Trade in Services and Innovation*

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Abstract

This paper studies how trade in services affects the innovation activities of firms through easing access to foreign ideas and technology. We assemble a new dataset containing detailed information regarding the trade in services, innovation and export activities of German firms and provide causal evidence that access to foreign innovation services increases firms' innovation activities, controlling and instrumenting for standard market size and competition effects of trade. Highly innovative firms are simultaneously firms with high import intensity of foreign innovation services and greater access to foreign markets via exports. Building on this observation, we argue that firm-level complementarities in selection into becoming an innovator, importing foreign innovation services, and exporting magnify the effect of changes in innovation service trade cost at the firm-level. We build a quantifiable model that is consistent with our reduced form findings and highlights the importance of complementarities in selection at the firm-level for the aggregate effects of trade on innovation.

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1 Introduction

International trade integration not only provides firms with greater access to foreign export markets but might also facilitate the spread of knowledge and technology across borders (IMF (2018)). While the effect of trade in goods on firms' innovation activities has received a considerable amount of attention, much less is known about how international trade affects innovation through facilitating access to foreign knowledge. In this paper, we use trade in innovation-related services as a direct measure of knowledge flows across countries and analyze their effect on firm-level innovation activity.

We assemble a new data set containing information on the international transactions of innovation services, innovation activities as well as exports of German firms. The exceptional level of detail in our data allows us to document and estimate the effects of international market integration on innovation activities that operate through facilitating access to foreign innovation services while accounting for traditional trade channels such as export market size and competition. To guide our empirical analysis, we build a new theoretical model of heterogeneous firms and innovation, trade in innovation services, and trade in goods.

We merge confidential firm-level data from the Deutsche Bundesbank and the ZEW – Leibniz Centre for European Economic Research. This allows us to jointly track firm-level imports and exports of innovation services - primarily in the form of R&D - as well as detailed information regarding their innovation and export activities. Beyond providing information on a firm's R&D and overall innovation expenditures, the data contains information on outcomes associated with innovation activity: reductions in unit cost, increases in product quality, and the sales accounted for by improved and new products.

After presenting our data, we begin by documenting salient empirical facts regarding the nature of firm-level innovation activities, trade in innovation services, and exports that guide and motivate our theoretical and empirical analysis. We document that few firms import innovation services. Conditional on doing so, these firms tend to import innovation services every year, which is consistent with imports being subject to both fixed and variable costs. Also, consistent with selection, innovation service importers display higher revenue to labor ratios, pay higher wages, and are more skill-intensive.

Our data indicate that innovation expenditures are a more comprehensive measure of innovation activity than R&D expenditures: R&D expenditures capture less than two-thirds of overall innovation-related expenses. This suggests that measures based on R&D miss a sizeable share of innovation activity. The data is consistent with selection into being an innovator. Further conditional on innovating once, most firms incur costs related to innovation activities every year. Variance decompositions of aggregate innovation activity further suggest that differences in innovation activity across similar firms are an essential driver of aggregate innovation outcomes. This motivates our focus on studying the determinants of within-industry differences in innovation outcomes across similar firms. Lastly, we document that there is suggestive evidence of selection complementarities between innovating, importing innovation services, and exporting.

To rationalize these reduced-form facts, we develop a model of heterogeneous firms, innovation, and trade in goods and innovation services.[1] In the model, firms devote resources separate from production to innovation activities, which are aimed to improve profitability. The model remains parsimonious as to whether innovation primarily affects demand (product innovation) or costs (process innovation). Incentives to innovate are (endogenously) shaped by profit margins (competition) and by the size of goods markets. Market size scales the benefits of innovation. The efficiency at which firms generate innovation outcomes increases through the integration of foreign innovation services, implying that access to foreign innovation output, through trade in innovation services, allows some firms to gain a competitive advantage in innovation efficiency. Our model of innovation service imports adopts the model developed in Halpern *et al.* (2015) to our context. Fixed costs to importing foreign innovation services imply that high innovation expenditures, better innovation outcomes, and higher import intensities in foreign innovation services are joint outcomes in the model. Further, our model predicts that access to foreign export markets increases a firm's innovation expenditures.

To test the core prediction of the model, we investigate the causal effect of heterogeneity in exposure to foreign markets and competition on innovation activities across firms. To account for the joint selection and resulting reverse causality between exporting, importing and innovation, we construct novel firm-level instruments using a shift-share design (Bartik (1991)) familiar from the international trade and labor literature (Garin & Silvero (2018); Lileeva & Trefler (2010)). We leverage intra-industry heterogeneity in firm exposure to international demand and supply shocks to identify the relative effects of access to foreign innovation services, market size, and competition on relative innovation activities of German firms within the same industry.

Our estimates confirm the key predictions of our model and give first direct evidence on the impact of trade in innovation services on firms' incentives to innovate. We find that firms with relatively better access to foreign innovation services undertake more

[1] The model is designed to speak directly to the data and is therefore closer to the oligopolistic innovation literature in industrial organization (Spencer & Brander (1983), Bloom *et al.* (2013)) than to the literature on trade, innovation and growth (e.g. Grossman & Helpman (1991)).

substantial innovation efforts, as measured by both overall innovation spending and total R&D spending. We also find that firms with relatively higher exposure to foreign supply shocks to innovation services achieve better innovation outcomes across all our measures relating to product and process innovation. As our core theoretical mechanism postulates that foreign innovation services improve the efficiency at which firms innovate, we interpret these findings as lending direct empirical support to the central predictions of our theoretical framework.

The results further indicate that firms' incentives to undertake costly innovation activities are positively affected by market size. We find that relatively larger exposure to foreign export markets incentivizes firms to spend more resources on both overall innovation activity and R&D. We find that these efforts translate into better product innovation outcomes - as measured by the revenue generated by new and significantly improved products. However, we cannot detect any statistically significant effects of foreign demand on the incentives to innovate on processes. Our results therefore confirm the positive effect of exports on firms' incentives to innovate documented found in recent studies (Lim *et al.* (2018), Aghion *et al.* (2018), Steinwender (2015)). However, our results indicate that the effects might differ across process and product innovation, as hypothesized in Dhingra (2013).

Our results shed new light on the effects of competition on firm-level innovation incentives. We find that higher competition in product markets disincentivizes firms from innovating, as measured by overall innovation expenditures. This effect is primarily driven by the fact that firms are disincentivized to innovate on production processes. This finding is consistent with the critical mechanism of our model, where innovation incentives, in part, depend on the elasticity of firms' profit margins with respect to unit cost. In the model, higher levels of competition may reduce the capacity of firms to achieve higher profit margins by increasing their market share. However, we also find that higher levels of competition increase firms' incentives to invest in R&D and product innovation. This is consistent with recent findings by Fieler & Harrison (2018), who argue that firms may aim to escape higher levels of competition by introducing new products.

Finally, we go back to our model to show that the aggregate effects of trade on a country's overall innovation activity depend on the micro-structure of the economy - in particular on selection complementarities at the firm-level. To emphasize this point, theoretically, we characterize the elasticity of firm-level innovation activities with respect to various trade shocks. The results show that the following sufficient statistics determine how firms' innovation incentives respond to change in trade costs: Initial shares in all final goods markets that firms serve, initial output levels across all markets, initial innovation expenditures as well as initial import intensities of foreign innovation services. This result highlights the interplay between complementarities in selection into innovating, importing innovation services and exporting, and the aggregate effects of trade on innovation. Due to selection complementarities, a moderate decrease in trade costs for innovation-related services might have a sizeable effect on aggregate innovation activity.

For example, the effect of an import trade cost shock will not only depend on a firm's competitiveness in the domestic markets, but also on the size and profit margins that it attains in other markets. If most innovators are also exporters, then the effects of import competition may be alleviated by the fact that these firms serve many markets. Similarly, a firm's ability to take advantage of supply shocks to foreign innovation services depends on the profit margins and size that a firm can achieve across all the markets that it serves. The effect of falling trade cost in innovation services on aggregate innovation activity will thus be amplified if the most profitable firms serve many markets and are the largest innovation service importers. As the data strongly suggest such complementarities in selection, falling trade costs in services might, therefore, have sizeable effects on aggregate innovation activity.

In our final result, we show that the size by which selection complementarities amplify or dampen the effect of trade shocks at the firm-level can be empirically measured through OLS regressions of trade cost shocks on firm-level innovation expenditures. The core implication of this finding is that important, yet unobserved, theoretical margins can be empirically measured. The framework thus bears the potential to provide quantitative insights into the aggregate effects of trade on innovation that operate through trade in innovation services.

Literature Our study is related to a large and growing literature on the inter-linkages of trade and innovation, and in particular, to Steinwender (2015), Aghion *et al.* (2018), Fieler & Harrison (2018) and Lim *et al.* (2018), all of which study the effect of trade in goods on firm-level innovation activity. Shu & Steinwender (2019) provide a comprehensive overview of the empirical literature, which the interested reader is referred to. Relative to the existing empirical literature, we make two contributions. Firstly, we provide the first causal evidence on the impact of trade in services on firm-level innovation activity. Further, we investigate innovation activities from many angles, thanks to the comprehensive nature of our data.

While previous work has mostly considered market size and competition to operate in isolation, our findings suggest that aggregate effects crucially depend on the interaction of all channels and, in particular, the joint processes that underlie selection into innovating, exporting, and market size. Our results indicate that the potentially detrimental effects of import competition depend on the extent to which the most innovative firms are simultaneously large exporters. Taking into account the role of selection complementarities, we provide a new perspective on ambiguous findings regarding the relationship between innovation and import competition in the literature. Accounting for the role of these micro-level channels for the aggregate impact of trade on innovation is a key contribution of this paper.

Our paper further relates to a small but growing literature on the effect of trade in services on aggregate and firm-level outcomes. As data and reliable measurement of firm-level trade in services have only recently become available, previous studies are mainly concerned with establishing empirical and conceptual differences between trade in goods and trade in services (e.g.,Breinlich & Criscuolo (2011), Ariu (2016), Ariu *et al.* (2017), Eaton & Kortum (2018)). Few, in contrast, have related changes in trade cost in services to aggregate outcomes. Two exceptions are Eckert (2019) and Eckert *et al.* (2019), who argue that changes in trade costs of business services are key to understanding the geographic variation of changes in the skill premium across the US. Relative to this literature, we are the first to study the effect of trade in innovation-related services on innovation activity.

2 Trade in Services

2.1 Measurement

According to the General Agreement on Trade in Services, services trades are classified across four modes:

1. Mode 1 corresponds to classical cross-border supply – a service is provided from the member of territory A to a member of territory B across borders. A French firm based in France providing innovation services for a German firm based in Germany would constitute such an instance.

2. Mode 2 resembles service consumption abroad – a service is provided from the member of territory A to the member of territory B within territory A. An example for such a case would be a French firm based in France providing innovation services to a subsidiary of a German firm located in France would.

3. Mode 3 - commercial presence - captures if a service is provided from the member of territory A to the member of territory B within territory A, for instance, the subsidiary of a French firm providing innovation services to a German firm within Germany.

4. Mode 4 corresponds to services provided through individual persons – a service is provided by a person living in territory A to a firm or person located in territory B. For example a French freelance engineer traveling to Germany to provide innovation services to German firms.

Within these Modes, Modes 1, 2 and 4 are captured by the official trade in service statistics as aggregate. Thus, it is not possible to distinguish between them. Mode 3 is part of the statistics on firms' multinational activities and FDI.1 While the data does not allow for further disentanglement, estimates for the US suggest that the vast majority of service trade happens through mode 1 and 3.

2.1.1 An Example of Trade and Barriers to Trade in Innovation Services

Major barriers to trade in innovation services include communication costs that affect the ease at which findings can be shared across distant locations as well as international copyright laws. All information in this section is based on publicly available information, found here and here.

