Trade in Knowledge Services and Innovation*

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Abstract

This paper shows how trade in services fosters innovation by providing firms with access to foreign knowledge. Using rich firm-level data on services trade and innovation activity from Germany, we provide evidence that access to foreign knowledge inputs via services trade increases firms' innovativeness and complements their indigenously sourced innovation inputs. We use our reduced-form estimates to quantify the aggregate gains from services trade in a heterogeneous firm model featuring endogenous competition and innovation. Our analysis suggests that the welfare gains from knowledge services trade are potentially sizable, albeit largely unrealized.

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1 Introduction

Innovation and international trade are intertwined drivers of economic growth.[1] Trade in services, in particular, has the potential to foster innovation by providing firms with access to foreign knowledge as an input to their innovation process (Burgess, 1995; Francois & Hoekman, 2010). Indeed, while services trade has increased substantially in recent decades, services facilitating knowledge transfer have recorded particularly rapid growth. For example, since 2005, global cross-border transactions related to research and development (R&D) services, on average, grew at 10 percent per year. (WTO, 2019). By 2020, R&D-related services accounted for 18 percent of U.S. and 13 percent of German services imports.[2] However, while knowledge-related services play an increasingly important role in international trade, evidence of their effect on innovation is limited.

In this paper, we study empirically and theoretically how acccess to foreign knowledge via services trade affects firm-level innovation and aggregate welfare. Our analysis leverages novel data from Germany that merges information on the universe of firm-level services trades from the Statistics on International Trade in Services (SITS) with survey data on firms' innovation activities from the Mannheim Innovation Panel (MIP). We define and measure knowledge-related service imports as firm payments related to foreign i) research, development, and testing, ii) patents, licenses, inventions, and processes, iii) artistic copyrights, and iv) other rights, such as franchise fees or trademarks. Regarding firms' innovation activities, our data provide detailed information on firms' product and process innovation activity, as well as on innovation inputs, such as R&D expenditures.

To estimate the causal effect of access to foreign knowledge service on the innovativeness of firms, we construct firm-specific export supply shocks. Using a quasi-experimental shift-share design (Bartik, 1991; Goldsmith-Pinkham *et al.*, 2020; Borusyak *et al.*, 2021), our shocks leverage variation in i) countries' aggregate knowledge service exports to Germany and ii) firms' pre-estimation expenditures on knowledge service imports from different source countries. For identification, we follow Borusyak *et al.* (2021) and assume that our shift-share design combines plausibly exogenous export supply shocks common to all firms with a potentially endogenous measure of firm-level shock exposure.[3]

Based on our shift-share design, we find that greater access to foreign knowledge services leads a firm to be more innovative than its competitors. Doubling a firm's export supply of foreign knowledge services increases its propensity to introduce new or significantly

[1] See Shu & Steinwender (2019), Melitz & Redding (2021) and Akcigit & Melitz (2022) for recent overviews of the literature on trade and innovation.

[2] Cross-border transactions related to R&D services are included in two categories: R&D activities, and licenses for the use of outcomes of R&D (WTO, 2019). R&D services import shares are calculated from the WTO Stats dashboard by dividing the sum of services imports related to "research and development" and "charges for the use of intellectual property" by a country's total commercial service imports.

[3] Following Borusyak *et al.* (2021), we show that the statistical properties of our knowledge service export supply shocks corroborate the plausibility of these assumptions.

improved products or processes by 0.4 to 1.8 percentage points. We find comparable effects across a rich set of innovation outcomes, providing evidence that access to foreign knowledge via services trade improves innovation outcomes on both the extensive and intensive margin. Regarding innovation inputs, our results show that improved access to foreign knowledge services leads firms to raise their domestic R&D expenditures, suggesting that foreign knowledge is complementary to domestically sourced innovation inputs. Lastly, the effect of services trade on innovation appears to be limited to knowledge services - an increase in a firm's export supply of services not explicitly related to foreign knowledge has no positive effect on innovation.

We then develop a theory of knowledge services trade and innovation to rationalize our empirical findings and assess their aggregate implications. In the model, heterogeneous firms set prices under monopolistic competition with variable markups and combine domestic R&D and imported knowledge services to generate profit-enhancing innovations. Imports are subject to fixed and variable trade costs, implying that not all firms find it profitable to source innovation inputs from abroad. Selection into importing and endogenous competition via variable markups imply that aggregate shocks to services import costs have unequal direct and indirect effects across firms and induce within-industry reallocations of innovativeness, profits, and employment. We characterize the model-implied gains from services trade, showing how the welfare effects of knowledge services trade are summarized by a few statistics capturing how shocks the innovation costs of firms translate into market-wide changes in competition, entry, and consumer prices.

To quantify the gains from trade in knowledge services, we show how our reduced-form estimates help inform the key structural elasticities capturing the returns to innovation. To calibrate the remaining statistics, we utilize markup estimates by Ganglmair *et al.* (2021) and cost pass-through estimates by Amiti *et al.* (2019). We find that the gains from services trade are sizeable: Our estimates suggest that a one percent decline in trade costs would lead to an increase of GDP by around 0.03 percent. Moreover, the associated gains in household welfare, which account for changes in the number of available varieties and resource reallocations across firms, exceed those implied by changes in GDP. Given that the barriers to services trade remain substantial, our results suggest that current and future policy efforts to liberalize trade in services are crucial to unlocking the gains from globalization.

Related Literature This paper is the first to systematically analyze the causal effects of trade in services on firm innovation. We contribute to three strands of literature addressing the connections between international trade and innovation.

Trade and Innovation. Our work relates to a vast body of research studying the effects of international trade on innovation (see Shu & Steinwender (2019), Melitz & Redding

(2021), and Akcigit & Melitz (2022)). Empirically, much of this work provides evidence on the connection between innovation and exporting (Lileeva & Trefler, 2010; Aw *et al.*, 2011; Bustos, 2011; Lim *et al.*, 2022) or import competition (Bloom *et al.*, 2015; Bombardini *et al.*, 2017; Fieler & Harrison, 2018;; Fieler *et al.*, 2018; Autor *et al.*, 2020; Chen & Steinwender, 2021). We relate most closely to empirical work examining how intermediate good imports affect productivity and innovation, e.g., Goldberg *et al.* (2010), Topalova & Khandelwal (2011), Halpern *et al.* (2015), Ariu *et al.* (2019), and Eppinger (2019). Our work is the first to document a causal relationship between a rapidly growing subset of service types and firm-level innovation outcomes.

Theoretically, we highlight a new channel shaping the static gains from trade in models with product differentiation and imperfect competition described in, e.g., Krugman (1979), Helpman & Krugman (1987), Melitz (2003), Arkolakis *et al.* (2012), and Arkolakis *et al.* (2019). Like other static models of endogenous innovation and competition (Dhingra, 2013,Aghion *et al.*, 2022) our work highlights the importance of endogenous changes in competition and entry for the welfare effects of trade.[4]

Trade in Services. Our paper adds to the growing literature on services trade (Francois & Hoekman, 2010, Benz *et al.*, 2020). One stream of research investigates the determinants of services trade flows (Mattoo & Sauve, 2007; Lipsey, 2009; Breinlich & Criscuolo, 2011; Jensen, 2011; Borchert *et al.*, 2013; Miroudot *et al.*, 2013; Ariu, 2016, Christen *et al.*, 2019; Eaton & Kortum, 2019), while another studies the effects of service trade on various economic outcomes (Jensen, 2011; Arnold *et al.*, 2011; Ariu, 2016; Lejarraga & Oberhofer, 2015; Eppinger, 2019; Hebous & Johannesen, 2021; Bamieh *et al.*, 2022). While previous literature has discussed the possibility that services trade may catalyze international knowledge transfers, e.g., in Francois & Hoekman (2010) and Ariu *et al.* (2019), our paper is the first to provide direct evidence on this chanel.

External Knowledge Management. Finally, we contribute to the literature studying the strategic management of external knowledge (Cassiman & Veugelers, 2006; Grimpe & Kaiser, 2010; Hagedoorn & Wang, 2012), and, in particular, innovation offshoring (Rosenbusch *et al.*, 2019; Tojeiro-Rivero *et al.*, 2019; Zhong *et al.*, 2022). Innovation offshoring, the management practice of sourcing innovation inputs abroad, includes both internal offshoring to foreign subsidiaries and external offshoring to external trade partners.[5] Our work contributes by exploiting trade in knowledge-related services to obtain systematic insights into the effects of innovation offshoring through external partners.

[4] Our theory abstracts from dynamic gains from innovation in growth models, analyzed, e.g., by Romer (1990), Grossman & Helpman (1991), Aghion & Howitt (1992), Ventura (1997), Eaton & Kortum (1999), Costantini & Melitz (2007), Atkeson & Burstein (2011), Sampson (2016), Buera & Oberfield (2020), Perla *et al.* (2021), Impullitti *et al.* (2022), Akcigit *et al.* (2021).

[5] In meta-analysis of a large set of quantitative studies, Rosenbusch *et al.* (2019) document a positive relationship between innovation offshoring and innovation performance, suggesting there is no statistical difference between the innovation impact of offshoring via subsidiaries and via external partners.

2 Trade in Services and innovation: data, variable construction, and descriptive statistics

2.1 Data Sources

We merge data on firms' innovation activities from the Mannheim Innovation Panel (MIP, Peters & Rammer, 2013) with administrative data on exports and imports of services by firms from the Statistics on International Trade in Services database (SITS, Biewen & Meinusch, 2021). The merging took place at the Research and Data Service Centre of the Bundesbank, the German central bank.

The MIP is an annual survey of a representative sample of manufacturing and service sector firms conducted by the ZEW - Leibniz Centre for European Economic Research - as part of the European Community Innovation Surveys. The data provide detailed firm-level information on the introduction of new or improved products, services, and processes, the degree of success achieved through product or process innovations, and expenditures on innovation. Moreover, the data contain information on general firm characteristics, such as size, age, industry, region, company group membership, and performance (e.g., revenues, export sales, profitability).

The SITS database is collected and administered by the Deutsche Bundesbank to compile Germany's balance of payments statistics. The data contain the universe of service trade between German residents - firms, individuals, and government agencies - and non-residents for all transactions exceeding a total monthly value of €12,500. In terms of coverage, we observe unit-level transaction values of services exports and imports by country and service type at a monthly frequency for the years 2001 to 2012. The classification of service types follows the Balance of Payments Manuel, and covers over 130 categories.[6] Trade flows in our data cover the following three modes of service trade defined in the WTO's General Agreement on Trade in Services (GATS):

1. Mode 1: Cross-Border trade - A service is provided from a member of country A to a member of country B across borders.
2. Mode 2: Consumption Abroad - A service is provided from a member of country A to a member of country B (or its property) within country A.
3. Mode 4: Presence of Natural Persons - A natural person from country A provides a service to a member of country B within country B.

[6] See Biewen & Meinusch (2021) for a detailed overview of the service types covered in the data.

2.2 Variable Construction

2.2.1 Firm Innovation

We use two yearly survey questions from the MIP data to define our broadest measure of firm innovation: i) a question asking whether firms introduced product innovations, defined as new or significantly improved products or services, within the last three years, and ii) a question asking whether a firm introduced process innovations, defined as new or significantly improved cost-reducing internal processes, during the last three years. Our baseline measure of firm innovation success takes the form of a dummy variable equal to one if a firm answered yes to at least one of the two questions and zero otherwise.

Further, to distinguish whether a firm introduced product or process innovations, we construct one dummy variable indicating that a firm introduced product or service innovations and another dummy indicating the introduction of process innovations. Finally, we add variables that allow distinguishing innovation outcomes across firms at the intensive margin. For product innovation, we extract information on i) yearly revenue shares attributable to new or significantly improved products or services and ii) yearly revenues from new or significantly improved products or services. Regarding process innovation, we extract information on i) the percentage point reduction in yearly unit costs attributable to new or improved processes and ii) the value of total yearly cost savings due to process innovations.[7]

Regarding innovation inputs, we extract information from the MIP data on firms' yearly R&D expenditures.

2.2.2 Knowledge Services

We are interested in assessing whether trade in services impacts innovation by providing firms with access to foreign knowledge. To this end, we classify for types of services as potential knowledge catalysts. Using the most disaggregated classification in the 5th Balance of Payments Manuel, our definition of "knowledge services" comprises transactions related to (i) research, development, and testing (BPM5 code 511), (ii) patents, licenses, inventions, and processes (502), (iii) artistic copyrights (501), and (iv) other rights, such as franchise fees, trademarks, and marketing rights (503). All these service categories are commonly subject of policy debates around the regulation of international knowledge and intellectual property dissemination (WTO, 2022). In Appendix C we provide concrete examples of international knowledge transfers captured by each of these ser-

[7] Revenue shares, total revenues, average cost reductions, and total cost reductions refer to the current year. The total yearly revenues with new or significantly improved products or services are calculated by multiplying firms' revenue shares with new or significantly improved products or services with their total revenues.The value of cost reductions are proxied by multiplying the stated percentage cost reduction resulting from process innovations by firms' total revenues.

vice types, including, e.g., the recent research collaboration between the U.S.-based firm Pfizer and the German company BioNTech that led to the development of mRNA-based vaccines against COVID-19.

