performers	Non-Performers
φ_{ij}/ω_{ij}	0.9832***	0.9907***	0.9025***	0.9071***
	(0.0025)	(0.0017)	(0.0059)	(0.0039)
r_{ij}	0.0095***		0.0051**	
	0.0020)		(0.0021)	
τ_j^{im}	-0.0040***	-0.0045***	-0.0033**	-0.0028**
	(0.0013)	(0.0009)	(0.0016)	(0.0011)
τ_j^{ex}	0.0052***	0.0035***	-0.0042***	-0.0009
	(0.0011)	(0.0008)	(0.0014)	(0.0010)
$s_{-ij}^{\varphi}/s_{-ij}^{\omega}$	-0.0054**	-0.0017	0.0203***	0.0126***
	(0.0025)	(0.0018)	(0.0037)	(0.0026)
N	8,841	16,317	8,394	15,663
R^2	0.9639	0.9551	0.7608	0.7859

Table reports coefficients from linear specification of transition functions for productivity and product quality with the inclusion of foreign tariffs. Standard errors in parentheses. Significance: * 90%, ** 95%, *** 99%.

Table 18: The Determinants of R&D Investments

	Coefficient	Standard Error
k_{ij}	2.0679***	(0.0729)
ω_{ij}	1.1732***	(0.1004)
φ_{ij}	1.9066***	(0.0874)
τ_j^{im}	-0.2001***	(0.0348)
τ_j^{ex}	-0.0269	(0.0291)
s_{-ij}^{ω}	2.5984***	(0.1109)
s_{-ij}^{φ}	-1.7761***	(0.0867)
N	28,213	
Pseudo R^2	0.1053	

Table reports Tobit coefficients from linear specification of the R&D policy function $h(\cdot)$ with the inclusion of foreign tariffs and time effects. Significance: * 90%, ** 95%, *** 99%.