Fast and sizable improvements on a global scale over several decades have vastly improved firms' capabilities to engage in service trade. File sharing and cloud storage services have become easily accessible, with many companies implementing professional business solutions and heightening their security and privacy standards. Further, all members of the WTO have committed to ensuring minimum standards of international copyright protection that do not discriminate against foreign inventors. We give two concrete examples of firms that engage in international R&D services trade.

Founded in 2007, WuXi Apptec is a global pharmaceutical company with headquarters in Shanghai.[2] WuXi provides services to customers primarily in the life science industries, offering R&D and testing of therapeutics, for instance, in small molecule, biologicals, or genomics. It is located in China, the US, and Germany and provides research services to over 3000 customers across 30 countries. In part, this reflects China's continued efforts to strengthen its IP protection – a process that started mainly with its accession into the WTO in 2001. The General Provisions of the Civil Law was, for instance, adopted in 2017 and ensures that trade secrets are protected under civil IP law and many preferential policies favoring Chinese IP development are wound back to not discriminate against foreign IP.

However, IP protection still is far from perfect, and despite the developments in communication technologies, it still poses a significant barrier to trade in services. An

[2] All information on WuXi is taken from its public Wikipedia page.

example in which the differences in IP right enforcement and the associated counterparty risk still impose significant trade cost to R&D services is the German roller coaster manufacturer Gerstlauer. The manufacturer has been expanding in heavily China. However, it never shares research-manufacturing plans digitally with potential clients; instead, a firm representative travels to China to present physical copies.[3]

2.1.2 Aggregate Trends in Trade in Services

Trade in services has increased sizeably over the last decades. We use the World Bank's Trade in Services Database to construct aggregate statistics on world imports of R&D related services. Figure A.1 shows that international flows in R&D services have increased and nearly five-fold between 2000 and 2011. Further, world trade in R&D is outgrowing the overall trade in services. The share of R&D imports in total service imports has increased from one to three percent in the same period.

2.2 Firm Level Data from Germany

We merge three confidential firm-level data sets. In total, our sample contains around 7,200 firms and 18,000 firm-year observations, covering firms active in manufacturing industries between the years 2002 and 2011.

Firm-level service imports The Statistics on International Trade in Services (SITS)[4] database, described in great detail in Biewen & Lohner (2017), provides information on the service transactions of German firms. Access to the data is provided through the Research and Data and Service Centre (RDSC) of the Deutsche Bundesbank. The database is used to compile Germany's Balance of Payments Statistics, and thus, each firm must report all service transactions whose joint volume exceeds the amount of 12,500 Euro for a given month, country, and service type. The data, therefore, practically includes all service trades of German firms. For our analysis, we extract the yearly values of firms' reported service transactions classified according to its service type, its direction, and the involved foreign country. In total, we label four types of service imports as innovation-related: (i) R&D, (ii) patents, licenses, and innovations, (iii) artistic copyrights, and (iv) other rights (such as franchises, trademarks, and marketing rights). R&D accounts for the bulk of these transactions and is the main focus of our analysis.

[3] See this article for more details.
[4] DOI: 10.12757/Bbk.SITS.0116.01.01.

Innovation Data The Mannheim Innovation Panel (MIP)[5] is gathered in the form of yearly surveys by the ZEW – Leibniz Centre for European Economic Research and constitutes the German contribution to the European Commission's Community Innovation Survey. The MIP is our primary source of information on firms' innovation activities and other firm-level outcomes, such as employment, goods exports, and internal R&D activities.

The data contain information on firms' expenditures on innovation activities broadly and on R&D in particular. Moreover, it contains data about the introduction of new products, services, and processes and their success. Firms declare whether their innovation activities yielded new or improved products or services, as well as the revenue share that these account for. The data allows us to distinguish further the revenue share of products that are (i) new to the firm, (ii) new to the firm and the market, and (iii) new to the firm without a predecessor product. Related to process innovation, firms state whether they introduced new or significantly improved processes and by how much these process innovations reduced unit costs and raise revenues by improving product quality.

Further, the MIP contains data on other firm characteristics, such as revenues, the volume of exports, total employment, wages, intermediate inputs and internal R&D activities.

Multinational Activity For information on FDI activity in Germany, we access the Microdatabase Direct Investment (MiDi),[6] described in detail in Schild & Walter (2017),[7] which contains information on all inward and outward FDI stock relations that German companies are involved in and considered as economically relevant for aggregate FDI statistics. Access to the data is provided by the Research and Data Services Centre (RSDC) of the Deutsche Bundesbank. A common concern in the trade in services literature is the phenomenon of profit shifting where firms use non-tangible transactions between subsidiaries in different countries to shift taxable income. Thus, to tackle this concern, we use the information stemming from the MiDi to control if a firm in our sample is part of such a connection and can be considered a multinational firm.

Merging The merging of the Mannheim Innovation Panel (MIP) with the Trade in Services Statistics (SITS) and the Microdatabase Direct Investment (MiDi) took place

[5] For more information, please see here: https://www.zew.de/en/forschung/mannheim-innovation-panel-innovation-activities-of-german-enterprises/

[6] DOI: 10.12757/Bbk.MiDi.9915.03.04

[7] The data report can be found here.

at the Research and Data Service Centre (RDSC) of the Deutsche Bundesbank and relied on the mapping tables described in Schild *et al.* (2017).[8]

3 New Facts on Firm-level Innovation and Trade in Innovation Services

In this section, we present descriptive facts that motivate our approach in the following theoretical and empirical analysis.

3.1 Firm-level innovation activities

Innovation Inputs Sixty-four percent of firms in our sample are innovators, which we define as firms that have strictly positive innovation expenditures. Table A.2 shows that innovative firms are larger both in terms of revenues and employment, with the average firm spending a total of 4.7 EUR million or around 4 percent of total revenues on innovation activities.

Innovation expenditures are a broader measure of innovation activity than R&D expenditure. Table A.2 hows that R&D expenditures on average account for about two-thirds of total innovation expenditures. Further, only 82 percent of firms that innovate conduct continuous R&D. Average R&D imports of firms with positive innovation expenditures equal 227.000 Euro, which corresponds to 5 percent of average total innovation expenditures.

Innovation Outcomes Our data is indicative of sizeable differences in both the objectives and outcome measures of innovation activities. While innovative efforts in general aim to improve a firm's profitability, a firm may target either product innovation – the development of new or the improvement of existing products and services - or process innovation – which affects the unit cost of production or the quality of its products and services.

Table A.2 indicates that 74 percent of innovating firms target product innovation. However, our data shows that the average revenue share of new product varieties only amounts to 11 percent, while 20 percent of revenues occur through adopted products. In line with this empirical regularity, the baseline version of our theoretical framework solely models product innovation that improves existing varieties.[9]

[8] The technical report is available here.

[9] However, our analysis readily extends to the case where innovation may take the form of adding new varieties to the extensive margin.

TABLE 3.1 VARIANCE DECOMPOSITION OF SAMPLE INNOVATION ACTIVITY

		Decomposition
Share of Variation Between Sectors	$\frac{\text{VAR}(\hat{\alpha}_{s,t})}{\text{VAR}(IE_{f,t})}$	1.5
Share of Variation Within Sectors	$1-\frac{\text{VAR}(\hat{\alpha}_{s,t})}{\text{VAR}(IE_{f,t})}$	98.5

Notes: This table presents a decomposition of the overall sample variance in logged innovation expenditures. Source: Mannheim Innovation Panel (MIP), 2002-2011, own calculations.

Conditional on being an innovator, about 50 percent of firms target process innovation. We observe that the average reduction in unit cost amounts to 3 percent, while the average revenue increase resulting from quality improvements equals 2.8 percent.

Aggregate relevance How important are firm-level differences in innovation activities for the aggregate, in particular, relative to differences in innovation spending across sectors? To answer this question, we provide a decomposition of the aggregate variation in innovation expenditures into a between-sector and a within-sector component. To do so, we regress innovation expenditures, IE, on a set of industry-year fixed effects α:

$$IE_{f,t} = \alpha_{s,t} + \varepsilon_{f,t}, \tag{3.1}$$

where f denotes firms, t denotes years and $\varepsilon_{f,t}$ is an error term. The total variance of innovation expenditures decomposes as follows:

$$\text{VAR}\left(IE_{f,t}\right) = \underbrace{\text{VAR}\left(\alpha_{s,t}\right)}_{\text{BETWEEN SECTORS}} + \underbrace{\text{VAR}\left(\varepsilon_{f,t}\right) + 2\text{COVAR}\left(\alpha_{s,t}, \varepsilon_{f,t}\right)}_{\text{Within Sectors}}. \tag{3.2}$$

We estimate the fixed effects 3.1 and decompose the sample variance in innovation expenditures according to equation (3.2) Table 3.1 displays the results and shows that the lion share of the overall sample variation in innovation expenditures stems from within-industry rather than between-industry heterogeneity in innovation activities.

3.2 Trade in Innovation Services

3.2.1 Few firms import foreign innovation services

As pointed out for other types of services and other countries (Ariu *et al.* (2017); Breinlich & Criscuolo (2011)), trade in innovation services is similar to trade in goods in that only few firms engage in this activity. Table A.1 displays the composition of firms in our sample. In total, 3 percent of manufacturing firms in our sample import foreign R&D.

3.2.2 Foreign Innovation Services are a Variable Input into Innovation Generation

Importing foreign R&D services does not constitute a one-time event for an individual firm. In our sample, an average of 69 percent of firms that import foreign R&D services in one year will import R&D services also in the next year. For comparison, an average of 88 percent of firms that export in one year will also export in the following year. Consistent with this fact, we model foreign R&D services as a variable input in the production of innovation outcomes.[10]

3.2.3 Innovation Service Imports and Innovation

Importers of innovation services are significantly more active as innovators than the average firm. As shown in Table A.2, R&D service importers outspend the average innovating firm by a factor of five on both total innovation and R&D expenditure. Further, R&D service importers also outspend the average multinational firm by a factor of two on both margins.

These expenditures translate into better innovation outcomes. Table A.2 shows that revenues accounted for by new products equal 23 percent for importers of R&D services, relative to 20 percent across the whole sample of innovators, while the revenue shares accounted for by new products accounts for 14 percent relative to 11 percent for the whole sample.

3.2.4 Selection into Importing R&D services

We assess the conditional correlation between R&D service imports and a simple empirical measure of firm productivity. To do so, we regress firm $f's$ importer status of foreign innovation services in year t $\left(1^{\mathrm{IMP}}_{f,t}\right)$ on its empirical revenue labor productivity $\left(\mathrm{RLP}_{f,t}\right)$, which we measure by the ratio of total revenues to total employment. We

[10] As highlighted in the later analysis, the results are qualitatively robust to this assumption.

control for the share of workers holding a university degree as a measure of skill intensity, its location (East or West Germany) as well as sector-year fixed effects $\left(\alpha_{s(f),t}\right)$:

$$1^{\text{IMP}}_{f,t} = \alpha_{s(f),t} + \beta \text{RLP}_{f,t} + \gamma' \text{Controls}_{f,t} + \epsilon_{f,t}. \tag{3.3}$$

Table A.3 displays the results and shows that, consistent with selection into service trade, importers of innovation services have higher measured labor revenue productivity and are more skill-intensive. For reference, the remaining columns of Table A.3 display the results of estimating equation (3.3) with exporter and innovator status as dependent variable.