2.2.3 Additional Firm Characteristics

We use our data to extract an array of firm characteristics that are likely determinants of cross-sectional differences in innovation success and will serve as controls in our empirical exercises.

Innovation Effort. Firms that consistently devote resources to innovation activities are more likely to introduce new or significantly improved products, services, and processes. They may also have a higher demand for foreign knowledge services due to, e.g., lower sourcing costs resulting from a higher knowledge stock or potential complementarities between domestic and foreign innovation inputs. To control for differences in innovation efforts across firms, we create dummy variables indicating a firm's involvement in i) occasional and ii) continuous engagement in internal R&D activities.

Foreign Market Exposure. A large body of empirical evidence suggests that firm-level innovation outcomes are linked to participation in international markets via, e.g., exports or multinational activity. To control for international market participation not related to service imports, we use the MIP to extract information on firm exporter and multinational status. Further, we use the SITS to control for potential unobserved differences in innovation activities across firms related to the particular countries from which firms source knowledge services. To do so, we construct separate "import-country-combination" fixed effects for each unique combination of possible source countries.[8]

Firm Structure. A firm's size and age tend to be negatively associated with the resource constraints it faces. Thus, larger and older firms may be more likely to find it profitable to incur potential fixed costs related to innovation activities and trade participation. To account for firm size, we construct a dummy variable taking the value one if a firm has more than 250 employees and a dummy indicating whether a firm is a member of a national company group. To control for age, we add a dummy variable indicating if a firm is more than 21 years old.[9]

Market Environment. To control for unobserved differences in innovation activities and demand for foreign knowledge services between industries, we construct three-digit industry fixed effects. Further, we account for unobserved differences in innovativeness or

[8] For example, three firms that import from France, France and Spain, and France and Austria each are assigned a separate fixed effect. Our import-combination fixed effects cover over 3,600 unique country combinations.

[9] Similarly, our company group dummies control for the ownership structure of a firm. Firms' ownership structure is linked to their governance and access to resources. Both are likely determinants of innovation outcomes and service import activities.

service imports stemming from a firm's location (e.g., due to taxes or market access) by adding fixed effects for the Federal state where a firm is headquartered.

2.3 Descriptive Statistics

Aggregate Statistics on Knowledge Services Trade Aggregate statistics from the SITS database indicate that Germany's annual knowledge service imports grew at an average rate of five percent per year from 2005 to 2012. Total imports on average, were equal to €13 billion, corresponding to about 10 percent of economy-wide innovation-related and 21 percent of total R&D expenditures. Table 1 lists the source countries and industries with the highest shares in Germany's knowledge service imports during our sample period. Countries accounting for more than five percent of total imports are the United States, the United Kingdom, Switzerland, France, and Austria. Industries accounting for more than five percent of imports are "chemicals and chemical products," "other business activities," "motor vehicles, trailers and semi-trailers," "electrical machinery and apparatus," "wholesale trade and commission trade," and "research and development."[10]

Across the four service types included in our definition of knowledge services, "Research, development, and testing" accounted, on average, for 46 percent of total knowledge service imports. Payments related to "patents, licenses, inventions, and processes" accounted for the second largest share of knowledge service imports, averaging 35 percent of total knowledge imports. "Other rights" and "Artistic copyrights", respectively, accounted for 19 percent and 5 percent.[11]

Sample Statistics Our regression sample covers 11,151 firms and 26,512 firm-year observations between the years 2005 and 2012. Table 2 displays descriptive statistics. showing that the average yearly share of firms importing knowledge services in our sample is four percent. Among importers, the average value of yearly knowledge service imports equals €0.62 million.

Importing knowledge services is strongly associated with better innovation outcomes. First, importers of knowledge services report innovation success, the introduction of product innovations, or the introduction of process innovations more than twice as frequently as non-importers. Among knowledge importers, on average, new or significantly improved products accounted for 19 percent of yearly revenues, compared to 8.2

[10] "Other business activities" includes market research and technical consulting services, potentially explaining this sector's high share in overall knowledge service imports. "Wholesale and commission trade" contains several services that are likely to import knowledge-related services, such as the wholesale of machinery, industrial equipment, ships, aircrafts, or chemical products. According to Eurostat, the wholesale trade and commission trade industries were among the largest within the EU-27's non-financial business economy (NACE Rev. 1.1. Sections C to I and K) in 2009.

[11] See Eppinger (2019), Kelle & Kleinert (2010), Kelle *et al.* (2013), and Hebous & Johannesen (2021) for other statistics on Germany's services trade.

percent among non-importers. New processes, in turn, reduced the unit costs of importers by 2.6 percent, compared to 1.2 percent among non-importers. The total revenue of product innovations is 20 times, and cost reductions through process innovation are 37 times larger for knowledge service importers than non-importers. Lastly, importers of knowledge services are more likely to engage in internal innovation efforts. Compared to 18 percent of non-importers, 61 percent of knowledge service importers continuously engage in internal R&D.

Regarding other firm characteristics, knowledge service importers tend to be larger and more integrated into international markets. Among importers, 43 percent have more than 250 employees, compared to seven percent in the sample of non-importers. The share of firms that are part of a multinational company is five times higher among importers compared to non-importers, and firms that import knowledge services are almost twice as likely to be exporters. Differences concerning age, occasional internal R&D activities, and being a member of a national company group are less pronounced.

3 Access to Foreign Knowledge Services and Innovation

This section empirically assesses how access to foreign knowledge services impacts firm-level innovation activities. First, we begin laying out our empirical strategy, followed by presenting our empirical results.

3.1 Empirical Strategy

To assess the effect of access to foreign knowledge services on firm innovation, we estimate the following empirical specification,

$$Y_{ft} = \beta S_{ft} + \gamma' X_{ft} + \alpha + \epsilon_{f,t}. \tag{1}$$

Y_{ft} is an innovation outcome of firm f at time t. S_{ft} is a firm-specific export supply shock to knowledge services that we describe in great detail further below. Our parameter of interest β describes the effect of changes in access to foreign knowledge services on firms' innovation outcomes. α is a set year, industry, regions, and import-country-combination fixed effects.[12] X_{ft} is a vector of time-varying firm controls and ϵ_{ft} is an idiosyncratic error term.

We rely on a quasi-experimental shift-share design (Bartik, 1991,Goldsmith-Pinkham *et al.*, 2020,Borusyak *et al.*, 2021) to construct firm-specific export supply shocks to knowledge

[12] We omit firm fixed effects in our specification because we, on average, observe a given firm for less than three years. Country-combination fixed effects, however, already absorb about 80 percent of the variation in our export supply shocks. Thus, their inclusion already represents a restrictive specification.

services. Our shocks exploit variation in i) a set of shocks common to all firms in a given industry and ii) firm exposure to a given shock. More precisely, we use the information on the universe of services trades from the SITS data to construct firm-specific shift-share variables taking the following form

$$S_{ft} = \begin{cases} \sum_n \omega_{fnt_o} I_{nt,-i(f)}, & \text{if } f \text{ is a knowledge service importer in 2002-04,} \\ 0 & \text{if } f \text{ is not a knowledge service importer in 2002-04.} \end{cases} \quad (2)$$

Common Shocks. The shocks $I_{nt,-i(f)}$ capture industry-level variation in the export supply of knowledge services. $I_{nt,-i(f)}$ is the total value of knowledge service exports from a country n to German in year t by all units in the SITS database active out f's industry $i(f)$. We assume that the demand for knowledge services from a given country n is uncorrelated across industries after conditioning on fixed effects α and firm controls X_{ft}. Given the "leave-one-out" correction,[13] variation in $I_{nt,-i(f)}$ then captures shocks to the export supply of knowledge services common to all firms in an industry i.[14]

Shock Exposure - The weight ω_{fnt_0} measures the exposure of a firm f to an export supply shock from country n in year t. It is defined as the share of firm f's knowledge service imports attributable to country n during the pre-estimation period t_0 spanning the years from 2002 to 2004.[15] The idea behind fixing shock exposure in a pre-period t_0 is that current import shares may be affected by lagged shocks in a way that is correlated with unobservables ϵ_{ft}.

Shift-Share Variable - Following (2), we sum the product of ω_{fnt_0} and $I_{nt,-i(f)}$ across all source countries n for each firm f and year t. The variable takes the value zero for all firms not importing knowledge services during the pre-estimation period t_0, effectively assigning them to a placebo country that never exports knowledge services.

Identification The identification of our parameter of interest β requires exogeneity of the shocks (Borusyak *et al.*, 2021), or exogeneity of the exposure shares (Goldsmith-Pinkham *et al.*, 2020). We assume that identification, in our setting, stems from the exogeneity of shocks. Indeed, it is *a priori* plausible that unobserved shocks affecting *firm-level* innovation outcomes are not systematically correlated with aggregate service

[13] Leaving out a firm's industry when estimating aggregate export supply shocks purges a mechanical source of bias arising from the fact that unobserved firm-level shocks to the demand for knowledge services are mechanically correlated with aggregate import volumes.

[14] Examples of such aggregate supply shocks include changes in i) the productivity at which a given country n produces knowledge services, ii) the services trade barriers between a given country $n$and Germany or iii) the quality of knowledge services provided by country n.

[15] Past import shares serve as a proxy for exposure if, e.g., knowledge services from different suppliers are imperfectly substitutable for a firm due to search costs, fixed costs associated with establishing supplier-buyer relationships, or unobserved preference shocks.

imports *in other industries* after conditioning on observables and fixed effects.[16] Under this assumption, a causal interpretation of β requires shocks to be conditionally quasi-randomly assigned and the existence of many only weakly correlated shocks. To corroborate these assumptions, we follow Borusyak *et al.* (2021) and investigate (i) the concentration of the exposure weights, (ii) the number, variation, and correlation structure of the shocks, and (iii) the predictive power of our export supply shocks for past innovation outcomes and the set of control variables.

Exposure Concentration. The shocks $I_{nt,-i(f)}$ feature variation across 62 countries, 43 industries, and eight years. Due to the leave-one-out correction, our shift-share variable does not have a convenient shock-level representation. Nevertheless, the measures proposed by Borusyak *et al.* (2021) to assess the assumption of many shocks are helpful in informing the dispersion of exposure weights in our data. In terms of average shock exposure, $\bar{\omega}_n = \frac{1}{N_f}\sum_f \omega_{fnt_0}$, where N_f is the number of firms in the sample, the largest value of $\bar{\omega}_n$ in our data equals 0.19. The inverse Herfindahl index (HHI) of average shock exposures, $1/\sum_{ni}\bar{\omega}_{ni}^2$, equals 16.4. In an equivalent shock-level regression, this would indicate an "effective" number of shocks equal to 16.4 per observation year. While these statistics are indicative of an adequate sample size,[17] we address the threat of overstating the statistical significance of our estimates in one of our robustness exercises.[18]

Shock Variation. The mean of our exposure-weighted country-industry shocks is around €33 million with a standard deviation of around the same magnitude. Residualizing our common shocks on years barely changes their standard deviation. Thus, there is sizable within-year shock variation across country-industry pairs.

Shock Correlation. We estimate the significance levels of all pairwise correlations between our common shocks. The mean significance level of all pairwise correlation coefficients equals 33 percent, while the first quartile equals 7 percent, the second equals 25 percent, and the third quartile equals 56 percent. Therefore, more than 75 percent of common shock correlations represent only weakly significant or insignificant correlations.[19]

Quasi-Random Assignment. To examine the conditional quasi-random assignment of shocks,

[16] We provide a more detailed discussion of the threats to exogneity and their relationship with our common shocks in Appendix D.

[17] Borusyak *et al.* (2021) conduct Monte-Carlo simulations to assess the finite-sample performance of shock-level shift-share instruments across various exposure concentration levels in the context of the "China Shock" (Autor *et al.*, 2013). Their approximation performs well for an effective total number of 20 shocks, yielding false rejection rates for a 5% level test of the true null that the coefficient of interest is zero of 7.3%. For an effective total number of 50 shocks, the false rejection rate decreases to 5.6%, increasing to 9% for an effective total number of 10 shocks.

[18] Specifically, we limit the estimation sample to firms with positive knowledge service imports during the pre-estimation period, which increases the inverse HHI of exposure weights to 51.6, and decreases the maximum average exposure across different shocks to 0.06.

[19] Restricting our estimation sample to the subsample of knowledge service importers also strengthens the plausibility of the assumption that our shocks are only weakly correlated. The mean significance of the pairwise shock correlations in this subsample equals 43 percent, while the first quartile equals 14 percent, the second quartile 41 percent, and the third quartile 70 percent.

we implement falsification tests proposed by Borusyak *et al.* (2021). If common shocks are conditionally as-good-as-randomly assigned to firms, the shift-share variable should neither predict the controls nor firms' past innovation activities. Table 3 shows the results of separately projecting the shift-share variable on the set of firm-level controls and our lags of our broadest innovation indicator. We find no statistically significant effect of our shift-share variable on our controls or lagged innovation activity.[20]

3.2 Export Supply Shocks to Knowledge Services and Firm Innovation

We begin our empirical analysis by assessnng how access to foreign knowledge affects our broadest measure of firm innovation success corresponding to a dummy indicating the introduction of new products, services, or processes. Table 4 reports the associated coefficient estimates of β in (1) across parallel specifications.[21] The first column displays estimates from a specification including year fixed effects and no firm controls, while the remaining subsequently add industry- (column 2), state- (column 3), and import-country-level fixed effects (column 4). Column 5 adds controls for general and column 6 for innovation-related firm characteristics.

Across all specifications, we find that an increase the supply of foreign knowledge services has a positive and statistically significant effect on a firm's propensity to innovate. In terms of magnitude, our estimates suggest that doubling a firm's access to foreign knowledge services raises the likelihood of process or product innovations by 0.4 to 1.8 percentage points relative to untreated firms.[22]

Additional Checks Before providing further insights on the implications of foreign knowledge services for firms' innovation activities, we conduct a suite of additional checks to solidify the causal interpretation of our estimate.

Excluding Non-Importers. Due to the small share of knowledge service importers in our sample, a substantial part of the variation in shock exposure across firms stems from the extensive margin. To test whether our results are driven primarily by extensive margin variation in shock exposure, we re-estimate (1) restricting the sample to firms with positive knowledge service imports in the pre-period. Removing non-importers also raises the effective size of our sample by further reducing the concentration of exposure weights across shocks.[23] Table 5 shows that our estimate of β persists at 0.004 and remains statis-

[20] In an additional robustness test, we use lags of our control variables as alternative outcomes. We do not find a statistically significant coefficient for our shift-share variable in these specifications.

[21] Standard errors are robust and clustered at the firm and country-combination-level. The reported levels of statistical significance are robust to implementing the standard error correction by Adao *et al.* (2019) addressing the concern that firms with similar exposure shares have similar residuals.

[22] A "doubling of supply" corresponds to an increase in treatment of about 1 standard deviation.

[23] All non-importers have exposure shares equal to one for their corresponding common placebo shock. Therefore, they increase the highest average exposure and reduce the inverse Herfindahl index. Re-

tically significant.

Excluding Multinationals. The intangible nature of services may tempt multinationals to report de facto non-existing cross-border service transactions to minimize their global tax burden by strategically shifting profits from high- to low-tax countries (Hebous & Johannesen, 2021). To ensure that our findings are not contaminated by issues related to multinationals, we repeat our empirical analysis, excluding firms that are part of a multinational company group. Table 5 displays the estimates of this subsample regression, showing that our estimated effect of export supply shocks on firm innovation success remains positive and statistically significant. However, compared to our baseline estimate, the magnitude of the estimated effect doubles from 0.004 to 0.008, suggesting that the inclusion of multinationals works against our obtained finding of a positive effect of knowledge service export supply shocks on innovativeness.

Shift-share construction. To add further robustness to our results, we consider alternative approaches to constructing export supply shocks to knowledge services. First, our baseline approach effectively limits shock exposure to firms founded before the year 2005. As an alternative, we change the reference period t_0 for shock exposure to the first year a firm is observed importing knowledge services in the SITS. Second, we investigate whether our results are driven by a few shocks with large leverage, i.e., the small group of countries accounting for the majority of service exports to Germany listed in Table 1.[24] To do so, we construct two sets of shift-share variables analogous to (2), but limiting the set of source countries to either only or all but the top five countries in terms of export volumes. Table 6 displays the results of re-estimating specification (1) replacing our baseline export supply shocks with these three alternative shift-share variables. Across all specifications, the estimated effects remain very close in magnitude to our baseline estimates and are statistically significant.

Service imports not related to knowledge. It is conceivable that our estimates capture a broader relationship between services imports and innovation, rather than the particular impact of knowledge-related service supply shocks. This may be the case if, e.g., shocks to the export supply of knowledge-related services are highly correlated with changes in firm-level acess to other types of service imports. To address this concern, we construct firm-level export supply shocks analogous to (2), but to all service types other than those related to knowledge.[25] Table 6 shows that replacing knowledge with non-knowledge-related service export supply shocks in (1) yields a negative estimated effect of service export supply shocks on innovation that is very close to zero and statistically

moving them increases the inverse Herfindahl index of average shock exposures from 16.4 to 51.6, and reduces maximum average exposure from 0.19 to 0.06.

[24] Sixty-eight percent of the total value of knowledge service exports to Germany stemmed from five countries between 2005 and 2012.

[25] The shocks are constructed as in (2) using data on firm-level and economy-wide imports of service types not included in knowledge services.

insignificant at a p-value of 5%. Including export supply shocks to both knowledge and non-knowledge services into the specification, we obtain a precisely estimated (negative) zero effect for supply shocks to non-knowledge-related services, while the estimated effect of access shocks to knowledge services remains identical to that reported in Table 4.

3.3 Product and process innovation

To provide further insights on the implications of foreign knowledge for firm innovation, we broaden our analysis to include richer set of innovation outcomes.

Extensive Margin Continuing to focus on the extensive margin of innovation success, we separately investigate the effects on product and process innovation. Table 7 reports the estimates of β in (1) for two binary outcome variables indicating the introduction of (i) new or significantly improved products or services and (ii) new or significantly improved cost-reducing processes.

Both specifications yield very similar, statistically significant point estimates, showing that doubling a firm's access to foreign knowledge leads to a 0.4 p.p. increase in the probability of introducing new products and a 0.5 p.p. increase in the chance of introducing new processes. However, given that among the firms in our sample, product innovations occur, on average, twice as frequently as process innovations, the implied, relative effects of a change in foreign knowledge access may differ substantially across product and process innovation activities.

Intensive Margin We now investigate how export supply shocks impact firms' innovation output at the intensive margin. First, regarding product innovation, Table 7 shows that a 1 point increase in foreign knowledge supply is associated with a statistically significant 0.1 percent increase in firm revenue from new or significantly improved products. However, we find a statistically insignificant, albeit positive effect on the revenue share of product innovations. This may indicate that within-firm cannibalization effects - reductions in the demand for old as a firm introduces new products - are moderate.

Regarding process innovation, Table 4 shows that a 1 point export supply shock to foreign knowledge raises the percentage reduction in unit costs attributable to new processes by 0.06 percent. Further, our estimates imply that 1 point increase in export supply raises total reduction in costs through process innovations by 0.08 percent.

3.4 Domestic R&D Expenditures

To shed light on the complementarity between foreign- and domestically-sourced innovation activities within firms, we assess how changes in access to foreign knowledge services affect a firm's expenditures on domestic R&D services. To measure firms' domestic R&D expenditures, we subtract the value of a firm's yearly imports of R&D-related services from its total annual R&D expenditures reported in the MIP.

Table 8 reports the results of re-estimating (1) using logged domestic R&D expenditures as a dependent variable across parallel specifications with varying controls and fixed effects. The coefficient estimates indicate that access to foreign knowledge services does not cause firms to reduce expenditures on domestically sourced R&D. On the contrary, we find a positive and statistically significant effect on domestic R&D expenditures in most specifications. According to our estimates, a one percent increase in exposure to foreign knowledge service supply shocks increases domestic R&D expenditures by 0.05 to 0.34 percent across specifications that include year, industry, and region fixed effects, as well as all time-varying firm controls. Adding import-country-combination fixed effects, we find a positive, albeit statistically insignificant relationship between foreign knowledge service imports and domestic R&D expenditures with a coefficient estimate for β of 0.03.

4 The Aggregate Gains From Knowledge Services Trade

To rationalize our empirical findings and assess their aggregate implications, we develop a model of services trade with endogenous competition and innovation.

4.1 Model Setup

We model a small open economy populated by a unit mass of identical households that inelastically supply one unit of the only factor of production at a wage $w = 1$.

Households Preferences are additively separable over the consumption of differentiated varieties of different types $\theta \in \Theta$,

$$\mathcal{U} = \int_{\theta \in \Theta} u\left(q_\theta\right) dF(\theta),$$

where q_θ is the consumption of a variety θ, $dF(\theta)$ is a measure of varieties of type θ, which is described in detail further below, and the utility index $u(.)$ is increasing and concave.

Households maximize utility subject to the following budget constraint,

$$\int_{\Theta} p_\theta q_\theta dF(\theta) = 1 \tag{3}$$

where p_θ is the price of a variety of type θ. The expression for the budget constraint anticipates that there are no profits to be redistributed in equilibrium due to free entry. The demand for a variety of type θ is given by,

$$q_\theta = D(p_\theta \lambda) \tag{4}$$

where $D(.) \equiv (u')^{-1}(.)$. The marginal utility of income $\lambda = \int_\Theta u'(q_\theta) q_\theta dF(\theta) > 0$ is the unique endogenous demand shifter that indexes the degree of market-wide competition.

Firms Varieties are produced by monopolistically competititve, single-product firms under free entry.[26] Firms incur a fixed cost f_e in terms of domestic labor to enter. Upon entry, firms draw their type θ from a cumulative distribution function $G(\theta)$, and have the opportunity to make costly innovation investments to acquire knowledge k. Knowledge is excludable and acquired via an innovation process that combines domestic inputs R with foreign knowledge inputs I, $k_\theta(R, I) = \kappa_\theta(R, I)$.[27] We impose that, for all θ, $\kappa_\theta(.,.)$ is homogeneous of degree less than or equal to 1, increasing and concave in both its arguments. Knowledge lowers a firm's marginal costs of production $c_\theta(k)$, where $c_\theta(0) > 0, c'_\theta < 0, c''_\theta > 0$.

Domestic knowledge inputs are produced by a competitive sector at constant marginal costs c_r, and a price $p_r = c_r$. Foreign knowledge is accessible via services trade at a fixed cost f_I and a per-unit cost τ, both denominated in domestic labor. The price of foreign knowledge services τ is exogenous to the small open economy.

From (4), the price elasticity of demand faced by a firm of type θ is given by,

$$\varepsilon_\theta = \varepsilon(p_\theta \lambda) \equiv -\frac{\partial \log q_\theta}{\partial \log p_\theta} = -\frac{p_\theta \lambda D'(p_\theta \lambda)}{D(p_\theta \lambda)}. \tag{5}$$

A firm seeks to maximize the market value of a variety, v_θ, taking competition λ as given,

$$v_\theta = \max_{\mathbf{1}_I} \pi_\theta(\mathbf{1}_I) = \max_{\mathbf{1}_I} \max_{p,k} \left[p - c_\theta(k)\right] D(p\lambda) - \Gamma_\theta(k, \mathbf{1}_I), \tag{6}$$

where $\mathbf{1}_I$ is an indicator function taking the value 1 if $I > 0$, and $\Gamma_\theta(k, \mathbf{1}_I)$ denotes the

[26] In Appendix B.4, we develop an extension of the model featuring both process and product innovation.

[27] Our decision to model knowledge services as flexible inputs into the innovation process is motivated by the fact that firms' importer status is persistent in the data. Within sectors, 70% of firms found importing knowledge services in one year also import in the next.

costs of acquiring k units of knowledge, conditional on an importing regime $\mathbf{1}_I$,

$$\Gamma_\theta(k, \mathbf{1}_I) = \min_{R,I} p_r R + \tau I \ s.t. \ \kappa_\theta \left(R, \mathbf{1}_I I\right) \geq k, \tag{7}$$

A firms's profit-maximizing price is a markup μ_θ over marginal cost,

$$p_\theta = \mu_\theta c_\theta(k_\theta) \tag{8}$$

where the markup μ_θ is inversely related to the price elasticity of demand:

$$\mu_\theta = \mu(p_\theta \lambda) = \frac{\varepsilon(p_\theta \lambda)}{\varepsilon(p_\theta \lambda) - 1} \tag{9}$$

A firm of type θ decides how much knowledge k_θ to acquire by equating the marginal benefits and costs of innovation,[28]

$$-\frac{\partial c_\theta(k_\theta)}{\partial k} q_\theta = \frac{\partial \Gamma_\theta(k_\theta, \mathbf{1}_I)}{\partial k}. \tag{10}$$

and decides to import knowledge services if, and only if,

$$X_\theta = \frac{\pi_\theta\left(1\right)}{\pi_\theta\left(0\right)} \geq 1. \tag{11}$$

We assume that firms are ordered so that X_θ is strictly increasing and continuously differentiable in $\theta \in \Theta$. Denoting $\theta^* \equiv \inf\left\{\theta \in \Theta : X_\theta \geq 1\right\}$, firms with types $\theta < \theta^*$ only source knowledge inputs domestically, while firms with types $\theta \geq \theta^*$ also import foreign knowledge services.

The measure of varieties of type θ equals $dF(\theta) = MdG(\theta)$, where M is the equilibrium mass of entrants. Free entry implies that firms will enter the market until the expected value of a variety equals the fixed cost of entry:

$$\int_\Theta v_\theta dG(\theta) = f_e. \tag{12}$$

Equilibrium Consumers maximize utility taking prices as given, firms maximize profits taking other prices as given, and markets clear. An equilibrium satisfies equations (3), (4), (5), (6), (7), (8), (9), (10), (11), and (12).

Notation Denote $s_\theta = Mp_\theta q_\theta$ the sales density.[29] For two variables $x_\theta \geq 0$ and y_θ, we denote the $x-$weighted average of y_θ by $\mathbb{E}_x[y_\theta] \equiv \int_\Theta \frac{x_\theta y_\theta}{\int_\Theta x_\theta dG(\theta)} dG(\theta)$.

[28] The assumptions $c_\theta'' > 0$ and $\kappa_\theta'' < 0$ ensure that $-c_\theta''(k_\theta)q_\theta - \frac{\partial^2 \Gamma(k_\theta, \mathbf{1}_I)}{(\partial k)^2} < 0$.