We interpret the correlations between a firm's labor revenue productivity and its R&D services importer status as being consistent with firms selecting based on unobserved productivity differences into importing foreign R&D services. Selection is the central mechanism in much of the modern heterogeneous firm literature on trade in goods through which the effects of international trade materialize, and our model of R&D service imports will inherit qualitatively similar features.[11]

3.3 Complementarities in Selection

Table A.4 displays the joint distribution of firms across their observed trade status. Fifty-four percent of firms that import foreign R&D services are multinationals. Further, 70 percent of firms that import foreign R&D services also export their products to foreign markets. Taken together with the previous facts, we argue that this pattern is consistent with a model where underlying productivity differences across firms drive selection into export, innovation, and import activities.

4 A Model of Foreign Knowledge Imports, Trade and Innovation

We develop a model of trade in goods, R&D services, and innovation in the context of oligopolistic competition in product markets, firm heterogeneity in productivity and selection into exporting, importing R&D, and innovation. The purpose of the model is to understand in which way changes in trade cost of goods and services shape the incentives of firms to undertake costly innovation.

[11] While Bernard & Jensen (1995) were the first to empirically document the importance of firm heterogeneity and selection into trade, Melitz (2003) laid the the foundation for most of the subsequent theoretical literature.

4.1 Model Overview

Single-product firms in a home market H - Germany in the application - are associated with an industry s and have the option to purchase external knowledge as an input to their innovation activities and to sell products on domestic and foreign markets, which we denote by m. The model is not dynamic. However, to capture the forward-looking nature of innovation activities, we model events across three stages.

In the first stage, firms randomly draw a multi-dimensional vector $\Theta \in \mathbb{R}^n_+$ from a cumulative distribution function $G(\Theta)$. Θ captures exogenous differences in production efficiency, innovation capacity, product appeal, and fixed cost.[12] Consistent with the suggestive evidence of selection, firms have fixed cost to selling products in foreign or domestic markets as well as to innovating at later stages. Firms make their optimal choice by maximizing their expected profits while anticipating outcomes of the upcoming two stages.

In the second stage, firms choose their innovation efforts and sourcing strategies for foreign innovation services. We assume that innovation efforts do not materialize immediately, but firms foresee their outcome in the third and final stage. This assumption yields the critical optimality condition that relates firms' incentives to innovate to all relevant channels in our model. As we focus on single product firms, our model does not capture product innovation in the form of adding new products. However, the model readily extends to this case without changing the qualitative results.

Finally, in the last stage, the chosen innovation efforts materialize, and firms compete oligopolistically in the product markets that they chose to enter in the initial stage.

The model, therefore, constitutes a game across three periods. We proceed by describing and simultaneously solving the game through backward induction, starting with describing the structure of demand and final good competition in the third stage.

4.2 Demand and Competition in Goods Markets

To characterize the outcome of product market competition in the final stage, and we drop subscripts for industries s and individual markets m. We describe the equilibrium in a given market and industry where a total of N firms, domestic firms that have selected into selling in this market as well as other foreign firms, are active. Individual firms are denoted by $f \in \{1, ..., N\}$.

Following Amiti *et al.* (2018), we impose assumptions on demand that imply that a

[12] While the correlation between draws on those dimensions is key to governing equilibrium patterns of joint selection, none of our results depend on its dimensionality. For most of the paper, it is easiest to think of Θ_i as a standard one-dimensional productivity parameter.

firm's market share is a sufficient statistic for the demand price elasticity it faces. In particular, we assume that demand is given by an invertible, homothetic demand system that can be written as $q_f \equiv \log Q_i = q\left(\mathbf{p_f}, \xi_f, \mathcal{A}\right)$, where $\mathbf{p}_f \equiv \left(p_f; \mathbf{p}_{-f}\right)$ is the vector of prices of firm f and all other $N-1$ firms active in the same market, and $\boldsymbol{\xi}_f \equiv \left(\xi_f, \boldsymbol{\xi}_{-f}\right)$ is a vector of non-price firm characteristics affecting demand.[13] $\mathcal{A}$ is a vector of aggregate demand shifters that is exogenous from the perspective of active firms.

We characterize the equilibrium in product markets under full-information simultaneous-move price-setting without any restrictions on the nature of competition, which might be monopolistically competitive or oligopolistic competition in prices or quantities. We restate the key properties of the product market equilibrium in this set-up derived by Amiti *et al.* (2018) in the following proposition.

Proposition 1 (Amiti *et al.* (2018)) *Assume that sectoral log expenditures z are a sufficient statistic for firm's perceived demand elasticities, $\sigma_f \equiv \frac{dq_f}{dp_f} = \sigma\left(p_f - z, \boldsymbol{\xi}_f\right)$. Then under any competition structure, the equilibrium price of firm f is a mark-up over marginal cost MC_f and solves the following fixed point:*

$$p_f = \log\left(\frac{\sigma_f}{\sigma_f - 1}\right) + \log MC_f. \tag{4.1}$$

Further, changes in market shares $S_f \equiv \frac{P_f Q_f}{\sum_{k=1}^{N} P_k Q_k}$ are a sufficient statistic for equilibrium changes in mark-ups:

$$d\log\left(\frac{\sigma_f}{\sigma_f - 1}\right) = \Omega\left(S_f\right) d\log S_f. \tag{4.2}$$

In equilibrium, marginal cost depend on the innovation effort that a firm has undertaken at the second stages of the game. Under the assumption that the log expenditure function summarizes all necessary information contained in competitor prices, Proposition 1 implies that market shares are a sufficient statistic for the level as well as for changes in firms' mark-ups.[14] Mark-ups, in turn, govern how profit margins shape innovation incentives: If high market-shares imply high mark-ups and, therefore profit margins, then firms will be more willing to undertake costly innovation activities that improve their competitiveness, market shares and thus profit margins.

In summary, the characterization of the final goods market competition nests many existing frameworks, and in particular, Atkeson & Burstein (2008). Hence, the results

[13] All results extend straightforwardly to the case where ξ_f is a function of firm innovation effort.

[14] This assumption holds exactly for the nested-CES demand structure commonly used in models of oligopolistic competition (in particular Atkeson & Burstein (2008)), but also more broadly to a first order for Kimball Kimball (1995) demand or the broad homothetic family of demand considered in Matsuyama & Ushchev (2017).

derived in the upcoming sections apply to a broad set of models that study the implications of market power and imperfect competition in product markets.

4.3 Innovation Decision and Import of Foreign Innovation Services

In the second stage, firms have incurred fixed costs to serve markets and to set up their capacity to innovate. Firms that did not choose to set up innovative capacity move on to the next stage. All other firms simultaneously choose the optimal amount of innovation x_f *non-strategically and without spillovers*. Firms also choose their sourcing strategy for foreign innovation services, which affects the cost of innovation $\Gamma_f(x)$. Firms foresee the outcome of the product market competition in the final period. Therefore, a firm with access to a set of markets $\mathcal{M}_f$, and unit cost of serving market m given by $C_{m,f}$ chooses innovation intensity x to maximize profits according to:[15]

$$\Pi\left(x_f;\Theta_f\right) = \sum_{m\in\mathcal{M}_i}\left\{P_{m,f}Q_{m,f}\left(x_f,\Theta_f\right) - C_{m,f}\left(x_f;\theta_f\right)Q_{m,f}\left(x_f;\Theta_f\right)\right\} - \Gamma_f\left(x_f,\theta_f\right), \tag{4.3}$$

subject to the outcome of the product market game summarized by the optimal pricing decision in equation (4.1). Note that innovation might affect both product demand and the unit cost of production. We assume that production functions are constant returns to scale for any given innovation effort x.

ASSUMPTION 1 1. *Production functions are constant returns to scale for any level of innovation effort x.*

2. *Product demand is weakly increasing and concave, while unit cost are weakly decreasing and concave in innovation effort x.*

We further assume that shipping goods to market m is subject to iceberg trade cost, which are denoted by $\tau_m \geq 1$. Assumption 1 implies that the unit cost $C_{m,f}$ of producing a unit of output for market m equal marginal cost, adjusted for trade cost: $C_{m,f} = MC_{m.f} = \tau_m C_f$. By the envelope theorem, the optimal amount of innovation effort x_f solves the following first-order condition:

$$\sum_{m\in\mathcal{M}_f}\left(\frac{1}{\sigma_{m,f}-1}\right)C_{m,f}\frac{\partial Q_{m,f}}{\partial x_f} - \frac{\partial C_m}{\partial x_f}Q_f = \frac{\partial\Gamma_f(x_f,\Theta_f)}{\partial x_f}, \tag{4.4}$$

where $Q_f \equiv \sum_{f\in M_f}\tau_f Q_{m,f}$ denotes total production of firm. f.

[15] For our purpose, it is inconsequential whether innovation yields certain or probabilistic outcomes, so long as firms hold common expectations about the effects of innovation. We, therefore, characterize the full information case.

It is worth pausing to discuss how this simple condition relates to the channels affecting firms' incentives to innovate. Focusing on the first term, we observe that both high unit costs C_f and profit margins $\frac{1}{\sigma_{mf}-1}$ will *ceteris paribus* give rise to larger innovation spending. The second term, on the other hand, summarizes the returns to process innovation. The returns to process innovation - summarized in the reduction in unit cost $\frac{\partial C_{m,f}}{\partial x_f}$ - are scaled by a firms' total output Q_m. Lastly, the impact of foreign innovation services on innovation materializes through the marginal cost of innovation, which is firm-specific and depends on the sourcing strategy of foreign R&D, which firms choose simultaneously with their innovation intensity. As we will show next, lower trade cost in services reduce the marginal cost of innovating, and by more so for firms with higher import intensities.

Production of Innovation and Innovation Cost Firms produce innovation x by combining factors F, and intermediate inputs M according to a Cobb-Douglas production function:

$$x_f = \chi\left(\Theta_f\right) M^{\phi} F^{m}{}_{f}^{1-\phi}. \tag{4.5}$$

$\chi\left(\Theta_f\right)$ governs firm heterogeneity in innovation efficiency. The factor F can be purchased at a common, exogenous price W.

We model foreign sourcing decisions by generalizing the setup in Halpern *et al.* (2015) to many potential sourcing countries. Intermediate inputs in innovation production consist of a bundle of innovation services indexed by $j \in [0,1]$- for example, basic research or product testing - and are aggregated according to Cobb-Douglas technology:

$$M_f = \exp\left\{\int_0^1 \alpha_j \log X_{f,j} dj\right\}. \tag{4.6}$$

The types of innovation services vary in their importance, measured by a weight α_j, where $\int_0^1 \alpha_j dj = 1$.

Each innovation service can be either produced at home or imported from market $m \in \mathcal{M}$. Home and foreign innovation inputs are combined to yield an innovation service input through to the following CES aggregator:

$$X_{f,j} = \left[Z_{f,j}^{\frac{\zeta}{1+\zeta}} + \sum_{m \in \mathcal{M}} a_{j,m}^{\frac{1}{1+\zeta}} M_{f,j,m}^{\frac{\zeta}{1+\zeta}} \right]^{\frac{1+\zeta}{\zeta}}, \tag{4.7}$$

where $Z_{f,j}$ and $M_{f,j,m}$ respectively denote the quantities of domestic and imported varieties from source country m. $a_{j,m}$ is a measure of technological advantage that foreign services may have over domestic ones. Note that the CES aggregation implies that the firm does not need to use foreign intermediates. However, because of the love-for- variety property of the CES as well as potential technological advantages $a_{m,f}$, the inclusion of foreign innovation services can be advantageous in terms of innovation output.

Firms pay fixed cost f_m in units of the domestic aggregate factor of production for each foreign innovation input that they wish to import from country m. Also, firms pay variable trade cost $\tau_m^{R\&D}$ on top of the foreign price $U_{j,m}$. The domestic price of innovation activity j is denoted by V_j.