[29] This is a density since $s_\theta \geq 0$ and $\int_\Theta s_\theta g(\theta) d\theta = 1$.

4.2 The direct and indirect effects of aggregate shocks to trade costs

To begin our analysis, we characterize how the profile of profits, prices, and innovation activity across firms responds to a change in the price of foreign knowledge τ. The envelope theorem implies that the response in profits of a firm θ to changes in trade costs is given by,

$$-\frac{\partial \ln \pi_\theta}{\partial \ln \tau} = \frac{\tau I_\theta}{v_\theta} - \varepsilon_\theta \frac{\partial \log \lambda}{\partial \log \tau}. \tag{13}$$

The first term on the right-hand side of (13) describes the direct effect of changes in trade costs on a firm's profits. Intuitively, in partial equilibrium, a decrease in trade costs weakly raises profits for all firms and more so for those with higher relative spending on foreign knowledge, captured by $\tau I_\theta / v_\theta$. In general equilibrium, profits also respond to adjustments in market-wide competition λ. Because profits weakly rise at the initial level of competition, competition must increase to ensure expected profits equal the fixed costs of entry. Indeed, in Appendix B we show that the free entry condition implies that,

$$-\frac{\partial \ln \lambda}{\partial \ln \tau} = \frac{1}{\mathbb{E}_v\left[\varepsilon_\theta\right]} \mathbb{E}_v\left[\frac{\tau I_\theta}{v_\theta}\right]. \tag{14}$$

Intuitively, lower values of $\mathbb{E}_v\left[\varepsilon_\theta\right]$ indicate that the average firm faces a less elastic demand curve, implying that a larger increase in competition is required to offset a given increase in expected profits upon entry. Together, equations (13) and (14) show that if firms with initially higher markups also rely more on knowledge imports, then a reduction in services trade costs shifts the profile of firm values towards initially more valuable firms, inducing a "Matthew Effect" (Mrázová & Neary, 2017).

$$-\frac{\partial \log \pi_\theta}{\partial \log \tau} = \left(\frac{I_\theta / v_\theta}{\mathbb{E}_v\left[I_\theta / v_\theta\right]} - \frac{\varepsilon_\theta}{\mathbb{E}_v\left[\varepsilon_\theta\right]}\right) \mathbb{E}_v\left[\frac{\tau I_\theta}{v_\theta}\right]. \tag{15}$$

Whether a given reallocation of profits is desirable from the perspective of households depends, in part, on the associated changes in consumer prices. Denoting the price cost pass-through of a variety θ by $\rho_\theta \equiv \frac{\partial \log \mu_\theta}{\partial \log c_\theta} = \frac{1}{1 - \frac{\mu'(p_\theta \lambda) p_\theta \lambda}{\mu(p_\theta)\lambda}}$, the response of firm-level prices to changes in trade costs can be written,

$$\frac{d \ln p_\theta}{d \ln \tau} = \rho_\theta \frac{d \ln c_\theta}{d \ln \tau} - (1 - \rho_\theta) \frac{d \ln \lambda}{d \ln \tau} \tag{16}$$

On the one hand, price responses depend on how a change in the costs of foreign knowledge affects the innovativeness and, thereby, production costs of firms. If markups are constant, $\mu' = 0$, then pass-throughs are complete, $\rho_\theta = 1$, and relative prices change in accordance with unit costs. However if a firm's desired markup declines in its price, when $\mu'(p\lambda) < 0$,[30] pass-throughs are incomplete, $\rho_\theta \in (0,1)$, and changes in competitive pressures $d\ln\lambda$ force firms to adjust prices via markups, even if trade costs do not direclty impact their knowledge acquisition and unit costs.

Finally, we examine how trade shocks affect knowledge acquisition. To a first order, that is,

$$-\frac{d\ln c_\theta}{d\ln\tau} = -\frac{\partial\ln c_\theta}{\partial\ln k_\theta}\frac{d\ln k_\theta}{d\ln\tau} = -\iota_\theta\varphi_\theta + \rho_\theta\iota_\theta\frac{\varepsilon_\theta}{\mathbb{E}_v\left[\varepsilon_\theta\right]}\mathbb{E}_v\left[\frac{\tau I_\theta}{v_\theta}\right], \tag{17}$$

where the share of innovation expenditures on foreign knowledge $\varphi_\theta \equiv \frac{\tau I_\theta(k_\theta)}{\tau I_\theta(k_\theta)+p_r R_\theta(k_\theta)}$, by Shephard's lemma, is the partial elasticity of innovation costs with respect to the price of imported knowledge services τ. ι_θ denotes the pass-through of shocks to the knowledge acquisition into unit costs,

$$\iota_\theta = \left(1 - \frac{c(k_\theta,\theta)}{c'(k_\theta,\theta)}\left(\frac{\partial\left(\frac{k_\theta c'(k_\theta,\theta)}{c(k_\theta,\theta)}\right)}{\partial k} + \frac{\partial\ln(\Gamma_\theta(k_\theta,\mathbf{1}_I))}{\partial k}\right) - \varepsilon_\theta\rho_\theta\right)^{-1}. \tag{18}$$

Equation (17) separates the partial and general equilibrium response of firm innovation to trade shocks. At the initial level of competition, innovation responses depend on how trade shocks impact firms' knowledge acquisition costs φ_θ, and the rate at which the returns to knowledge acquisition diminish, ι_θ. In turn, if $\iota_\theta > 0$, then rising competition discourages innovation to varying degrees across firms depending on markups, as well as price and innovation cost pass-throughs. E.g., ceteris paribus, firms with initially higher markups μ_θ and lower pass-throughs ρ_θ are more insulated from and hence their innovation activity responds less to changes in competition.[31]

In summary, firms are not equally exposed to changes in trade costs. In a given allocation, cross-sectional differences in exposure can be summarized by a few firm-level statistics: markups μ_θ, price pass-throughs ρ_θ, import intensities of knowledge services φ_θ and $\tau I_\theta/v_\theta$,as well as innovation pass-throughs ι_θ. Next, we show how the gains from services trade are summarized by aggregates of these statistics.

4.3 Welfare Analysis

We now characterize the gains from trade. First, we evaluate how changes in foreign knowledge services cost τ affect real GDP $\mathcal{Y}$. Changes in GDP $d\ln\mathcal{Y}$ are given by the Divisa price index, $d\ln\mathcal{Y} = -\mathbb{E}_s\left[\frac{\partial\ln p_\theta}{\partial\ln\tau}\right]d\ln\tau$. We prove the following in Appendix B.

[30] This is sometimes referred to as Marshall's second law of demand.

[31] Aghion *et al.* (2022) show that competition discourages innovation by more for less productive firms. In our model, markups, pass-throughs, and the innovation multiplier are the relevant statistics for characterizing how competition affects innovation incentives across firms. Firm productivity only matters to the extend that it may be a sufficient statistic

Proposition 1. *In response to a change in trade costs $d\ln\tau$, changes in GDP are given by,*

$$-\frac{d\ln\mathcal{Y}}{d\ln\tau}=\mathbb{E}_s\left[\rho_\theta\iota_\theta\varphi_\theta\right]+\mathbb{E}_s\left[1-\rho_\theta(1+\rho_\theta\varepsilon_\theta\iota_\theta)\right]\frac{\mathbb{E}_v\left[\tau I_\theta/v_\theta\right]}{\mathbb{E}_v\left[\varepsilon_\theta\right]},\tag{19}$$

where $\varphi_\theta=\frac{\tau I_\theta}{rI_\theta+p_rR}$, $\rho_\theta=\frac{\partial\ln p_\theta}{\partial\ln c_\theta}=1/(1-\frac{p_\theta\lambda\mu'(p_\theta\lambda)}{\mu(p_\theta\lambda)})$, and $\iota_\theta\equiv\frac{\partial\ln c_\theta}{\partial\ln\Gamma_\theta}$ is the innovation cost pass-through given by (18).

Intuitively, changes in GDP can be calculated by averaging the previously discussed direct and indirect price effects across firms. The first term in (19) describes how trade-induced changes in marginal innovation costs (φ_θ) are passed through to unit costs (ι_θ), and then prices (ρ_θ). The indirect effect is given by the second term, and captures how innovation incentives and markups respond to competition. An important implication of Proposition 1 is that GDP may decrease upon trade liberalization if the innovation-discouraging effects of rising competition outweigh the direct effect of falling trade costs.

Next, we characterize changes in welfare. Denote $\delta_\theta\equiv\frac{u(q_\theta)}{u'(q_\theta)q_\theta}\geq 1$ the infra-marginal consumer surplus generated by a firm θ, and $x_{\underline{\theta}}\equiv\lim_{h\to 0}x_{\theta-h}$. To a first order, changes in welfare equal,

$$d\ln\mathcal{U}=\underbrace{\left(\mathbb{E}_s\left[\delta_\theta\right]-1\right)d\ln M}_{\substack{\text{Consumer Surplus}\\ \text{from entry of varieties}}}-\underbrace{\left(s_{\theta^*}(\delta_{\theta^*}-1)-s_{\underline{\theta}^*}(\delta_{\underline{\theta}^*}-1)\right)\frac{g(\theta^*)}{1-G(\theta^*)}d\theta^*}_{\substack{\text{Consumer Surplus from changes}\\ \text{in selection into importing knowledge}}}-\underbrace{\mathbb{E}_s\left[d\ln p_\theta\right]}_{\substack{\text{Marginal Surplus}\\ \text{price changes}}},\tag{20}$$

Intuitively, welfare changes $d\ln\mathcal{U}$ account for the consumer surplus generated by the entry of new varieties $d\ln M$ or changes in selection into importing foreign knowledge via the first two terms on the right-hand side of (20). The final term is Shephard's lemma and captures changes in the Divisa price index. Hence, if the model did not allow fo the creation of varieties and changes in the importing behavior of firms, changes in welfare would coincide with changes in GDP. The following characterizes how welfare responds to a change in the import price of foreign knowledge services .

Proposition 2. *Upon a change in trade costs $d\ln\tau$, changes in welfare are given by,*

$$\begin{aligned}-\frac{d\ln\mathcal{U}}{d\ln\tau}=\;&\mathbb{E}_s\left[\delta_\theta-1\right]\left(\mathbb{E}_s\left[\varepsilon_\theta\rho_\theta\left(1+\iota_\theta\varepsilon_\theta\rho_\theta\right)\right]\frac{\mathbb{E}_v[\tau I_\theta/v_\theta]}{\mathbb{E}_v[\varepsilon_\theta]}-\mathbb{E}_s\left[\varepsilon_\theta\rho_\theta\iota_\theta\varphi_\theta\right]\right)-\mathbb{E}_s\left[\delta_\theta\right]\frac{d\ln\mathcal{Y}}{d\ln\tau}\\&+\left(s_{\theta^*}(\delta_{\theta^*}-\mathbb{E}_s\left[\delta_\theta\right])-s_{\underline{\theta}^*}(\delta_{\underline{\theta}^*}-\mathbb{E}_s\left[\delta_\theta\right])\right)\gamma_{\theta^*}\left(\frac{\tau I_{\theta^*}}{v_{\theta^*}}-(\varepsilon_{\theta^*}-\varepsilon_{\underline{\theta}^*})\frac{\mathbb{E}_v[\tau I_\theta/v_\theta]}{\mathbb{E}_v[\varepsilon_\theta]}\right),\end{aligned}\tag{21}$$

where $\delta_\theta\equiv\frac{u(q_\theta)}{u'(q_\theta)q_\theta}\geq 1$, $\varphi_\theta=\frac{\tau I_\theta}{rI_\theta+p_rR_\theta}$, $\rho_\theta=\frac{\partial\ln p_\theta}{\partial\ln c_\theta}=1/(1-\frac{p_\theta\lambda\mu'(p_\theta\lambda)}{\mu(p_\theta\lambda)})$, $\varepsilon_{\underline{\theta}^*}=\lim_{h\to 0}\varepsilon_{\theta^*-h}$, $\iota_\theta=\frac{\partial\ln c_\theta}{\partial\ln\Gamma_\theta}$ is the innovation cost pass-through given by (18), $\rho_\theta=\frac{\partial\ln p_\theta}{\partial\ln c_\theta}$, and $\gamma_{\theta^*}>0$ is the hazard rate of the profit distrbibution evaluated at the selection cutoff, $\gamma_{\theta^*}=\frac{g(\theta^*)}{1-G(\theta^*)}\left[\left.\frac{\partial\theta}{\partial\log X_\theta}\right|_{\theta=\theta^*}\right]$.

Proposition 2 decomposes the welfare effects of trade shocks into changes in GDP, entry and selection. The first term on the right-hand side of (21) describes how changes in entry contribute to rising competitive pressures upon trade liberalization. Intuitively, at the initial level of entry, a decline in trade costs raises competition for the average firm by enhancing the relative innovative capacity of knowledge importers. If this effect causes competition to increase beyond the level required for the free entry condition to hold, then entry must fall in equilibrium, and vice versa. The second line in (21) captures the contribution of changes in selection to welfare. Falling trade costs weaken (strengthen) selection into importing if, at the initial cutoff, the gap between the profits of the marginal importer θ^* and non-importer $\underline{\theta}^*$ increases.[32] Weaker (stronger) selection is welfare-enhancing if marginal importers initially generated a larger (smaller) consumption surplus than non-importers.

In summary, the gains from services trade can be summarized by a few statistics that capture how the features of demand (price pass-throughs ρ_θ, markups μ_θ, social rents δ_θ), trade $(\varphi_\theta, \tau I_\theta / v_\theta)$, and innovation (ι_θ) shape the direct and indirect effects of services trade liberalization. We now turn to quantifying our theoretical results, explaining, in particular, how we use our reduced-form estimates to inform the innovation cost pass-through ι_θ.

4.4 Quantification

4.4.1 Calibration

Identifying innovation cost pass-throughs To ease notation, we use θ and f interchangeably to refer to firms. Firms in our data report the percentage decrease in unit cost between $t-1$ and t attributable to process innovation, $Y_{\theta,t} = 1 - \frac{c_{\theta,t}(k_{\theta,t})}{c_{\theta,t-1}(k_{\theta,t-1})}$. To map this outcome into our model, first, imagine firms can source knowledge services from multiple countries $n \in \mathcal{N}$ at a fixed cost $f_{In,\theta}$ and variable cost τ_n. The model implies that $Y_\theta = -\frac{\partial \ln c_\theta}{\partial \ln k} d\ln k_\theta$ can be approximated as,

$$Y_\theta = -\mathbb{E}\left[\iota_\theta \varphi_\theta\right] \sum_{n\in\mathcal{N}} \omega_{\theta n} d\ln \tau_n + \alpha + \epsilon_\theta$$

where $\omega_{\theta n} \equiv \frac{\tau_n I_{\theta n}}{\sum_n \tau_n I_{\theta n}}$ is import share for firm θ on knowledge services from country n, $\alpha = \mathbb{E}_s\left[\iota_\theta \varphi_\theta \sum_{n\in\mathcal{N}} \omega_{\theta n} d\ln \tau_n\right]$, and ϵ_θ is a structural residual given by

$$\epsilon_\theta = \left(\mathbb{E}\left[\iota_\theta \varphi_\theta\right] - \iota_\theta \varphi_\theta\right) \sum_{n\in\mathcal{N}} \omega_{\theta n} d\ln \tau_n + \left(\rho_\theta \iota_\theta - \mathbb{E}\left[\rho_\theta \iota_\theta\right]\right) d\ln \lambda.$$

[32] Inspecting (21), a sufficient condition for $-d\theta^*/d\ln\tau < 0$ is that the marginal importing variety is less exposed to competition, $\varepsilon_{\theta^*} < \varepsilon_{\underline{\theta}^*}$.

Our empirical shift-share design, in turn, proxies structural shocks to trade costs via aggregate import volumes of knowledge services. Surpressing time subscripts, our reduced-form specification in (1) can be written,

$$Y_\theta = -\mathbb{E}\left[\iota_\theta \varphi_\theta\right](1-\bar{\sigma})\sum_{n\in\mathcal{N}}\omega_{\theta n} d\ln\tau_n + \gamma' X_\theta + \tilde{\alpha} + \epsilon_\theta,$$

where $\bar{\sigma}$ is the price elasticity of aggregate knowledge service imports. Under the identifying assumption of many, randomly assigned shocks, $Cov\left[\left(\sum_{n\in\mathcal{N}}\omega_{\theta n} d\ln\tau_n\right), \epsilon_\theta \left|X_\theta, \tilde{\alpha}\right.\right] = 0$, our OLS estimate of β in (1) on outcome Y_θ identifies,

$$\hat{\beta} = -\mathbb{E}\widehat{\left[\iota_\theta \varphi_\theta\right](1-\bar{\sigma})}.$$

Given that $\iota_\theta > 0$, our point estimate of $\hat{\beta} = 0.06$ implies that $\bar{\sigma} > 1$. If, further, $\bar{\sigma} > 2$, then our estimate provides an upper bound for $\mathbb{E}\left[\iota_\theta \varphi_\theta\right]$.

To infer $\mathbb{E}\left[\iota_\theta\right]$, we impose that primitives are such that $\mathrm{Cov}\left[\iota_\theta, \varphi_\theta\right] \geq 0$. Then, dividing our estimate by the average knowledge service import shares in the data,[33] $\hat{\beta}/\left(\frac{1}{T}\sum_{f,t}\varphi_{f,t}\right) = 0.6$, provides a lower bound for $\mathbb{E}\left[\iota_\theta\right]$, implying that, on average, a 1 point reduction in the marginal cost of acquiring knowledge lowers unit costs by 0.6 percentage points.

Other firm-level statistics To estimate markups, we utilize firm-level estimates for German firms by Ganglmair *et al.* (2021). Using the Orbis database, the authors deploy the production function approach by (De Loecker & Warzynski, 2012) to estimate firm-level markups.[34] Given that there are no systematic estimates of firm-level price cost pass-throughs for Germany, we use pass-through estimates by Amiti *et al.* (2019) for the Belgian manufacturing industry.[35]

We calculate the ratio of knowledge services imports to profits directly from the our data. To measure profits, we first subtract personal and material costs from firm revenues. Lacking information on investment and capital expenditures, we assume that firms have a common labor share of 60 percent.

Table 9 summarizes the estimates of the aggregates highlighted by the theory for the years 2005 to 2012.

[33] Average aggregate innovation expenditures in the MIP equal

[34] We infer the price elasticity of demand from their markup estimates, and calculate the relevant statistics in their sample for our estimation period from 2005 to 2012 and industries covered by the MIP data. One caveat of this approach is that, empirically, smaller firms tend to have smaller markups. Given that the Orbis database oversamples large firms, our markup estimates likely have a positive bias. We address this concern when we discuss our results.

[35] Amiti *et al.* (2019) estimate the average sales-weigthed elasticity of a firm's price with respect to its marginal cost to be equal to 0.6. In our model, which is consistent with the theoretical framework underlying the estimates by Amiti *et al.* (2019), this implies that sales-weighted average elasticity of prices with respect to market-wide competition λ equals 0.4.

4.4.2 Gains from Knowledge Services Trade

As a first pass, we quantify our theoretical results assuming that $G(\theta)$ is a degenerate distribution. Thereby, we effectively ignore welfare effects stemming from firm-level correlations between markups, pass-througs, and innovation multipliers at the firm-level, as well as of changes in selection.

First, we calculate the gains from knowledge services trade in terms of GDP, following Proposition 1. The results are displayed in table 10. Our estimates suggest that a 1 percent decline in knowledge services trade costs results in an increase in German GDP of 0.03 percent. The direct effect operating through reductions in the unit cost of knowledge service importers accounts for 103 percent of the total effect. Thus, in general equilibrium, the price-reducing indirect effect of rising competitive pressures operating via markups is dominated by the negative indirect effect of competition on innovation incentives.

Proposition 1 highlighted that changes in GDP ignore welfare effects stemming from the creation of varieties and changes in service imports at the extensive margin. Quantifying the full welfare gains from knowledge services trade requires estimates of the average inframarginal surplus that available consumption varieties provide. While no systematic estimates of the distribution of economy-wide infra-marginal surpluses exist, we can use the moment estimates in table 11 to assess whether the welfare gains from services trade are larger or smaller than those measured in terms of GDP.

Table 11 displays the overall welfare gains from knowledge services trade under two alternative assumptions on the size of economy-wide infra-marginal surpluses. We find that the welfare gains from services trade exceed those measured in terms of GDP, suggesting that the decrease in services trade costs induces welfare-enhancing entry behavior of firms. It is easy to see that the associated gains from additional entry scale with the size of the average consumer surplus: If the average consumer surplus equalled 5 percent, overall welfare gains from services trade are about 13 percent larger than those implied by GDP.

4.4.3 Discussion

We conclude by briefly discussing how changes to our model and calibration approach affect would affect our welfare analysis.

Markup estimates. Our markup estimates are relatively high. Assuming, instead, a moderate average markup of 1.05, we find that gains in terms of GDP equal 3.3%, a decrease of 0.2 percentage points. This reflects that a higher price elasticity of demand elasticity raises firm exposure to competition, lowering innovation incentives. In terms of welfare, however, the implied gains are twice as high as in our basline calculations. Intuitively, a higher average demand elasticity scales both the entry-discouraging (competition) and entry-encouraging (lower cost) effects of a fall in trade costs. Since the combined welfare effect of both forces is positive, the welfare gains from entry are lower markups imply significantly.

Process Innovation. In Appendix B.4, we develop a theoretical extension of our model featuring multi-product firms with endogenous product scope (Dhingra, 2013). In the model, knowledge acquisition no longer only only affects firms' production process, but also the costs of adding new varieties to their brand. When adding products, firms face a trade-off between raising profits on the extensive margin and lowering average profits per product. The latter effect arises due to cannibalization effects within firms. We show that welfare changes can be summarized via analogous sufficient statistics that capture the direct and indirect effects of trade shocks on firms' incentives to engage in product and process innovation.

5 Conclusion

In this paper, we used detailed data on the service imports and innovation activity of German firms to analyze how supply shocks to foreign knowledge impact firm innovation and market-wide economic outcomes. To disentangle the direction of causality between export supply of knowledge services and innovation, we utilized a shift-share design to construct firm-level access shocks to foreign knowledge services.

We first showed that increasing a firm's access to knowledge-related service imports raises its innovativeness. On the extensive margin, greater access to foreign knowledge makes a firm more likely to introduce new products and production processes. On the intensive margin, it leads to greater revenues from product and greater cost reductions from process innovation. Second, we showed the positive impact on innovation outputs is accompanied by higher expenditures on domestically-sourced R&D, suggesting that foreign- and indigeneously-sourced knowledge are complementary inputs into firms' innovation process. Third, we traced the direct and indirect effects of knowledge services trade in a theoretical model with endogenous innovation and competition. Based on our theoretical model, we quantified the gains from services trade via a small set of sufficient statistics informed by our data and estimates, showing that

Moreover, our results show the potential for sizable economic gains resulting from trade in knowledge services for the German economy. As a result, our estimates provide tentative policy advice. Policy makers should be aware of the importance of access to foreign knowledge services within their trade negotiations. First, foreign knowledge leads to an improved innovation performance of their domestic firms. Second, firms' domestic innovation efforts are complemented by foreign knowledge access. Therefore, the effect of an increase in foreign knowledge access via service trades is not limited to raising knowledge imports but raises indigenous innovation efforts at the same time. In addition, as a result of technological progress, it is reasonable to expect that trade in knowledge services is going to expand further. It might even be that the bulk of international service trade still lies ahead (Eppinger, 2019). Thus, policy makers should aim at utilizing this potential opportunity for economic gains resulting from increasing access to foreign knowledge. However, while trying to utilize the potential gains from service trade, it is necessary to consider the heterogeneous effects of different service types, as access to foreign services unrelated to knowledge did not seem to foster domestic firm innovation.

There are several starting points for future research. First, Germany was the focus of our study. However, the effects of foreign knowledge services might differ between more and less developed countries. At this point, the previous literature already showed that countries differ with regard to their imports of intermediate goods (Shu & Steinwender (2019)). As a result, studies exploring the importance of country characteristics for the effects of foreign knowledge service access would be promising additions to the literature. Second, our model predicts a heterogeneous relevance of knowledge service access between firms, whereas our analysis concentrates on the average firm. Thus, similar to contributing by focusing on country characteristics, systematically investigating the heterogeneous effects of foreign knowledge access for firms with different characteristics has the potential to provide valuable insights. Third, we cannot investigate the separate effects of different knowledge service types because of sample limitations. Thus, constructing a similar database for a larger sample, such as a large sample of US or EU firms, and repeating our analysis could contribute to the literature by shedding light on a potentially differing relevance of our covered knowledge service types.

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A Tables

Table 1 Knowledge Exports to Germany: Industry and Country Composition

	Share in Total Knowledge Service Imports (%)
Source Country	
United States	36
United Kingdom	10
Switzerland	9
France	8
Austria	5
Others	32
Sourcing Industry	
Chemicals and Chemical Products	22
Other Business Activities	17
Motor-Vehicles, Trailers, Semi-Trailers	15
Electrical Machinery and Apparatus	7
Wholesale and Commission Trade	5
Research and Development	5
Others	27

Notes: Estimates are based on the yearly average values of knowledge service imports by all German residents in the SITS data during the period 2005 to 2012.

Table 2 Descriptive Statistics

	Knowledge Service Importers		Non-Importers	
Firm Observations	512		10,639	
Firm-Year Observations	1,334		25,718	
Innovation-related firm characteristics	Mean	Standard Dev.	Mean	Standard Dev.
Knowledge Service Imports (in €millions)	0.64	0.75	0	0.0
Product or Process Innovation (%)	68.6	46.4	33.2	47.1
Product innovation (%)	64.5	47.9	29.8	45.7
Revenue Share Product Innovations (%)	18.6	25.5	8.2	18.6
Revenues Product Innovation (in €millions)	60.0	79.5	3.1	5.4
Process Innovation (%)	30.3	45.9	12.1	32.5
Unit cost reduction from process innovation (%)	2.6	5.9	1.2	4.7
Cost reduction from process innovation (in €millions)	1.74	24.9	0.05	0.7
Occasional internal R&D (%)	11.1	31.5	10.1	32.9
Continuous internal R&D (%)	61.9	48.6	18.9	30.2
General firm characteristics				
Older than 21 years (%)	53.1	49.9	42.2	49.4
More than 250 employees (%)	42.8	49.5	6.7	25.0
Domestic Company Group (%)	13.6	34.3	12.3	29.8
Exporter (%)	88.1	32.3	48.1	49.9
Multinational Company Group (%)	53.8	49.8	9.8	29.7

Notes: Descriptive statistics are based on averages across all firms and years in our estimation sample spanning the years 2005 to 2012. A firm's knowledge service imports are calculated from the SITS data, and defined as total yearly imports of services related to (i) research, development, and testing (BPM5 code 511), (ii) patents, licenses, inventions, and processes (502), (iii) artistic copyrights (501), and (iv) other rights, such as franchise fees, trademarks, and marketing rights (503). All other firm characteristics are taken from the MIP data.