To derive innovation cost, we assume that firms have chosen the set of varieties that they wish to import, $J_f = \left\{j \in [0,1], m \in \mathcal{M} : M_{f,j,m} > 0\right\}$, and are left with choosing the quantities $M^*_{f,j,m}$,$Z^*_{f,j}$ and F^*_f. The total cost of generating innovation, evaluated at optimal quantities denoted by asterisks, are then given by:

$$\Gamma(x_f|J^*_f) = WF^* + \int_0^1 V_f Z^*_f dj + \sum_{m\in M} \int_{J^*_f} \left(\tau_m^{R\&D} U_{j,m} M^*_{f,j,m} + W f_m\right) dj. \tag{4.8}$$

In Appendix B.1, we show that the variable part of total innovation cost, conditional on a set of imported varieties J^*_f is given by:

$$\Gamma(x_f|J^*_f) = \frac{C}{B_f^{\phi} \chi\left(\Theta_f\right)} x_f, \tag{4.9}$$

C is a cost-index for firms that do not import innovation services as part of their innovation activities.[16] B_f is a cost-reduction factor that summarizes how foreign innovation services improve the efficiency at which a firm produces innovation activities: $B_f = B\left(J_f\right) = \exp\left\{\int_{J_f} \alpha_j \log b_j\left(J_m\right) dj\right\}$ where $b_j\left(J_m\right) \equiv \left[1 + \sum_{\{j,m\}\in J_f} a_{j,m} \left(\tau_m^{R\&D} U_{j,m}/V_j\right)^{-\zeta}\right]^{1/\zeta}$. Thus, importing foreign technology services affects the *efficiency* at which firms produce innovation output though the term B_f. Within the model, gains from trade in services arise as they allow domestic firms to achieve innovation outcomes at lower cost.

One main goal of our model is to characterize the determinants that govern heterogeneity in innovation responses to a change in the trade cost of foreign innovation services across firms. The import intensity in foreign innovation services from country m, defined as the share of expenditures on innovation services from country m in total

[16] This index is given by: $C = \left(\frac{U}{\phi}\right)^{\phi} \left(\frac{W}{1-\phi}\right)^{1-\phi}$ with $U \equiv \int_0^1 \alpha_j \log\left(\frac{U_j}{\alpha_j}\right) dj$.

variable cost of innovation, is a key statistic for this purpose and defined as follows:

$$\varphi_{f,m} \equiv \frac{\int_J \tau_m U_{j,m} M^*_{f,j,m} dj}{\Gamma(x, J_f)} = \phi \int_0^{J_f} \alpha_j a_{j,m} \left(\tau_m^{R\&D} U_j / V_{j,m}\right)^{-\zeta} dj. \tag{4.10}$$

The following proposition relates overall import shares of foreign innovation services to the variable and marginal cost of innovation. Further, it shows that $\varphi_{i,l}$ is a sufficient firm-level statistic to characterize changes in the marginal costs of innovation due to changes in trade costs in services, $\tau_m^{R\&D}$.

Proposition 2 *(i) Within sectors firms with larger total innovation expenditures have a larger overall import intensity* $\varphi_f \equiv \sum_m \varphi_{f,m}$. *(ii) The partial elasticity of marginal innovation cost with respect changes in the variable trade cost of foreign innovation services* $\tau_m^{R\&D}$ *equals* $\frac{\partial \log \Gamma'(x_f|J_f^*)}{\partial \log \tau_m^{R\&D}} = \varphi_{f,m}$ *if the set of imported varieties is fixed and* $\frac{\partial \log \Gamma'(x_f)}{\partial \log \tau^{R\&D}} = \kappa\varphi_{f,m}$ *to a first order if the set of imported varieties adjusts as well.* κ *is a constant specified in the appendix.*

Proof. See Appendix B.1. ■

Proposition 2 highlights that the model provides a direct link between the import intensity of foreign innovation services, changes in service trade costs and firm-level innovation efforts: From (ii), we know that the elasticity of marginal innovation cost with respect to the costs of service trade is increasing in a firm's exposure to imported innovation services. Changes in trade costs, thus, have a larger effect on the total innovation costs of firms with higher import shares. Moreover, from (i), we also know that firms with higher import intensities also have larger total innovation expenditure. Therefore, reductions to trade cost in services, for instance, pose disproportional high benefits for firms with larger total innovation expenditure.[17]

4.4 Selection and Entry

In the first stage, an exogenous number of firms M each choose which subset $\mathcal{M}_f$ of the markets $\{H, \mathcal{M}\}$ to enter and whether or not to build the capacity to innovate, 1_I. The associated fixed costs, F_H^E, F_m^E and F^I, respectively, are produced by an aggregate factor with price normalized to 1. Firms also choose the set of innovation services J_f that they would like to import by anticipating the outcomes of the second and third stages of the game.

[17] The implications for fixed costs are simple and in particular first-order invariant across firms: The partial elasticity of marginal innovation cost with respect to a change in fixed cost is given by:equal to some constant: $\frac{\partial \log \Gamma'(x_f)}{\partial \log f_m} = \bar{\kappa}_1$.

The problem of each potential entrant in the first stage reads:

$$\max_{\mathcal{M}_f, J_f, 1_f} \Pi\left(\mathcal{M}_f, J_f, 1_f; \Theta_f\right) - \sum_{m \in \mathcal{M}_f} \mathbb{1}\left\{m \in \mathcal{M}_f\right\} F_f^E - 1_{I,f} F^I, \tag{4.11}$$

where Π denotes profits accrued in the later stages.

As a last step, we characterize J_f, the set of imported innovation service varieties. Firms foresee outcomes at later stages of the game, and hence the envelope theorem implies that firms choose their set of imported innovation services J to minimize their expected total cost of innovation.

$$J_f^* = \arg\min_{J_f} \mathbb{E}\left(\Gamma\left(x_f | J_f\right)\right) = \mathbb{E}\left(\frac{C}{B_f^{\phi} \theta_f} x_f - W \sum_{j \in J_f} f_{j,m(j)}\right).$$

In the appendix, we show that this choice can be uniquely characterized. Firms with higher innovation effort x_f import a weakly larger set of innovation services and thus display higher import intensities according to Proposition 2.

4.5 Key Predictions

We collect key predictions that we will take to the data in the following proposition.

Proposition 3 *The model implies the following relationships:*

1. *Imports of innovation-related services: Firms with higher levels of foreign innovation imports have larger overall innovation expenditures and innovate more.*
2. *Exports: Firms with higher levels of exports (both on the extensive and intensive margin) innovate more.*
3. *Competition: Firms with higher profit margins innovate more.*

Proof. Please see Appendix B.2. ∎

Proposition 3 provides testable implications for the relationship between firms' innovation activity, foreign innovation service imports, exports, and competition. The first prediction is borne out of the relationship between foreign innovation imports and the cost of innovation. The second prediction stems from a standard market size effect. The last prediction implies that increased levels of competition reduce innovation activity if profit margins respond negatively to competition.[18]

[18] However, mark-ups and in particular, their elasticitiy with respect to more innovation activity may be non-monotone in sales market shares. As a consequence, the model predicts no linear relationship

5 Empirical Evidence

In this section, we test the key predictions of our theoretical model. We investigate the effect of our three variables of interest – innovation service imports, exports, and competition – on firms' innovation activities.

5.1 Specification

Letting f index firms, s index 2 digit NACE Rev. 1 manufacturing industries and t index the years from 2001 to 2012,, we consider regressions of the following form:

$$y_{f,t} = \alpha \cdot \log(1 + \text{Innovation Imports})_{f,t} + \beta \cdot \log\left(1 + \text{Exp}_{f,t}\right) + \gamma \cdot \text{Comp}_{f,t} + \boldsymbol{\delta} \cdot \boldsymbol{X}_{f,t} + \omega_{s,t} + \epsilon_{f,t}. \quad (5.1)$$

$y_{f,t}$ denotes innovation measures at the firm level. The main predictions of our model are in terms of innovation expenditures. We also include R&D expenditures as an alternative measure of innotation inputs. As our data also allows us to observe innovation outcomes, such as product and process related measures of innovation success, we include these in our analysis as well.

Innovation $\text{Imports}_{f,t}$ and $\text{Exp}_{f,t}$ measure the value of firm-level innovation service imports and export revenues. $Comp_{f,t}$ is a measure for a firm's competitive environment that will be described shortly.

$\omega_{s,t}$ denotes industry-year fixed effects. The inclusion of fixed effects ensures that our estimates do not reflect variation across industries and instead are driven by variation across firms within industries. $\boldsymbol{X}_{f,t}$ is a vector of time-varying firm characteristics. It contains three binary variables: one indicating if a firm is part of an FDI relation, one indicating if a firm is located in East Germany, and one indicating if a firm performs internal R&D at least occasionally. Moreover, it includes a firm's number of employees as a proxy for size as well as the average wage of a firm's industry within East- or West Germany as a proxy for cost shocks.

The parameters of interest are the coefficients α, β and γ which measure the impact of trade in innovation services, exports and profit margins on firm-level innovation activities respectively. To identify causal effects, we construct firm-level instrumental variables for exports and service imports.

between changes in competition and changes in innovation activity. Fieler & Harrison (2018) stress that increases in competition may cause more innovation through an import-competition escape effect. While we don't model this excplicitly, our model does not rule such mechanisms out.

5.2 Instrumental Variables

5.2.1 Imports of Foreign Innovation Services

Firms might become more innovative by importing more innovation services. However, firms might also import more innovation services because they innovate more. To address this reverse causality, we construct a firm-level supply shock by implementing a standard Bartik instrument approach.

To construct the shift-share instrument, we consider a firm f that is observed importing foreign innovation services for the first time in year t_0. Denote by $\omega_{f,n,t_0}^{\text{Imp}^{\text{Innov}}}$ the share of the expenditures on foreign innovation output that is sourced from origin country n. Further, denote by $\text{IMP}_{n,f,t}^{Innovation}$ the *total* value of year t imports of foreign innovation by all German firms from country n that are *not* in the same NACE Rev.1 two digit industry as firm n.

The instrument for firm $f's$ imports of foreign innovation services in year t is defined as the sum of the aggregate innovation imports by all firms not in firm $f's$ industry over all countries, weighted by firm $f's$ initial import share from country n :

$$Z_{f,t}^{\text{Imp}^{\text{Innov}}} = \sum_n \omega_{f,n,t_o}^{\text{Imp}^{\text{Innov}}} \text{IMP}_{n,f,t}^{Innovation}. \tag{5.2}$$

Aggregate innovation service imports measure shocks to the supply of innovation services from a specific country. The initial shares imply differences in firm exposure to these supply shocks.[19]

The aggregation of innovation service imports for firms not in the same industry as firm f ensures that the aggregate supply shock is exogenous. Earlier, we have shown that large firms account for a large share of total innovation services. Aggregate changes in innovation imports of f's own industry could thus reflect changes in the behavior of f itself. By excluding a firm's own industry when constructing the supply shocks, we aim to minimize this threat to exogeneity.

5.2.2 Exports

We construct an instrument for exports by constructing exogenous firm-level demand shocks. The logic of the instrument is symmetric to the supply shocks constructed in

[19] The theoretical framework microfounds the construction of our instrument. More specifically, our model predicts that the responsiveness of a firm's innovation activity to shocks in the cost of foreign trade in services will be a function of the firm's initial import shares. Intuitively speaking: Firms that rely more on foreign innovation services as an input to their own innovation activities will be affected stronger by changes in the cost of importing services as their innovation costs depend more on them.

the previous section.