Table 3 Falsification Test for the Quasi-Random Assignment of Common Shocks

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
								Innovation indicator		
Dep. Variable	Old	Large	Exporter	Multin. Group	Ger. Group	Occ. R&D	Cont. R&D	1-yr lag	2-yr lag	3-yr lag
$log(S_{ft}+1)$	0.003	0.002	−0.001	0.005	−0.002	−0.000	−0.000	0.002	0.001	0.004
	(0.004)	(0.002)	(0.001)	(0.003)	(0.002)	(0.002)	(0.002)	(0.003)	(0.005)	(0.004)
Old Firm		0.036***	−0.007***	−0.019***	−0.016***	−0.018***	−0.029***	−0.022***	−0.021***	−0.025***
		(0.004)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.002)	(0.004)	(0.003)
Large Firm	0.121***		−0.002	0.254***	0.240***	0.020***	0.142***	0.087***	0.117***	0.117***
	(0.007)		(0.006)	(0.008)	(0.012)	(0.004)	(0.006)	(0.004)	(0.005)	(0.013)
Exporter	0.008***	−0.000		0.070***	0.023***	0.082***	0.159***	0.074***	0.074***	0.078***
	(0.001)	(0.002)		(0.001)	(0.001)	(0.001)	(0.003)	(0.002)	(0.001)	(0.002)
Multinational	−0.046***	0.182***	0.157***		−0.220***	0.038***	0.123***	0.035***	0.015***	0.041***
Group	(0.004)	(0.004)	(0.008)		(0.001)	(0.002)	(0.014)	(0.003)	(0.005)	(0.005)
German	−0.030***	0.136***	0.041***	−0.174***		0.022***	−0.050***	0.043***	0.045***	0.025***
Group	(0.002)	(0.002)	(0.002)	(0.016)		(0.001)	(0.002)	(0.002)	(0.002)	(0.004)
Occasional	−0.042***	0.014***	0.157***	0.036***	0.027***		−0.302***	0.411***	0.402***	0.394***
R&D	(0.003)	(0.002)	(0.002)	(0.003)	(0.001)		(0.015)	(0.006)	(0.002)	(0.003)
Continuous	−0.051***	0.074***	0.258***	0.089***	0.046***	−0.231***		−0.570***	−0.547***	−0.502***
R&D	(0.007)	(0.002)	(0.005)	(0.008)	(0.002)	(0.008)		(0.007)	(0.012)	(0.014)
R^2	0.24	0.28	0.31	0.27	0.10	0.11	0.36	0.43	0.40	0.39
Year FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Industry FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
State FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Import-Origin FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Observations	26512	26512	26512	26512	26512	26512	26512	11106	8662	6005

Notes: The table presents the results of estimating (1) using firm controls and various lags of our innovation indicator as dependent variables. Estimates are based on OLS. Fixed effects are included as indicated. Standard errors are displayed in parentheses and clustered at the firm- and import-country-combination-level. P-values correspond to * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 4 Supply of foreign knowledge services and firm propensity to innovate

	(1)	(2)	(3)	(4)	(5)	(6)
Export Supply of Knowledge Services	0.018^{***}	0.011^{***}	0.010^{***}	0.004^{***}	0.004^{**}	0.004^{***}
	(0.002)	(0.001)	(0.001)	(0.002)	(0.002)	(0.001)
Old Firm					-0.042^{***}	-0.019^{***}
					(0.002)	(0.002)
Large Firm					0.163^{***}	0.079^{***}
					(0.004)	(0.004)
Exporter					0.177^{***}	0.063^{***}
					(0.002)	(0.002)
Multinational Group					0.100^{***}	0.021^{***}
					(0.010)	(0.002)
German Group					0.07^{***}	0.036^{***}
					(0.002)	(0.002)
Occasional R&D						0.503^{***}
						(0.002)
Continuous R&D						0.621^{***}
						(0.005)
R^2	0.02	0.157	0.16	0.18	0.22	0.446
Year FE	✓	✓	✓	✓	✓	✓
Industry FE		✓	✓	✓	✓	✓
Federal State FE			✓	✓	✓	✓
Import Origin FE				✓	✓	✓
Unique Firms	11151	11151	11151	11151	11151	11151
Observations	26512	26512	26512	26512	26512	26512

Notes: Coefficient estimates for specification (1) with a firm dummy indicating the introduction of new or significantly improved products or processes as dependent variable. Shocks to the export supply of foreign knowledge equal $\log(S_{ft}+1)$, where the shift-share variable S_{ft} is constructed following the definition in (2). Fixed effects are included as indicated. Standard errors are displayed in parentheses and clustered at the firm- and import-country-combination-level. P-values correspond to * p < 0.1, ** p < 0.05, *** p < 0.01. P-values are robust to implementing the standard error correction proposed by Adao *et al.* (2019).

Table 5 Supply of foreign knowledge services and innovation propensity: Alternative Samples and Controls

	Knowledge Importers	Non-Multinationals
Export Supply of Knowledge Services	0.004***	0.008***
	(0.001)	(0.002)
Old Firm	0.081**	−0.019***
	(0.034)	(0.001)
Large Firm	0.105***	0.083***
	(0.038)	(0.002)
Exporter	0.111*	0.062***
	(0.061)	(0.002)
Multinational Group	0.023	
	(0.036)	
German Group	0.003	0.034***
	(0.038)	(0.001)
Occasional R&D	0.482***	0.505***
	(0.001)	(0.001)
Continuous R&D	0.588***	0.626***
	(0.010)	(0.005)
R^2	0.63	0.42
Year FE	✓	✓
Industry FE	✓	✓
Federal State FE	✓	✓
Import Origin FE	✓	✓
Observations	1330	23308

Notes: Subsample estimates for specification (1) on a firm-level dummy indicating successful product, service, or process innovation. Column 1 reports estimates for the subsample of firms with positive imports of knowledge-related services during the pre-estimation years 2002-2004. Column 2 reports estimates for the subsample of firms firms that are not part of a multinational company group. Estimates are based on a linear probability model with fixed effects included as indicated. Standard errors are displayed in parentheses and clustered at the firm- and import-country-combination-level. P-values correspond to * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 6 Alternative shift-share variables and firm propensity to innovate

	(1)	(2)	(3)	(4)	(5)
Export supply knowledge services	0.005***	0.002**	0.009**		0.004***
	(0.000)	(0.001)	(0.004)		(0.001)
Export supply non-knowledge services				−0.000*	−0.000**
				(0.000)	(0.000)
Old Firm	−0.019***	−0.019***	−0.019***	−0.019***	−0.019***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Large Firm	0.079***	0.079***	0.079***	0.081***	0.081***
	(0.004)	(0.003)	(0.004)	(0.003)	(0.003)
Exporter	0.063***	0.063***	0.063***	0.063***	0.063***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Multinational Group	0.020***	0.021***	0.021***	0.023***	0.023***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
German Group	0.036***	0.036***	0.036***	0.037***	0.037***
	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)
Occasional R&D	0.503***	0.503***	0.503***	0.503***	0.503***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Continuous	0.621***	0.621***	0.621***	0.621***	0.621***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
R^2	0.44	0.44	0.44	0.44	0.44
Year FE	✓	✓	✓	✓	✓
Industry FE	✓	✓	✓	✓	✓
Federal State FE	✓	✓	✓	✓	✓
Import Origin FE	✓	✓	✓	✓	✓
Observations	26512	26512	26512	26512	26512

Notes: The table presents the results of estimating specification (1) with a product, service, or process innovation dummy as dependent variable and under alternative approaches to constructing the shift-share variable defined in equation (2). Column (1) reports results when shock exposure is measured by import shares during the first year a firm is observed in the SITS database. Column (2) restricts the set of source countries used to construct the shift-share variable to the largest countries listed in Table (1), while column (3) constructs the shocks excluding them. Column (4) reports results for an alternative shift-share variable capturing shocks to the export supply of services not related to knowedge services, and column (5) simultaneosuly includes our baseline set of supply shocks to foreign knowledge services and shocks to non-knowledge-related services. Estimates are based on a linear probability model, and fixed effects are included as indicated. Standard errors are displayed in parentheses and are clustered at the firm- and import-country-combination-level. P-values correspond to * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 7 Other innovation measures and export supply shocks to knowledge services

	Cost Reduction due to Process Innovation			New Product or Service Innovation		
	dummy (0/1)	in % of unit costs	log(total reduction)	dummy (0/1)	in % of revenue	log(total revenue)
Estimate	0.004**	0.062***	0.081**	0.004***	0.051	0.098***
	(0.002)	(0.022)	(0.034)	(0.002)	(0.079)	(0.002)
Old Firm	−0.006**	−0.242***	−0.036	−0.017***	−1.865***	−0.18***
	(0.002)	(0.019)	(0.045)	(0.002)	(0.097)	(0.043)
Large Firm	0.111***	0.330***	2.606***	0.064***	−1.277***	2.236***
	(0.005)	(0.047)	(0.089)	(0.006)	(0.271)	(0.015)
Exporter	0.015***	0.180***	0.274***	0.064***	2.102***	1.248***
	(0.002)	(0.015)	(0.036)	(0.002)	(0.127)	(0.003)
Multinational	0.055***	0.256***	1.219***	0.019***	−0.371***	0.939***
Group	(0.005)	(0.041)	(0.092)	(0.003)	(0.129)	(0.064)
German	0.036***	0.283***	0.703***	0.022***	0.031	0.670***
Group	(0.002)	(0.027)	(0.052)	(0.002)	(0.109)	(0.044)
Occasional	0.195***	1.676***	3.365***	0.454***	9.809***	7.966***
R&D	(0.003)	(0.021)	(0.062)	(0.003)	(0.101)	(0.033)
Continuous	0.248***	2.519***	4.446***	0.611***	18.773***	11.256***
R&D	(0.002)	(0.039)	(0.061)	(0.006)	(0.271)	(0.081)
R^2	0.18	0.10	0.21	0.45	0.32	0.48
Observations	26512	26512	26512	26512	26512	26512

Notes: Coefficient estimats for specification (1) on various innovation outcomes. Estimates are based on OLS, and include year, industry, federal state, and import-origin fixed effects. Standard errors are displayed in parentheses and clustered at the firm- and import-origin-level. P-values correspond to * p < 0.1, ** p < 0.05, *** p < 0.01.

Table 8 Supply of foreign knowledge services and expenditures on domestically-sourced R&D

	(1)	(2)	(3)	(4)	(5)	(6)
Export supply knowledge services	0.358***	0.222***	0.220***	0.109***	0.047**	0.027
	(0.024)	(0.019)	(0.020)	(0.002)	(0.009)	(0.024)
Old Firm (0/1)				−0.324***	0.024	0.013
				(0.054)	(0.024)	(0.014)
Large Firm (0/1)				2.652***	1.050***	0.983***
				(0.105)	(0.05)	(0.05)
Exporter (0/1)				2.291***	0.300***	0.063***
				(0.050)	(0.012)	(0.002)
Multinational Group				1.942***	0.501***	0.292***
				(0.084)	(0.054)	(0.008)
German Group				0.830***	0.204***	0.444***
				(0.036)	(0.014)	(0.026)
Occasional R&D					8.455***	8.455***
					(0.056)	(0.048)
Continuous R&D					10.90***	10.90***
					(0.095)	(0.041)
R^2	0.05	0.27	0.27	0.35	0.85	0.865
Year FE	✓	✓	✓	✓	✓	✓
Industry FE		✓	✓	✓	✓	✓
Federal State FE			✓	✓	✓	✓
Import-Origin FE						✓
Observations	26512	26512	26512	26512	26512	26512

Notes: Estiamtion restults for specification (1) using log(domestic R&D expenditures+1) as dependent variable. Estimates are based on OLS. Fixed effects are included as indicated. Standard errors are displayed in parentheses and clustered at the firm- and import-country-combination-level. P-values correspond to * p < 0.1, ** p < 0.05, *** p < 0.01.

Table 9 Calibrated Moments

Moment		Estimate	Source
Knowledge Import Ratios	$\mathbb{E}_\pi\left[\frac{\tau_\theta I_\theta}{\pi_\theta}\right]$,$\mathbb{E}_s\left[\varphi_\theta\right]$	0.004, 0.1	Authors' estimates
Demand Elasticity	$\mathbb{E}_\pi\left[\varepsilon_\theta\right]$	3	Ganglmair *et al.* (2021)
Innovation cost pass-through	$\mathbb{E}_s\left[\iota_\theta\varphi_\theta\right], \mathbb{E}_s\left[\iota_\theta\right]$	0.06, 0.6	Authors' estimates
Price cost Pass-Through	$\mathbb{E}_s\left[\rho_\theta\right]$	0.6	Amiti *et al.* (2019)

Table 10 GDP Gains from Knowledge Services Trade

GDP Gains	$-\frac{d\log\mathcal{Y}}{d\log\tau}$	0.035
Direct Effect (%)	$\mathbb{E}_s\left[\rho_\theta\varphi_\theta\iota_\theta\right]$	103%
Indirect Effect (%)	$\frac{\mathbb{E}_s[1-\rho_\theta(1+\rho_\theta\varepsilon_\theta\iota_\theta)]}{\mathbb{E}_\pi[\varepsilon_\theta]}\mathbb{E}_\pi\left[\frac{\tau_\theta I}{\pi_\theta}\right]$	-3%

Notes: This table presents the estimate of the elasticity of GDP with respect to the relative costs of service imports in Proposition 1, using the estimates in Table 9.

Table 11 Welfare Gains from Services Trade

		$\mathbb{E}_s\left[\delta_\theta\right]-1=0.05$	$\mathbb{E}_s\left[\delta_\theta\right]-1=0.2$
Welfare Gains from Services Trade	$-\frac{d\log U}{d\log\tau}$	0.04	0.05
Contribution of GDP		87 percent	58 percent

Notes: This table presents estimates of the elasticity of welfare with respect to the relative costs of service imports in Proposition 2, using the estimates in Table 9.

B Theoretical Appendix

B.1 Proof of Proposition 1

Proof. The change in competition follows from applying the envelope theorem to the free entry condition:

$$\begin{array}{rrl} & \int_\Theta \frac{v_\theta}{\int_\Theta v_\theta dG(\theta)} \varepsilon_\theta dG(\theta) d\ln\lambda = & \int_\theta \frac{v_\theta}{\int_\Theta v_\theta dG(\theta)} \frac{\tau I_\theta}{v_\theta} d\log\tau + (\pi_{\theta^*}(1) - \pi_{\theta^*}(0)) \frac{g(\theta^*)}{1-G(\theta^*)} d\theta^* \\ \Leftrightarrow & \frac{d\ln\lambda}{d\ln\tau} = & (\mathbb{E}_v[\varepsilon_\theta])^{-1} \mathbb{E}_v\left[\frac{\tau I_\theta}{v}\right] \end{array},$$

where the second line follows from the fact the marginal variety θ^* is indifferent between importing and not importing knowledge services since $X_{\theta^*} = 1$. The proposition follows from plugging $\frac{\partial ln\lambda}{\partial\ln\tau}$ given above and $\frac{\partial\ln c_\theta}{\partial\ln k_\theta}\frac{d\ln k_\theta}{d\ln\tau}$ given in the main text into the expression for changes in GDP.

$$\frac{d\ln\mathcal{Y}}{d\ln\tau} = \mathbb{E}_s\left[\rho_\theta \frac{\partial\ln c_\theta}{\partial\ln k_\theta}\frac{d\ln k_\theta}{d\ln\tau} - (1-\rho_\theta)\frac{dln\lambda}{d\ln\tau}\right]. \tag{B.1.1}$$

□

B.2 Proof of Proposition 2

Proof. Totally differentiating the marginal utility of income, we obtain:

$$d\ln M = d\ln\lambda - \mathbb{E}_s\left[\left(1 - \frac{1}{\varepsilon_\theta}\right) d\ln q_\theta\right] + (s_{\theta^*} - s_{\underline{\theta}^*}) \frac{g(\theta^*)}{1-G(\theta^*)} d\theta^*. \tag{B.2.1}$$

Changes in prices and quantities are given by,

$$d\ln p_\theta = \rho_\theta d\ln c_\theta - (1-\rho_\theta) d\ln\lambda. \tag{B.2.2}$$

$$d\ln q_\theta = -\varepsilon_\theta\rho_\theta (d\ln c_\theta + d\ln\lambda) \tag{B.2.3}$$

Changes in the import selection cutoff, in turn, equal,

$$d\theta^* = \gamma_{\theta^*}\left[\frac{\tau I_{\theta^*}}{v_{\theta^*}} + (\varepsilon_{\theta^*} - \varepsilon_{\underline{\theta}^*}) \frac{\partial\ln\lambda}{\partial\ln\tau}\right] d\ln\tau, \tag{B.2.4}$$

where $\frac{1}{\gamma_{\theta^*}} \equiv \left[\frac{\partial\log X_\theta}{\partial\theta}\right]_{\theta=\theta^*}$.

Changes in welfare measured in terms of the equivalent variation are given by:

$$\begin{array}{rl} d\ln\mathcal{U} & = \mathbb{E}_s[\delta_\theta - 1] d\ln M - \mathbb{E}_s[d\ln p_\theta] \\ & - (s_{\theta^*}(\delta_{\theta^*} - 1) - s_{\underline{\theta}^*}(\delta_{\underline{\theta}^*} - 1)) \frac{g(\theta^*)}{1-G(\theta^*)} d\theta^* \end{array} \tag{B.2.5}$$

We replace $d\ln M$, $d\ln p_\theta$, and $d\ln q_\theta$ in the expression for welfare and re-arrange to obtain,

$$\begin{aligned} d\ln\mathcal{U} &= \mathbb{E}_s\left[\delta_\theta\right] d\ln\mathcal{Y} + \mathbb{E}_s\left[\delta_\theta - 1\right]\mathbb{E}_s\left[\rho_\theta\varepsilon_\theta\left(d\ln c_\theta + d\ln\lambda\right)\right] \\ &\quad + \left(s_{\theta^*}(\delta_{\theta^*} - \mathbb{E}_s\left[\delta_\theta\right]) - s_{\underline{\theta}^*}(\delta_{\underline{\theta}^*} - \mathbb{E}_s\left[\delta_\theta\right])\right)\tfrac{g(\theta^*)}{1-G(\theta^*)}d\theta^* \end{aligned} \tag{B.2.6}$$

Substituting the following expressions

$$\frac{\partial\ln\lambda}{\partial\ln\tau}d\ln\tau = -\frac{\mathbb{E}_v\left[\tau I_\theta/v_\theta\right]}{\mathbb{E}_v\left[\varepsilon_\theta\right]},$$

$$\frac{d\log c_\theta}{d\log\tau} = \iota_\theta\varphi_\theta - \iota_\theta\rho_\theta\varepsilon_\theta\frac{\mathbb{E}_v\left[\tau I_\theta/v_\theta\right]}{\mathbb{E}_v\left[\varepsilon_\theta\right]},$$

as well as (B.2.4) into (B.2.6) yields the expression given in the proposition. □

B.3 Extension: Destruction of varieties and selection into innovating

We extend the model allowing for the destruction of varieties and selection into being an innovator. To that end, we assume that production is subject to an overhead costs f_o, while becoming an innovator requires firms to incur a fixed cost f_k, both in terms of domestic labor.

We maintain the assumption that varieties are ordered such that $X_\theta = \frac{\max_{I,R,p}(p-c_\theta(\kappa_\theta(I,R))q_\theta - p_R R - \tau I - f_I - f_k}{\max_{R,p}(p-c_\theta(\kappa_\theta(0,R))q_\theta - p_R R - f_k}$ is increasing and continuously differentiable in θ. Then there exist cutoffs $\theta_I^* > \theta_k^* > \theta_e^*$, such that entrants require a draw $\theta > \theta_e^*$ to produce, $\theta > \theta_k^*$ to innovate, and $\theta > \theta_I^*$ to import foreign knowledge via services trade.

The following summarizes the welfare gains from services trade in this economy.

Proposition. *Upon a change in trade costs $d\ln\tau$, changes in welfare are given by*

$$\begin{aligned} -\tfrac{d\log\mathcal{U}}{d\log\tau} = \quad & -\tfrac{d\ln\mathcal{Y}}{d\ln\tau} \\ & - \left(\mathbb{E}_s\left[\delta_\theta\right] - 1\right)\left(\mathbb{E}_s\left[\tfrac{\varepsilon_\theta}{\mu_\theta}\rho_\theta\iota_\theta\varphi_\theta\right] - \mathbb{E}_s\left[1 - \tfrac{\varepsilon_\theta}{\mu_\theta}\rho_\theta(1 + \mathbf{1}_{\{\theta\geq\theta^*\}}\rho_\theta\iota_\theta)\right]\tfrac{\mathbb{E}_v[\tau I_\theta/v_\theta]}{\mathbb{E}_v[\varepsilon_\theta]}\right) \\ & + \left(s_{\theta^*}(\delta_{\theta_I^*} - \mathbb{E}_s\left[\delta_\theta\right]) - s_{\underline{\theta}_I^*}(\delta_{\underline{\theta}_I{}^*} - \mathbb{E}_s\left[\delta_\theta\right])\right)\gamma^I\left(\tfrac{\tau I_{\theta^*}}{v_{\theta^*}} - (\varepsilon_{\theta_I^*} - \varepsilon_{\underline{\theta}_I^*})\tfrac{\mathbb{E}_v[\tau I_\theta/v_\theta]}{\mathbb{E}_v[\varepsilon_\theta]}\right) \\ & + \left(s_{\theta^*}(\delta_{\theta_k^*} - \mathbb{E}_s\left[\delta_\theta\right]) - s_{\underline{\theta}_k^*}(\delta_{\underline{\theta}_k{}^*} - \mathbb{E}_s\left[\delta_\theta\right])\right)\gamma^k(\varepsilon_{\underline{\theta}_k^*} - \varepsilon_{\theta_k^*})\tfrac{\mathbb{E}_v[\tau I_\theta/v_\theta]}{\mathbb{E}_v[\varepsilon_\theta]} \\ & + \left(s_{\theta_e^*}(\delta_{\theta_e^*} - \mathbb{E}_s\left[\delta_\theta\right]\right)\gamma^e\varepsilon_{\theta^*}\tfrac{\mathbb{E}_v[\tau I_\theta/v_\theta]}{\mathbb{E}_v[\varepsilon_\theta]}, \end{aligned} \tag{B.3.1}$$

where changes in GDP are given by

$$-\frac{d\ln\mathcal{Y}}{d\ln\tau} = \mathbb{E}_s\left[\rho_\theta\iota_\theta\varphi_\theta\right] + \mathbb{E}_s\left[1 - \rho_\theta(1 + \mathbf{1}_{\{\theta>\theta_k^*\}}\rho_\theta\varepsilon_\theta\iota_\theta)\right]\frac{\mathbb{E}_v\left[\tau I_\theta/v_\theta\right]}{\mathbb{E}_v\left[\varepsilon_\theta\right]}, \tag{B.3.2}$$

$$\frac{1}{\gamma^I} = \frac{1-G(\theta_I^*)}{g(\theta_I^*)}\left[\left.\frac{\partial\log\frac{\max_{I,R,p}(p-c_\theta(\kappa_\theta(I,R))q_\theta - p_R R - \tau I - f_I - f_k}{\max_{R,p}(p-c_\theta(\kappa_\theta(0,R))q_\theta - p_R R - f_k}}{\partial\theta}\right|_{\theta=\theta_I^*}\right], \quad \frac{1}{\gamma^k} = \frac{1-G(\theta_I^*)}{g(\theta_I^*)}\left[\left.\frac{\partial\log\frac{\max_{R,p}(p-c_\theta(\kappa_\theta(I,R))q_\theta - p_R R - f_k}{\max_{R,p}(p-c_\theta(\kappa_\theta(0,R))q_\theta}}{\partial\theta}\right|_{\theta^*=\theta_I^*}\right.$$

and $\frac{1}{\gamma^e} = \frac{1-G(\theta_e^*)}{g(\theta_e^*)} \left[\frac{\partial \log \max_p (p - c_\theta(0) q_\theta}{\partial \theta} \bigg|_{\theta^* = \theta_e^*} \right]$.

Compared to Proposition 2, welfare changes now account for changes in selection into becoming an innovator and producing.

B.4 Extension: Process and Product Innovation

We provide an extension of the model featuring both process and product innovation.

Model Set-up

Our model of product innovation combines elements of Dhingra (2013). We maintain our focus on a small open economy populated by a unit mass of households that inelastically supply one unit of labor at a competitive wage $w = 1$.

Households Consumers derive utility from consuming differentiated products $\theta j \in J_\theta$ produced by brands of type $\theta \in \Theta$:

$$\mathcal{U} = \int_{\theta \in \Theta} v(Q_\theta) dF(\theta), \quad Q_\theta = \int_{j \in J_\theta} u(q_{\theta j}) dj, \tag{B.4.1}$$

where $q_{\theta j}$ denotes consumption of variety θj and Q_θ is the composite bundle of θ varieties. The indices u and v are thrice continuously differentiable, strictly increasing, and concave on $(0, \infty)$. The inverse demand for variety θj is given by,

$$q_{\theta j} = D\left(p_{\theta j} \lambda \left(v'(Q_\theta)\right)^{-1} \lambda \right), \tag{B.4.2}$$

where $D(.) \equiv (u')^{-1}(.)$. The marginal utility of income λ indexes market wide competition, and is given by

$$\lambda = \int_{\theta \in dF(\theta)} (v')^{-1}(Q_\theta) \int_{j \in J_\theta} v'(q_{\theta j}) q_{\theta j} dj dF(\theta). \tag{B.4.3}$$

As before, an increase in competition reduces the demand for good θj. However, note that the model features cannibalization effects: an increase in Q_θ, from an increase in consumption of all varieties of varieties of type θ, say, lowers the demand for any individual variety θj. Intuitively, varieties are substitutable to each other, and consumers' willingness to pay falls as she consumes more varieties of the same brand.