Consider a firm f that is first observed in year t_0. and denote by $\omega^{\text{EXP}}_{f,t_0}$ the share of its total revenues that is accounted for by exports. Let $\text{IMP}^{\text{World}}_{s(f),t}$ denote the value of world imports of industry s in year t. The instrument for exports for firm f in year t is then defined as:

$$\text{bartik}^{\text{EXP}}_{f,t} = \omega^{\text{EXP}}_{f,t_0} \cdot \text{IMP}^{\text{World}}_{s(f),t}. \tag{5.3}$$

Changes in the aggregate import demand of a given industry act as demand shocks. We argue that these shocks are exogenous to changes in the innovation activity of individual German firms. Weighting the industry-level shocks with a firm's initial export shares generates variation in exposure to the export demand shock across firms.[20]

5.2.3 Competition Measure

Following Lim *et al.* (2018), we measure competition in an industry by the number of active domestic firms in a given two-digit NACE Rev. 1 industry. To generate variation in competition exposure across firms within a given industry, we interact with this measure a firm's position in its industry's domestic sales distribution. Firms located in higher deciles of their industry's sales distribution have higher market shares, which, according to our framework, directly affects their exposure to competition.

Let $\tilde{d}_{f,s,t}$ denote a variable that takes the value 1 if firm f is in the top decile of the domestic sales distribution in industry s in year t, the value 2 if firm f is in the second-highest decile and henceforth until it takes the value 10 for a firm in the lowest decile. In addition, denote by $n_{s,t}$ the number of active firms in industry s in year t. The competition variable combines both measures as follows:

$$\text{comp}^2_{f,t} = \tilde{d}_{f,s,t_{0,f}} \times \log\left(n_{s,t}\right). \tag{5.4}$$

Our empirical competition measure of competition takes higher values for smaller firms that are active in industries with more competitors. We treat the number of firms in any given year to be exogenous to the actions and shocks affecting individual firms. As we observe industries at the two-digit level, we think that this assumption is appropriate. Further, to ensure that a firm's position in its industry's sales distribution is not correlated with unobserved factors affecting innovation, we hold this variable's value fixed at the value that it attained in the first year t_0 in which f is observed and exclude the firm-year observation from the sample.

[20] Again, this construction is consistent with the structural model.

5.3 Results

5.3.1 OLS

A simple OLS regression serves as a first check on the key predictions of our model regarding the cross-sectional equilibrium correlation between innovation efforts and innovation service imports, exports as well as competition. Table 5.1 presents the results of estimating the full specification in (5.1) via OLS across all innovation outcomes of interest.

Innovation Inputs Our theoretical framework predicts that firms with higher levels of innovation service imports and exports spend more resources on innovative activities. The first two columns of Table 5.1 show that this prediction is confirmed by the conditional correlations obtained through our OLS regression. Firms with higher levels of innovation imports and exports spend larger overall amounts on both innovation activities as a whole and R&D in particular.

We find that competition correlates negatively with overall innovation expenditures. Simultaneously, we find a statistically significant positive relationship between competition and R&D expenditures. As we will see below, only the former effects remain statistically significant in the second-stage IV estimates.

Innovation Outcomes Higher levels of innovation service imports are positively related to all measures of innovation success. As higher levels of innovation expenditures are positively related to better innovation outcomes, we interpret this as further validation of the cross-sectional predictions of our model.

Exports correlate positively with revenues generated by new products. However, we cannot detect a statistically significant relationship between higher levels of exports and better process innovation outcomes.

Our results indicate that while higher exposure to competition relates to better product innovation outcomes, it is simultaneously correlated with worse process innovation outcomes. As such, these results may shed light on the ambiguous effects that the literature assigns to competition as a determinant firm-level innovation activity. Consistent with the findings in Fieler & Harrison (2018), the results indicate that higher competitive pressure might induce firms to innovate on products in order to escape competition in other product markets. Interpreted through the lens of our model, higher levels of competition reduce the elasticity of mark-ups with respect to market shares and reduce the incentives for firms to invest in cost-saving technologies in order to solidify market shares and thus profit margins.

Table 5.1 OLS Results

	Inputs		Outcomes				
	Expenditures		Sales Products New to			Processes	
	Innovation	R&D	Firm	Firm & Market	Firm wo predec.	Unit Cost	Quality
Innov. Imports	0.10***	0.12***	0.09	0.15**	0.21***	0.11	0.11
	(4.84)	(6.25)	(1.55)	(2.01)	(2.79)	(1.52)	(1.46)
Exports	0.06***	0.03***	0.11***	0.09***	0.08***	-0.01	-0.01
	(7.57)	(7.30)	(8.52)	(8.61)	(7.53)	(-0.76)	(-0.95)
Competition	−0.005***	0.004***	-0.003	0.008*	-0.002	−0.01**	-0.006
	(−2.63)	(2.75)	(-0.76)	(1.92)	(-0.43)	(-2.12)	(-1.81)
Controls							
Labor Cost	-0.05	−0.06	-0.22	-0.09	-0.25	0.57	0.53
	(−0.24)	(−0.46)	(-0.56)	(-0.21)	(-0.60)	(1.39)	(1.33)
Employment	0.53***	0.47***	0.58***	0.48***	0.35***	0.71***	0.26***
	(12.2)	(13.14)	(7.25)	(5.29)	(3.99)	(7.87)	(3.68)
Cont. R&D	9.28***	10.45***	11.27***	6.21***	6.93***	4.45***	4.14***
	(101.31)	(101.31)	(67.63)	(40.73)	(45.08)	(30.37)	(29.91)
East	-0.01	0.02	0.19	-0.37	0.56**	−0.66***	-0.01
	(−0.08)	(0.30)	(0.77)	(-1.43)	(2.13)	(-2.67)	(-0.03)
Multinational	−0.01	0.44	0.42	0.17	0.05	0.58	-0.13
	(−0.05)	(0.10)	(1.31)	(0.51)	(0.16)	(1.67)	(-0.44)
Observations	17890	17890	17890	17890	17890	17890	17890
Firms	7222	7222	7222	7222	7222	7222	7222
R^2	0.65	0.85	0.49	0.22	0.24	0.16	0.11
Year-Ind FE	✓	✓	✓	✓	✓	✓	✓

Notes: This table presents the OLS results of estimating equation (5.1) on the baseline sample of German manufacturing firms. t-statistics are in parentheses and clustered at the firm level. *** indicates significance at the 1%, ** at the 5% and * at the 10% level. Source: Reasearch Data and Service Centre (RDSC) of the Deutsche Bundesbank, Trade in Service Statistics (SITS), Microdatabase Directinvestment (MiDi); Leibniz Centre for European Economic Research Mannheim Innovation Panel (MIP), 2002-2011, own calculations.

5.3.2 Second Stage

Table A.5 displays the first-stage regressions of the full set of instruments on innovation service import intensities and exports. We find a strong first stage for both, as evident by the *F*-statistics.[21]

Table 5.2 presents the second-stage IV estimates.[22] We find support for the hypothesis that relatively greater access to foreign innovation services leads to relatively higher innovation activity, as well as overall better innovation outcomes. We find statistically significant effects on near all innovation outcomes. This lends further support to our modeling assumption that foreign innovation services provide firms with greater over-

[21] The correlation structure between the instrumented variables is displayed in Table A.6. Evidently, the fitted values entering the second stage regression are far from collinear.

[22] We do apply the standard error adjustment to proposed in Adao *et al.* (2018). A future version of this paper will provide updated standard errors.

Table 5.2 Second Stage Results

	Inputs		Outcomes				
	Expenditures		Sales Products New to			Process	
	Innovation	R&D	Firm	Firm & Market	Firm wo predec.	Unit Cost	Quality
Innov. Imports	0.09***	0.13***	0.09	0.21*	0.27**	0.19*	0.25**
	(3.79)	(5.01)	(0.97)	(1.85)	(2.40)	(1.72)	(2.17)
Exports	0.07***	0.06***	0.14***	0.14***	0.08***	-0.01	-0.04
	(4.59)	(6.32)	(4.65)	(4.49)	(2.67)	(-0.42)	(-1.27)
Competition	−0.006*	0.003	-0.006	0.004	-0.005	-0.008	-0.001
	(−1.89)	(1.31)	(-1.19)	(0.77)	(-0.89)	(-1.31)	(-0.11)
Observations	10666	10666	10666	10666	10666	10666	10666
Firms	3974	3974	3974	3974	3974	3974	3974
R^2	0.67	0.85	0.45	0.22	0.24	0.17	0.11
Year-Ind FE	✓	✓	✓	✓	✓	✓	✓

Notes: Second stage IV results of estimating equation (5.1) on our baseline sample of German manufacturing firms. t-statistics are displayed in paentheses. Standard errors are clustered at the firm level. *** indicates significance at the 1%, ** at the 5% and * at the 10% level. Source: Reasearch Data and Service Centre (RDSC) of the Deutsche Bundesbank, Trade in Service Statistics (SITS), Microdatabase Directinvestment (MiDi); Leibniz Centre for European Economic Research Mannheim Innovation Panel (MIP), 2002-2011, own calculations.

all innovation efficiency, independently of whether innovative efforts target product or process innovation.

As indicated by the second row in Table 5.2, firms with relatively larger exposure to foreign export demand shocks undertake larger innovation efforts. We find that higher exposure to demand shocks incentivizes firms to adopt or develop new products, as indicated by increased product innovation revenues. Conversely, we do not find that market size has a statistically significant effect on process innovation, implying that innovation efforts induced through scale primarily materialize through product innovation.

We find that competition has a statistically significant negative effect on innovation expenditures. The effect on R&D expenditures is positive, as in the OLS regression, however not statistically significant. In line with the OLS estimates, we find that higher levels of competition disincentivize firms to invest in cost-saving innovations. However, we cannot detect a statistically significant effect on product innovation. Our findings are thus consistent with the theoretical model's predictions: Higher levels of competition may reduce the responsiveness of profit margins to market shares and therefore disincentivize firms to undertake innovations that allow them to undertake competitor's prices.

5.4 Robustness

We check the robustness of our baseline results across multiple dimensions. First, we augment the construction of our export demand and innovation service supply shocks to address potential shortcomings stemming from the fact that the firm-level variation stems from the shift-shares in the Bartik instrument. Second, we show that our empirical results are robust to variations in the baseline sample; more specifically, they remain largely unaltered when only years before the financial crisis are considered.

5.4.1 Alternative Instruments

A recent literature investigates the sources of exogeneity in shift-share instruments. First, the shift shares themselves can serve as a source of exogeneity. Goldsmith-Pinkham *et al.* (2018) show that if the shift-shares are exogenous to current unobserved factors affecting the outcome of interest, then the shift shares will capture exogenous and thus causal variation. Second, Borusyak *et al.* (2018) and Adao *et al.* (2018) show that the necessary exclusion restriction can be satisfied even if shift shares are correlated with current unobserved factors affecting the outcome of interest. These authors show that as long as the shocks themselves are exogenous to the individual firm, sufficient variation over industries provides identification of the parameter of interest.

In our set-up, we rely on the shift shares as a source of exogenous variation. We now follow Lim *et al.* (2018) and augment our baseline instruments by constructing probabilities of exporting and importing innovation services at the firm-level to generate additional exogenous variation. The probability that a firm exports/imports innovation services in year t aims to capture the impact of exogenous shocks that prevent a firm from taking advantage of export and import opportunities.

Consistent with the evidence that firms select into exporting based on their productivity, we include a firm's past position in the distribution of labor revenue productivities, Pos, as a predictor for a firm's propensity to export/import. Further, consistent with the existence of initial fixed cost to participating in international trade, this probability also depends on a firm's history of exporting. Further, we consider sectors and regions as potential determinants of trade participation. Using these predictors, we run a Probit model to estimate a firm-specific predicted probability of exporting, denoted $p^x_{f,t}$:

$$\mathbb{1}\left\{\text{Exports}_{f,t} > 0\right\} = \Phi\left(\alpha_{East} + \alpha_t + \alpha_{sector} + \beta \text{Pos}_f\left(\frac{\text{Sales}_{f,t_0}}{L_{f,t_0}}\right) + \gamma \mathbb{1}\left\{\text{Exports}_{f,t-1} > 0\right\} + \epsilon_{f,t}\right). \quad (5.5)$$

We estimate the probability $p^I_{f,t}$ of a firm being an innovation service importer analogously by regressing a firm's import status on its lagged importer status and a similar set of dependent variables in the following Probit model:

$$\mathbb{1}\left\{\text{Imports}_{f,t}^{Innov} > 0\right\} = \Phi\left(\alpha_{East} + \alpha_t + \alpha_{sector} + \beta \text{Pos}_f\left(\frac{\text{Sales}_{f,t_0}}{L_{f,t_0}}\right) + \gamma \mathbb{1}\left\{\text{Imports}_{f,t-1}^{Innov} > 0\right\} + \epsilon_{f,t}\right). \tag{5.6}$$

Our alternative firm-level instruments for exports and innovation service imports combine the Bartik part described in the previous section with the estimated probability of exporting or importing:

$$\widetilde{Z}_{f,t}^{\text{EXP},a} = p_{f,t}^{x} \log\left(1 + \text{bartik}_{f,t}^{\text{EXP}}\right). \tag{5.7}$$

$$\widetilde{Z}_{f,t}^{\text{Imp}^{\text{Innov}}} = p_{f,t}^{I} \log\left(1 + \text{bartik}_{f,t}^{\text{EXP}}\right). \tag{5.8}$$

We re-estimate our empirical model using this new set of instruments. The results are displayed in Table A.7. We again find a strong first stage and qualitative results that remain broadly unchanged relative to our baseline estimates.

5.4.2 Financial Crisis

The financial crisis in 2008 was followed by a global decrease in international trade volumes (Eaton *et al.* (2016)). However, trade volumes in services trade have seen a significantly lower decrease during the financial crisis, as documented in Ariu (2016). We investigate whether our results are driven by the impact of the great recession by re-estimating our baseline specification on a restricted sample that only includes years before the financial crisis. Table A.8 displays the second-stage results and confirms that our baseline results are robust to this sample restriction.

6 Selection Complementarities and the Effect of Trade on Aggregate Innovation Actvity

In Section 5 we have shown that a significant share of the variation in innovation expenditures occurs within sectors. In the previous section, we have confirmed the key prediction of our theoretical model. Here, we highlight the structural determinants of the heterogeneity in firm-level responses to trade shocks and showcase how selection complementarities at the firm-level affect the aggregate effects of trade on innovation.

To do so, we derive sufficient statistics that govern firm level responses in innovation activity x_f to changes trade cost. We focus on changes in variable trade cost in final goods - both in terms of exporting, τ_m, and importing, τ_H- as well as variable trade cost for trade in innovation services, τ_m^{IMP}.

We compare changes in innovation activities predicted by the model across two periods for firms that maintain the same exporter, innovation, and innovation service importer status. Changes over equilibrium outcomes that are beyond the control of the firm in the model - such as aggregate income levels, factor prices, demand shifters, and prices of innovation services - are treated as realizations of random variables. We take expectations over the joint realizations of these random variables and characterize $\mathbb{E}\left[\frac{d \log x_f}{d \log \tau}\right]$ as the expected elasticity of firm f's innovation activities with respect to a change in final good exports or innovation service imports.[23]

For intuition, it is worth reconsidering the key implications of our model. Proposition 2 shows that a firm's innovation import intensity is a sufficient statistic to capture heterogeneity in firms' responses to changes in the costs of importing innovation output. Proposition 1, in turn, implies that market shares are a sufficient statistic for firm-level markups - which in turn govern the exposure to market competition and thus profit-margin incentives for innovation activities. Therefore both import intensities and market shares emerge as primary determinants of how a firm will respond to a change in aggregate trade cost.

The following assumption provides restrictions on the correlation of trade cost with other model parameters and outcomes.

Assumption 2 *Changes in trade cost are uncorrelated with initial levels of sector level aggregates and idiosyncratic shocks to and initial levels of exogenous firm characteristics Θ_f.*

Note that this assumption allows arbitrary correlation structures between changes in trade cost and changes in aggregate general equilibrium objects, which naturally are to be expected in any general equilibrium model of trade.[24]

The following proposition summarizes the effects of changes in trade cost on firm-level innovation activity.

Proposition 4 *In addition to Assumption 2, assume that the elasticity of demand and unit cost with respect to innovation effort x is constant. Then market shares, import intensities and*

[23] As we condition on firms that do not change decisions on the extensive margin - whether or not to export, innovate or import innovation services at all - we do not characterize the entry margin effect of falling trade cost. We leave this margin to future work. However, given that trade costs have fallen over the sample period, our key message that trade may have large effects on aggregate innovation activity is entirely unaltered by this omission.

[24] Assumption 2 may be violated if for example part of the trade cost in innovation services reflect advancements in the technology sector, implying that trade cost in services decline faster if income in the technology sector are high in levels. However, as we focus broadly on manufacturing industries we believe that this concern would only concern a small subset of sectors and that our characterization remains accurate the majority of sectors.

output size in each market $\left\{\left\{S_{m,f}, Q_{m,f}\right\}_{m\in\mathcal{M}_f}, \varphi_f\right\}$ *are first order sufficient statistics for the firm-level elasticity of innovation activities with respect to trade cost* $\mathbb{E}\left\{\frac{d\log x_i}{d\log\tau}\right\}$.
In particular, for $\tau \in \{\tau_m, \tau_H\}$ *we have that, omitting sector subscripts:*

$$\mathbb{E}\left(\frac{d\log x_{f,m}}{d\log\tau}\right) = \alpha^{\tau} + \sum_{m\in\mathcal{M}_f} \beta^{\tau}_m S_{f,m} + \sum_{m\in\mathcal{M}_f} \gamma^{\tau}_m Q_{f,m}, \tag{6.1}$$

and for $\tau = \tau^{R\&D}_m$*:*

$$\mathbb{E}\left(\frac{d\log x_{m}}{d\log\tau}\right) = \alpha^{\tau}_m + \varphi_f\left\{\alpha^{\tau,\varphi}_m + \sum_{m\in\mathcal{M}_f} \beta^{\tau}_m S_{f,m} + \sum_{m\in\mathcal{M}_f} \gamma^{\tau}_m Q_{f,m}\right\}. \tag{6.2}$$

The parameters $\{\alpha, \beta, \gamma\}$ *are constants given in the appendix.*

Proof. See Appendix B.1. ■

The key implication of Proposition 4 is that complementarities in the initial firm selection into output markets, importing of innovation services and innovating are crucial to governing firm-level and, therefore, the aggregate consequences of trade integration on innovation.

Equation (6.2) illustrates that a change in the trade costs of innovation services has a more sizeable effect on innovation incentives of firms that previously had higher import shares of these services. Further, the effects of a reduction in innovation services import cost on firm-level innovation activity depend on a firm's exposure to market size and competition in goods markets. Firms with large sales volumes in many markets are bound to react differently from firms with only a few destination markets.

Similar considerations hold for shocks to final goods trade cost. equation (6.1) show that market shares are a primary driver of heterogeneity in firms' innovation responses to import competition shocks. This is intuitive: A reduction in, for instance, the profit margins of the home market is less consequential for a firm that is also profitable in other markets.

A key insight is, therefore, that the aggregate effects of trade integration on innovation might be sizeable and, most importantly, can only be fully assessed by jointly understanding how the innovation incentives generated by trade in innovation services interact with the incentives to trade in goods and domestic competition.

A quantification of this mechanism is beyond the scope of this paper, and we leave it to future research. However, we give a final result which shows that the parameters governing the responsiveness in firm-level innovation activities can be recovered from simple OLS regressions, provided that one is able to measure changes in trade cost. We state the result for the simplified model where the home economy only exports to an aggregate Rest of the World (ROW).

Proposition 5 *A sector-weighted average of firm level elasticities of innovation expenditures with respect to trade cost* $\{\alpha, \beta, \gamma\}$ *are given in equation (6.1) and (6.2) can be recovered from OLS regressions of the form:*

$$\begin{aligned} \Delta x_{f,t} = \quad & \left\{a^{R\&D} + \textstyle\sum_{m=\{H,RoW\}} b_m^{R\&D} S_{f,m,t-1} + \sum_m d_m^{R\&D} Q_{f,m,t-1}\right\} \tilde{\varphi}_{i,t-1} \Delta\tau_t^{R\&D} \\ + \quad & \left[a_{m,H} + b_H S_{f,H,t-1} + c_H S_{f,RoW,t-1} + \textstyle\sum_m d_m^{IMP} Q_{f,m,t-1}\right] \left(\Delta\tau_{RoW\Rightarrow GER,t}^{IMP}\right) \\ + \quad & \left[a_{m,F} + b_F S_{f,F,t-1} + c_F S_{f,H,t-1} + \textstyle\sum_m d_m^{EXP} Q_{f,m,t-1}\right] \left(\Delta\tau_{GER\Rightarrow ROW,t}^{EXP}\right) \\ + \quad & \ldots + \epsilon_{f,t} \end{aligned}, \qquad (6.3)$$

where Δ *denotes percentage changes between* $t-1$ *and* t*,*

Proof. See Appendix B.3. ■

The left-hand side outcome variables in equations (6.1) and (6.2) are not observable. However, Proposition 5 shows that the theoretical coefficients of interest can be recovered directly from ordinary least square regressions of firm-level changes in innovation expenditures on changes in observable trade shocks.

7 Conclusion

This paper uncovers new dimensions of the connection between trade integration and innovation. We use an unusually detailed dataset that allows us to conduct the first study into the connection between trade in services, trade in goods, and firm-level innovation activity.

We have provided novel descriptive statistics that suggest that firm-level differences in innovation activity are essential for shaping aggregate trends in innovation, that document that trade in foreign knowledge exhibits similar properties to trade in goods and, lastly, that suggest the existence of complementarities in the selection of firms into innovating, exporting goods and importing foreign knowledge.

We have developed a new theoretical model of trade in services, and innovation rationalizes these facts. We empirically tested its key predictions. Our results imply that the firm-level effects of trade in innovation services on firm innovation are of similar magnitudes to the effects of trade that operate through export opportunities and competition.

Further, we have highlighted that complementarities in selection have the potential to amplify the effects of trade integration on aggregate innovation activity through disproportionally incentivizing the largest and most productive firms to innovate more. We have formalized this intuition using our structural model and have shown how future work based on this study can use our results to take further steps at quantifying the aggregate effects of trade in innovation services.

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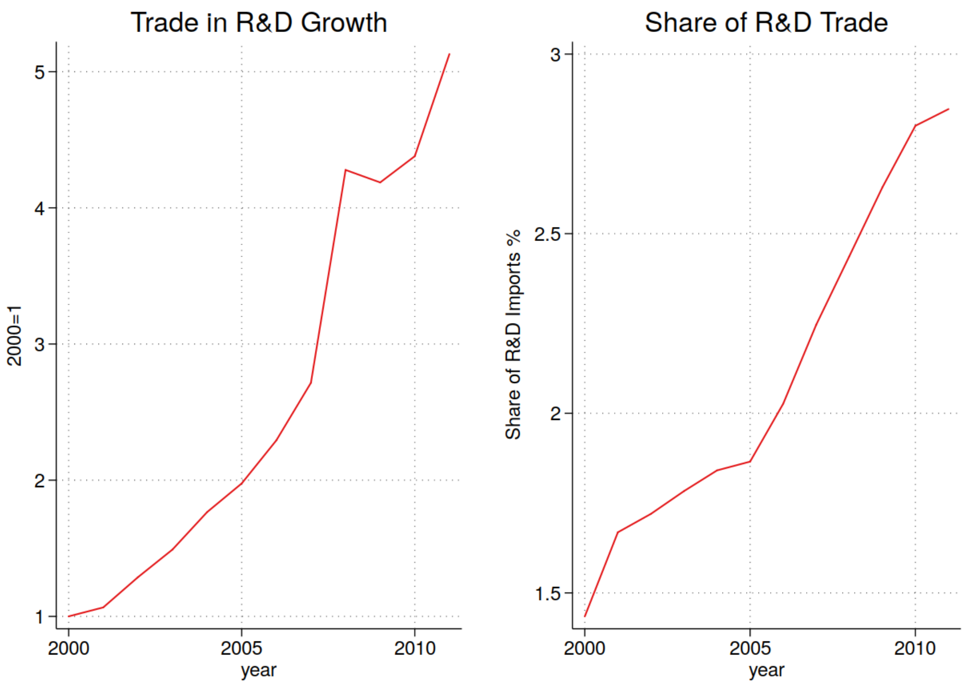
A Table and Figure Appendix

Figure A.1 World Trade in R&D services



Notes: The right figure shows the percentage share of R& D service imports as a fraction of world imports in trade in services from 2000 to 2010. Source: 'Trade in Services' database, World Bank. The left figure shows world volumes of trade in R& D services normalized to 2000.

Table A.1 Sample Descritptive Statistics (unweighted)

Description	Mean
Employment	249.48
Revenues ($\times 10^3$)	57,037
Share of Exporters	68.2
Share Exports in Sales	20
Share Innovators	69
Share Innovation Service Importers	3.1
Share Innovation Service Exporters	1.2
Share Multinationals	8.3

Notes: (where applicable) averages over all firm-year observations. All shares in percent. Source: Reasearch Data and Service Centre (RDSC) of the Deutsche Bundesbank, Trade in Service Statistics (SITS), Microdatabase Directinvestment (MiDi); Leibniz Centre for European Economic Research Mannheim Innovation Panel (MIP), 2002-2011, own calculations.

Table A.2 Innovation Activity in German Manufacturing Firms

	Innovation Measure	Sample	Multinationals	Innov. Importers
Inputs	Innovation Expenditures	4752	13162	26129
	R&D Expenditures	2950	8621	14838
	R&D Imports	227	1827	
	Continuous R&D (%)	82	93	93
Outcomes	Product innovator (%)	74	82	83
	Revenue Share Products			
	improved/new to firm	20.4	18.89	22.8
	new to market	5.8	4.9	7.6
	new product	5.7	4.2	6.6
	Process innovator (%)	49.9	58	61
	Reduction of unit cost			
	Yes?	32.9		45.1
	In percent	3.0	3.5	3.6
	Increase in Quality			
	Yes?	34.2		40.2
	In percent	2.8	2.7	2.5

Notes: Averages across all firm year observations with positive innovation expenditures. Revenues, innovation expenditures and imports of foreign innovation services are in Euro thousands. Source: Reasearch Data and Service Centre (RDSC) of the Deutsche Bundesbank, Trade in Service Statistics (SITS), Microdatabase Directinvestment (MiDi); Leibniz Centre for European Economic Research Mannheim Innovation Panel (MIP), 2002-2011, own calculations.

Table A.3 Firm Status and Productivity Measures

	Innovation Imp.	Exporter	Innovator	Innovation Exp.
Rev/L	0.03***	0.15***	0.09***	0.01***
	(7.97)	(19.7)	(11.2)	(3.24)
Skill Intensity	0.001***	0.002***	0.004***	0.000***
	(3.08)	(6.0)	(12.5)	(3.09)
East Germany	−0.01***	−0.10***	-0.002	−0.01***
	(-3.51)	(-5.7)	(-0.19)	(-2.06)
Year×Ind FE	✓	✓	✓	✓
Observations	15,605	15,605	15,605	15,605

Notes: Estimation results of regressing a dummy for a firm's trade participation and innovation activity on controls and a firm's labor revenue product, denoted Rev/L. Standard errors are in parentheses and clustered at the firm level. *** indicates significance at the 1%, ** at the 5% and * at the 10% level. Source: Reasearch Data and Service Centre (RDSC) of the Deutsche Bundesbank, Trade in Service Statistics (SITS), Microdatabase Directinvestment (MiDi); Leibniz Centre for European Economic Research Mannheim Innovation Panel (MIP), 2002-2011, own calculations.

Table A.4 Conditional Sample Composition

	Multinat.	Imp. Innov. Serv.	Exporter
Multinational			
Yes	100	22.5	69
No	100	2	48
Importer Innov. Serv.			
Yes	54	100	70
No	7	100	50

Notes: Conditional sample composition of innovating firms (firms with strictly positive innovation expenditures). Read: Conditional on having status x (row), what share of firms has status y (column). Source: Reasearch Data and Service Centre (RDSC) of the Deutsche Bundesbank, Trade in Service Statistics (SITS), Microdatabase Directinvestment (MiDi); Leibniz Centre for European Economic Research Mannheim Innovation Panel (MIP), 2002-2011, own calculations.

TABLE A.5 BASELINE FIRST-STAGE RESULTS

	Innovation Imports	Exports
Instrument Innovation Imports	0.53^{***}	0.16^{***}
	(22.11)	(6.71)
Instrument Exports	-0.00	0.86^{***}
	(−0.17)	(36.53)
Observations	10,666	10,666
Unique Firms	3,974	3,974
F-Statistic	253.13	728.48
Year×Industry FE	✓	✓

Notes: First Stage results of projecting endogenous outcomes on the instruments constructed in Section 5.2. Standard errors are in parentheses and clustered at the firm level. *** indicates significance at the 1%, ** at the 5% and * at the 10% level. Source: Reasearch Data and Service Centre (RDSC) of the Deutsche Bundesbank, Trade in Service Statistics (SITS), Microdatabase Directinvestment (MiDi); Leibniz Centre for European Economic Research Mannheim Innovation Panel (MIP), 2002-2011, own calculations.

TABLE A.6 BASELINE: CORRELATIONS BETWEEN INSTRUMENTED INDEPENDENT VARIABLES

	Innovation Imports	Exports	Competition
Innovation Imports	1		
Exports	0.21	1	
Competition	-0.14	-0.25	1

Notes: This table presents the correlation between the fitted first stage variables for innovation imports and exports, as well as competition. Source: Reasearch Data and Service Centre (RDSC) of the Deutsche Bundesbank, Trade in Service Statistics (SITS), Microdatabase Directinvestment (MiDi); Leibniz Centre for European Economic Research Mannheim Innovation Panel (MIP), 2002-2011, own calculations.

Table A.7 Second-Stage IV Results for Alternative Instruments for Exports and Innovation Imports

	Inputs		Outcomes				
	Expenditures		Sales Products New to			Process	
	Innovation	R&D	Firm	Firm & Market	Firm wo predeces.	Unit Cost	Quality
Innovation Imports	0.08*	0.10***	0.021	0.09	0.27*	0.18	0.52***
	(1.71)	(2.54)	(0.15)	(0.48)	(1.66)	(0.97)	(2.89)
Exports	0.07***	0.06***	0.17***	0.17***	0.08**	-0.02	-0.04
	(4.2)	(4.60)	(4.63)	(4.19)	(1.97)	(-0.6)	(-1.07)
Competition	−0.006	0.006**	-0.005	0.004	-0.008	-0.007	-0.001
	(−1.55)	(2.26)	(-0.75)	(0.62)	(-1.05)	(-0.92)	(-0.11)
Observations	6361	6361	6361	6361	6361	6361	6361
Unique Firms	2659	2659	2659	2659	2659	2659	2659
R^2	0.68	0.86	0.45	0.21	0.25	0.18	0.13
First-stage F							
Exports	599.0						
Innovation Imports	214.1						
Firm Controls	✓	✓	✓	✓	✓	✓	✓
Year×Industry FE	✓	✓	✓	✓	✓	✓	✓

Notes: Second stage results of estimating equation (5.1) on our baseline sample of German manufacturing firms. Standard errors are in parentheses and clustered at the firm level. *** indicates significance at the 1%, ** at the 5% and * at the 10% level. Firm controls include local labor cost, total employment, and indicator variables for whether a firm conducts R&D continuously, is located in former Eastern German States and is a multinational. Source: Reasearch Data and Service Centre (RDSC) of the Deutsche Bundesbank, Trade in Service Statistics (SITS), Microdatabase Directinvestment (MiDi); Leibniz Centre for European Economic Research Mannheim Innovation Panel (MIP), 2002-2011, own calculations.

TABLE A.8 SECOND STAGE IV RESULTS FOR PRE 2008 SAMPLE

	Inputs		Outcomes				
	Expenditures		Sales Products New to			Process	
	Innovation	R&D	Firm	Firm & Market	Firm wo predeces.	Unit Cost	Quality
Innovation Imports	0.08**	0.11***	0.021	0.24*	0.21	0.26**	0.15
	(2.12)	(3.26)	(0.15)	(1.80)	(1.53)	(1.99)	(1.17)
Exports	0.07***	0.07***	0.17***	0.20***	0.12***	0.002	-0.02
	(3.49)	(4.82)	(4.63)	(4.02)	(2.43)	(0.05)	(-0.41)
Competition	−0.009**	−0.002	-0.005	0.001	-0.01	-0.01	-0.008
	(−2.15)	(−0.55)	(-0.75)	(0.07)	(-1.28)	(-1.16)	(-0.97)
Observations	4109	4109	4109	4109	4109	4109	4109
Unique Firms	2076	2076	2076	2076	2076	2076	2076
First-stage F							
Exports	495.21						
Innovation Imports	144.9						
Firm Controls	✓	✓	✓	✓	✓	✓	
Year×Sector FE	✓	✓	✓	✓	✓	✓	✓

Notes: Second stage results of estimating equation (5.1) on our baseline sample of German manufacturing firms. Standard errors are in parentheses and clustered at the firm level. *** indicates significance at the 1%, ** at the 5% and * at the 10% level. Firm controls include local labor cost, total employment, and indicator variables for whether a firm conducts R&D continuously, is located in former Eastern German States and is a multinational. Source: Reasearch Data and Service Centre (RDSC) of the Deutsche Bundesbank, Trade in Service Statistics (SITS), Microdatabase Directinvestment (MiDi); Leibniz Centre for European Economic Research Mannheim Innovation Panel (MIP), 2002-2011, own calculations.

B Technical Appendix

B.1 Proposition 2

Proof. We first prove the following lemma:

Lemma 1 *The cost minimization problem for a given target level of innovation has a unique solution.*

Proof. To prove this proposition, we need to derive the entire cost function. These derivations follow essentially the argument in Amiti *et al.* (2018), adjusted for multiple input origins. First, drop firm identifier i for simplicity. Conditional on a set of imported intermediaries J, the problem reads:

$$TC\left(x|J\right) = \min_{F,M,\{Z_{j,k},M_{j,k}\},X_j} \left\{ WF + \int_0^1 V_j Z_j dj + \sum_k \int_J \left(\tau_k U_{j,k} M_{j,k} + W f_k\right) dj \right\}.$$

Denoting by λ, ψ and ω the Lagrange multiplier on the constraints given by equation (4.5), (4.6) and (4.7) respectively, this yields the following first order conditions:

$$\begin{aligned} W &= \lambda(1-\phi)x/F \\ \psi &= \lambda\phi x/M \\ \chi &= \psi\alpha_j X/X_j, && j \in [0,1] \\ V_j &= \omega\left(X_j/Z_j\right)^{\frac{1}{1+\zeta}}, && j \in [0,1] \\ \tau_k U_{j,k} &= \omega\left(a_{j,k}X_j/M_{j,k}\right)^{\frac{1}{1+\zeta}}, && \{j,k\} \in J \end{aligned}$$

,

with $M_{j,k} = 0$ and $X_j = Z_j$ for varieties $\{j,k\} \notin J$ that are not imported in the set J. We can solve out ω and ψ and rearrange to obtain:

$$WF = \lambda\left(1-\phi\right)x$$

$$V_j X_j = \lambda\phi\alpha_j x\left(X_j/Z_j\right)^{\frac{1}{1+\zeta}}$$

$$\frac{\tau_k U_{j,k} M_{j,k}}{V_j Z_j} = \alpha_j \left(\frac{\tau_k U_{j,k}}{V_j}\right)^{-\zeta}.$$

The last expression can be substituted into equation (4.7), which yields

$$X_j = Z_j \left[1 + \sum_{\{j,k\} \in J} a_j \left(\frac{\tau_k U_{j,k}}{V_j} \right)^{-\zeta} \right]^{\frac{1+\zeta}{\zeta}},$$

which together with the expression for the total spending on intermediate input variety X_j yields:

$$V_j X_j = \lambda \phi \alpha_j x b_j,$$

where $b_j = \left[1 + \sum_{\{j,k\} \in J} a_j \left(\frac{\tau_k U_{j,k}}{V_j} \right)^{-\zeta} \right]^{\frac{1}{\zeta}}$ and $b_j = 1$ if $\{j,k\} \notin J$ for all k. We can then solve for the lagrange multiplier on the total production function for innovation, λ, which will of course also give us the characterization of total variable cost and in particular:

$$\lambda = \frac{C}{B^{\phi} \chi},$$

where

$$B = \exp \left\{ \int \alpha_j \log b_j dj \right\}$$

and C is a price index for innovation for firms that do not import any foreign knowledge sevices.

The total cost function is then given by:

$$TC(x; J) = \lambda Y + \sum_k \int_j W f_k dj. \tag{B.1}$$

Next, we need to minimize these cost, by choosing an optimal bundle J :

$$\min_J TC(x, J),$$

given a target level of innovation x. In the main text, this choice is made under uncertainty, however, none of the derivations change as the timing of decisions implies that firms minimize $\mathbb{E}TC(x, J)$. As in Amiti *et al.* (2018), the net change of adding another variety $\{j,k\} \notin J$ to the set J is given by:

$$\frac{\partial B}{\partial j_k} + W f_k = x \frac{\partial \lambda}{\partial B} \alpha_j \log b_j + W f_k = - \underbrace{\phi \lambda x}_{\text{total int cost of innovation}} \alpha_j \log b_j + W f_k$$

The optimal set J therefore must satisfy:

$$J = \left\{ \{j,k\} \in [0,1] \times \mathcal{K} : \phi \frac{C/\chi}{\exp\left\{\phi \int_J \alpha_l \log b_l dl\right\}} x \times \alpha_j \log b_j \geq W f_k \right\}.$$

We can order $\alpha_j \log b_j$ for $\{j,k\} \in [0,1] \times \mathcal{K}$ so that $\alpha_j \log b(j,k) - W f_k$ is decreasing (so that in principle we would first add a given j variety from the US and then another variety j' from the US and then j from the UK). This immediately implies that the optimal solution is an interval $J_k = [0, \bar{j}_k]$ for each country k. Of course, the lefthand side of thie equation is decreasing and thus the solution will be unique. ■

To prove the proposition, we first note that we can write the fraction of total variable cost of innovation spent on imports from abroad as:

$$\varphi = \frac{\sum_k \int_J \tau_k U_{j,k} M_{j,k} dj}{\lambda x} = \int_J \alpha_j \left(1 - b_j^{\zeta}\right) dj.$$

Of course, this share increases in the size of the set J (both in the number of countries and varieties). By the above lemma, this set increases in x and decreases in the size of the fixed cost f_k.

Lastly, to prove the property of the local elasticity (that is on the intensive margin) of marginal cost with respect to trade cost in services in country k, denoted τ_k :

$$\frac{\partial \log MC}{\partial \log \tau_k} = \frac{\partial \log \lambda}{\partial \log B} \frac{\partial \log B}{\partial \log \tau_k} = -\phi \int_J \alpha_j \frac{\partial \log b_j}{\partial \log \tau_k} dj$$

We also have that

$$\frac{\partial \log b_j}{\partial \log \tau_k} = \frac{\tau_k}{b_j} \frac{\partial b_j}{\partial \tau_k} = -\frac{\tau_k}{b_j} \frac{1}{\zeta} * b_j^{1-\zeta} \frac{\zeta}{\tau_k} = -a_{jk} \left(\frac{\tau_k U_{j,k}}{V_j} \right)^{-\zeta} b_j^{-\zeta},$$

which equals exactly the fraction intermediates in variety j that is imported from country k. Summed over all intermediates and pre-multiplied with the overall fraction of variable cost of innovation, this thus equals the fraction of total variable cost that is spend on intermediates from country k, or the import intensity from country k by firm i.

Thus:

$$\frac{\partial \log MC}{\partial \log \tau_k} = \phi \int_J \alpha_j a_{j,k} \left(\frac{\tau_k U_{j,k}}{V_j} \right)^{-\zeta} b_j^{-\zeta} dj = \varphi_{i,k}.$$

□

B.2 Proposition 3

Proof. The first assertion follows directly from Proposition 2 and inspecting the first order condition in equation (4.4). Firms with higher levels of imports of foreign innovation services have lower marginal cost. The left-hand side of equation (4.4) is convex in innovation effort x_f, which directly implies the statement.

The second part follows similarly. Higher levels of exports raise the value of the left-hand-side of equation (4.4), implying that x_f has to increase to satisfy the first order condition.

The last part follows from similar considerations. Higher profit margins increase the profitability of any given level of innovation activity. As the returns to innovation activity are conex, the first order condition that pins down firms' optimal innovation effort implies that higher profit margins are correlated with higher innovation activity. ■

B.3 Proposition 4 and 5

Proof. First, we differentiate optimality condition (4.4). We thereby denote all aggregate variables, such as demand shifters and factor prices by aggregate vectors A, B and C. In the below, let $\Delta y_{i,t} = \frac{y_{i,t+1} - y_{i,t}}{y_{i,t}}$ for any variable y. This yields the folllowing expressions

$$\begin{aligned}
&\sum_k \left(\tfrac{1}{\sigma_{i,k,t}-1}\right) \tau_{k,t} C_{i,k,t} \tfrac{\partial Q_{i,k,t}}{\partial x_{i,t}} \left\{ \frac{\partial \log\left\{\left(\frac{1}{\sigma_{i,k,t}-1}\right)\tau_{k,t} C_{i,k,t} \frac{\partial Q_{i,k,t}}{\partial x_{i,t}}\right\}}{\partial \log \tau_{k,t}} \Delta\tau_{k,t}^{EXP} + \frac{\partial \log\left\{\left(\frac{1}{\sigma_{i,k,t}-1}\right)\tau_{k,t} C_{i,k,t} \frac{\partial Q_{i,k,t}}{\partial x_{i,t}}\right\}}{\partial \log x_{i,t}} \Delta x_{it} + \right\} \\
&\sum_k \left(\tfrac{1}{\sigma_{i,k,t}-1}\right) \tau_{k,t} C_{i,k,t} \tfrac{\partial Q_{i,k,t}}{\partial x_{i,t}} \left\{ \frac{\partial \log\left\{\left(\frac{1}{\sigma_{i,k,t}-1}\right)\tau_{k,t} C_{i,k,t} \frac{\partial Q_{i,k,t}}{\partial x_{i,t}}\right\}}{\partial \log \tau_{k,t}^{IMP}} \Delta\tau_{k,t}^{IMP} 1_{k=home} + A_{k,s}\Delta A_{k,s} \right\} \\
&-\left(\tfrac{\partial C_{i,k,t}}{\partial x_{i,t}} \sum_k \tau_{k,t} Q_{i,k,t}\right) \left(\frac{\partial \log\left(\frac{\partial C_{i,k,t}}{\partial x_{i,t}} \sum_k \tau_{k,t} Q_{i,k,t}\right)}{\partial \log x_{i,t}} \Delta x_{it} + \frac{\partial \log\left(\frac{\partial C_{i,k,t}}{\partial x_{i,t}} \sum_k \tau_{k,t} Q_{i,k,t}\right)}{\partial \log \tau_{k,t}} \Delta\tau_{k,t}^{exp} \right) \\
&-\left(\tfrac{\partial C_{i,k,t}}{\partial x_{i,t}} \sum_k \tau_{k,t} Q_{i,k,t}\right) \left\{ \frac{\partial \log\left(\frac{\partial C_{i,k,t}}{\partial x_{i,t}} \sum_k \tau_{k,t} Q_{i,k,t}\right)}{\partial \log \tau_{k,t}^{imp}} \Delta\tau_{k,t}^{IMP} 1_{k=home} + B_{k,s}\Delta B_{k,s} \right\} \\
&= \varphi_i \Delta\tau_{IMP}^{R\&D} + C_{k,s}\Delta C_{k,s} + \epsilon_{i,t}^{\Gamma},
\end{aligned} \tag{B.2}$$

The last line uses the result in Proposition 2 and $\epsilon_{i,t}^{\Gamma}$ is an error term given by:

$$\epsilon_{i,t}^{\Gamma} \equiv \zeta \int_J \frac{\alpha_j a_{j,k} \left(\tau_{k,t} U_{j,k,t} / V_{j,t}\right)^{-\zeta}}{\varphi_{j,k,t}} \left[d\log \frac{U_{j,k,t}}{\bar{U}_t} - d\log \frac{V_{j,t}}{\bar{V}_t} \right] dj,$$

with $\bar{V}_t \equiv \int_0^1 \alpha_j \left(d \log V_j \right) dj$ denotes an average change in prices. The model structure implies that market shares $S_{i,k}$ are a sufficient statistic for mark-ups. $\{\theta_i, \omega_i, \chi_i\}$ as well as differences in output $Q_{i,k,t}$ together with market shares thus completely characterize any firm level heterogeneity in the firm-specific derivatives in the above term. By virtue of the assumption that both product demand and unit cost are iso-leastic in innovation effort, the inital level of innovation is no such sufficient statistic.

We can thus first order approximate all terms relating to these derivatives in each of the variables $\{S_{i,t}, Q_{i,k,t}, x_{i,t}, \theta_i, \omega_i, \chi_i\}_i$. Collecting the relevant terms and solving the resulting equation for $\Delta x_{i,t}$ then gives equation (5.1) with the firm-specific error term:

$$\epsilon_{i,t} \equiv \epsilon_{i,t}^{\theta,\omega,\chi} + Constant_{s,t} \epsilon_{i,t}^{\Gamma},$$

where $\epsilon_{i,t}^{\theta,\omega,\chi} = \text{constant}^{\theta} \log \frac{\theta_{i,t}}{\bar{\theta}_t} + \text{constant}^{\omega} \log \frac{\omega_i}{\bar{\omega}_t} + \text{constant}^{\chi} \log \frac{\chi_{i,t}}{\bar{\chi}_{i,t}}$.

We are left to show that this error term is uncorrelated with changes in trade cost, which will prove the desired result. Under Assumption 2, we have that $\mathbb{E}\left(\epsilon_{i,t} \Delta \tau\right) = 0$ for all changes in trade cost, evaluating $\mathbb{E}\left(\frac{d \log x_{i,t}}{d \log \tau}\right)$ then implies that $\mathbb{E}\left(\frac{\epsilon_{i,t}}{d \log \tau}\right) = 0$ and thus that $\{S_{i,t}, Q_{i,k,t}, \varphi_{i,t}\}$ denotes a set of sufficient statistics that characterizes within sector heterogeneity in the elasticity of innovation expenditures with respect to changes in any trade costs.

Further, it is evident that the relevant model given parameters can be consistently estimated by regressing the change in innovation expenditures on changes in trade cost according to equation (5.1), which completes the proof.

■