Firms The timing and cost structure of entry decisions and knowledge service import is modeled as in the main text. Firms have to decide how much knowledge to acquire (innovation capacity), which production process to use (process innovation), what quantity to produce, and how many products to supply (product innovation). As before, knowledge acquisition results from the combination of domestic and foreign R&D, $k_\theta = \kappa(R, I)$. As before marginal cost of product θj depend on knowledge k, $c_\theta(k)$. Firms of type θ choose a range h of products by investing in product $R\&D$ at rate $\eta_\theta(k)$.

Under these assumptions, brand θ maximizes the following profit function:

$$v_\theta = \max_{I,R,p_{\theta j},h_\theta,\mathbf{1}_I} \int_0^{h_\theta} \underbrace{\left[\left(p_{\theta j} - c_\theta\left(\kappa_\theta(R, \mathbf{1}_I I)\right)\right) q_{\theta i} - \eta_\theta(k)\right]}_{\pi_{\theta j}} dj - p_r R - \mathbf{1}_I\left[\tau I - f_I\right] \tag{B.4.4}$$

Optimal prices for each variety are a markup over marginal cost, $p_{\theta j} = \mu_{\theta j} c_\theta$. Markups depend inversely on the price elasticity of demand for an individual variety, now given by:

$$\varepsilon_{\theta j} = \varepsilon(p_{\theta j}\lambda, Q_\theta) \equiv -\frac{\partial \log D\left(p_{\theta j}\lambda\left(v'(Q_\theta)\right)^{-1}\right)}{\partial \log p_{\theta j}}. \tag{B.4.5}$$

Denote the elasticity of the demand shifter $(v')^{-1}(Q_\theta)$ for product θj with respect a firm's product range by $\sigma_{\theta j}$,

$$\sigma_{\theta j}(Q_\theta) = -\frac{\partial \log v'(Q_\theta)}{\partial \log h_\theta}. \tag{B.4.6}$$

The symmetry of costs implies that $q_\theta \equiv q_{\theta j}$, $p_\theta \equiv p_{\theta j}$, $\varepsilon_{\theta j} = \varepsilon_\theta$, $\sigma_{\theta j} = \sigma_\theta$. To set their optimal product range firms equate the marginal increase in profits at the extensive margin from adding a product to the marginal loss in per-product profits,

$$\pi_\theta = \sigma_\theta \frac{p_\theta q_\theta}{h_\theta}. \tag{B.4.7}$$

Knowledge acquisition is determined by the following first-order condition:

$$-\left(\frac{\partial \ln c_\theta(k_\theta)}{\partial \ln k} q_\theta c_\theta + \frac{\partial \ln \eta_\theta(k_\theta)}{\partial \ln k}\eta_\theta\right) h_\theta = \frac{\partial \ln \Gamma_\theta(k_\theta, \mathbf{1}_I)}{\partial \ln k}\Gamma_\theta\left(k_\theta, \mathbf{1}_f\right) \tag{B.4.8}$$

The conditions determining selection into importing knowledge services and entry, as well as the definition of equilibrium are analogous to the main text.

Welfare Analysis

Product innovation implies that changes in welfare account for the creation of brands $d\ln M$ and products within brands, $d\ln h_\theta$.

$$d\ln\mathcal{U} = \mathbb{E}_s\left[(\delta_\theta - 1)\left(d\ln M + d\ln h_\theta\right)\right] - \mathbb{E}_s\left[d\ln p_\theta\right] - \left(s_{\theta^*}(\delta_{\theta^*} - 1) - s_{\underline{\theta}^*}(\delta_{\underline{\theta}^*} - 1)\right)\frac{g(\theta^*)}{1 - G(\theta^*)}d\theta^*,$$

where $s_\theta = Mp_\theta q_\theta h_\theta$ os the sales sjare of brand θ and $\delta_\theta = \frac{u(q_\theta)}{u'(q_\theta)q_\theta} \geq 1$ the infra-marginal surplus consumers attain from each of its products. Changes in a product prices, in turn, also depend on changes in the product range offered by each brand θ, due to the cannibalization effect that new have on old products,

$$-\mathbb{E}_s\left[d\ln p_\theta\right] = -\mathbb{E}_s\left[\rho_\theta d\ln c_\theta - (1-\rho_\theta)d\ln\lambda - (1-\rho_\theta)\sigma_\theta d\ln h_\theta\right]$$

The following proposition provides sufficient statistic results for changes in GDP and welfare.

Proposition. *The response in GDP to a change in trade costs $d\ln\tau$ is given by,*

$$-\frac{d\ln\mathcal{Y}}{d\ln\tau} = \mathbb{E}_s\left[\left(\rho_\theta\iota_\theta^c - (1-\rho_\theta)\sigma_\theta\iota_\theta^h\right)\varphi_\theta\right] + \mathbb{E}_s\left[(1-\rho_\theta)(1+\sigma_\theta\xi_\theta^{h,\lambda}) - \rho_\theta\xi_\theta^{c,\lambda}\right]\frac{\mathbb{E}_v\left[\tau I_\theta/v_\theta\right]}{\mathbb{E}_v\left[\varepsilon_\theta\right]},$$

and welfare changes equal,

Proof. Changes in aggregate competition are as in the model with process innovation except that the relevant averages are now taken over the value of brands rather than varieties:

$$-\frac{\partial\ln\lambda}{\partial\ln\tau} = \frac{\mathbb{E}_v\left[\tau I_\theta/v_\theta\right]}{\mathbb{E}_v\left[\varepsilon_\theta\right]}.$$

Denoting $\rho_\theta = \frac{\partial\ln p_\theta}{\partial\ln c_\theta}$ the pass-through of marginal cost shocks into the price of a variety, changes in prices equal,

$$\frac{d\ln p_\theta}{d\ln\tau} = \underbrace{\rho_\theta\frac{d\ln c_\theta}{d\ln\tau}}_{\text{Unit Costs}} - \underbrace{(1-\rho_\theta)\frac{d\ln\lambda}{d\ln\tau}}_{\text{Competition}} - \underbrace{(1-\rho_\theta)\sigma_\theta\frac{d\ln h_\theta}{d\ln\tau}}_{\text{Within-Firm Cannibalization}}.$$

Totally differentiating the demand for a product of brand θ yields,

$$d\ln q_\theta = -\varepsilon_\theta\rho_\theta\left(d\log c_\theta + d\ln\lambda + \sigma_\theta d\ln h_\theta\right).$$

Totally differentiating the FOC for knowledge acquisition, we obtain,

$$\omega_\theta^c(d\ln c_\theta - \frac{\partial^2\ln c_\theta}{\partial\ln k^2}\frac{\partial\ln k_\theta}{\partial\ln c_\theta}d\ln c_\theta + d\ln q_\theta) - (1-\omega_\theta^c)\left(\frac{\partial\ln\eta_\theta}{\partial\ln k_\theta}\frac{\partial\ln k_\theta}{\partial\ln c_\theta} + \frac{\partial^2\ln\eta_\theta}{\partial\ln k^2}\frac{\partial\ln k_\theta}{\partial\ln c_\theta}\right)d\ln c_\theta$$
$$= \quad -d\ln h_\theta + \frac{\partial\ln\Gamma_\theta}{\partial\ln k_\theta}\frac{\partial\ln}{\partial\ln}$$

where $\omega_\theta^c \equiv \frac{\frac{\partial\ln c_\theta(k_\theta)}{\partial\ln k}q_\theta c_\theta}{\frac{\partial\ln c_\theta(k_\theta)}{\partial\ln k}q_\theta c_\theta + \frac{\partial\ln\eta_\theta(k_\theta)}{\partial\ln k}\eta_\theta}$. Thus, changes in unit costs are given by,

$$d\ln c_\theta = \alpha_\theta^c\varphi_\theta d\ln\tau + \alpha_\theta^c\omega_\theta^c\varepsilon_\theta\rho_\theta d\ln\lambda - \alpha_\theta^c(1-\omega_\theta^c\varepsilon_\theta\rho_\theta\sigma_\theta)d\ln h_\theta,$$

where $\frac{1}{\alpha_\theta^c} \equiv \omega_\theta^c - \frac{\partial\ln k_\theta}{\partial\ln c_\theta}\left(\omega_\theta^c\frac{\partial^2\ln c_\theta}{\partial\ln k^2} + (1-\omega_c^\theta)(\frac{\partial\ln\eta_\theta}{\partial\ln k_\theta} + \frac{\partial^2\ln\eta_\theta}{\partial\ln k^2})\right) - \varepsilon_\theta\rho_\theta$.

Denoting $\omega_{\pi_\theta}^{\frac{1}{\varepsilon}pq} = \frac{(1-\frac{1}{\mu_\theta})p_\theta q_\theta}{\pi_\theta}$, the total derivative of the FOC pinning down the desired product range of brand θ equals,

$$\left(\frac{\rho_\theta}{\mu_\theta} - \omega_{\pi_\theta}^{\frac{1}{\varepsilon}pq}\right) d\ln\lambda = \left(\frac{1}{\varepsilon_\theta}\frac{\partial \log \sigma_\theta}{\partial \log h_\theta} - \frac{\rho_\theta \sigma_\theta}{\mu_\theta}\right) d\ln h_\theta - \rho_\theta d\ln c_\theta.$$

Denoting $\frac{1}{\alpha_\theta^h} = \frac{1}{\varepsilon_\theta}\frac{\partial \log \sigma_\theta}{\partial \log h_\theta} - \frac{\rho_\theta \sigma_\theta}{\mu_\theta}$, changes in h_θ hence equal,

$$d\ln h_\theta = \alpha_\theta^h \rho_\theta d\ln c_\theta + \alpha_\theta^h \left(\frac{\rho_\theta}{\mu_\theta} - \omega_{\pi_\theta}^{\frac{1}{\varepsilon}pq}\right) d\ln\lambda.$$

Combining the expression for changes in h_θ and c_θ, we obtain

$$d\ln h_\theta = \underbrace{\frac{\alpha_\theta^h \alpha_\theta^c \rho_\theta}{1+\zeta_\theta^h}}_{\equiv \iota_\theta^h} \varphi_\theta d\ln\tau + \underbrace{\frac{\alpha_\theta^h \rho_\theta \left(\alpha_\theta^c \rho_\theta \varepsilon_\theta + \left(\frac{1}{\mu_\theta} - \frac{1}{\rho_\theta}\omega_{\pi_\theta}^{\frac{1}{\varepsilon}pq}\right)\right)}{1+\zeta_\theta^h}}_{\xi_\theta^{h,\tau}} d\ln\lambda,$$

where $\zeta_\theta^h \equiv \alpha_\theta^h \rho_\theta \alpha_\theta^c (1 - \omega_\theta^c \varepsilon_\theta \rho_\theta \sigma_\theta)$, and

$$d\ln c_\theta = \underbrace{\alpha_\theta^c \left(1 - (1 - \omega_\theta^c \varepsilon_\theta \rho_\theta \sigma_\theta)\iota_\theta^h\right)}_{\iota_\theta^c} \varphi_\theta d\ln\tau + \underbrace{\alpha_\theta^c \left(\omega_\theta^c \varepsilon_\theta \rho_\theta - (1 - \omega_\theta^c \varepsilon_\theta \rho_\theta \sigma_\theta)\zeta^{h,\lambda}\right)}_{\xi_\theta^{c,\lambda}} d\ln\lambda.$$

Plugging the expressions for changes in a firm's unit costs and welfare into changes in prices and the Divisa price index. $d\ln\mathcal{Y} = -\mathbb{E}_s\left[\frac{\partial \ln p_\theta}{\partial \ln \tau}\right] d\ln\tau$, yields the characterization of GDP changes given in the proposition.

Totally differentiating the competition index λ yields

$$d\ln M + \mathbb{E}_s\left[d\ln h_\theta\right] = d\ln\lambda - \mathbb{E}_s\left[\frac{1}{\mu_\theta} d\ln q_\theta\right] + \left(s_{\theta^*} - s_{\underline{\theta}^*}\right)\frac{g(\theta^*)}{1-G(\theta^*)} d\theta^*.$$

Plugging into welfare, this implies,

$$\begin{aligned} d\ln\mathcal{U} = \; & \mathbb{E}_s\left[(\delta_\theta - 1)\left(d\ln\lambda + d\ln h_\theta - \mathbb{E}_s\left[d\ln h_\theta\right] - \mathbb{E}_s\left[\tfrac{1}{\mu_\theta} d\ln q_\theta\right]\right)\right] \\ & - \left(s_{\theta^*}(\delta_{\theta^*} - \mathbb{E}_s\left[\delta_\theta\right]) - s_{\underline{\theta}^*}(\delta_{\underline{\theta}^*} - \mathbb{E}_s\left[\delta_\theta\right])\right)\tfrac{g(\theta^*)}{1-G(\theta^*)} d\theta^*, \end{aligned}$$

Finally, the change in the importing cutoff $d\theta^*$ is given by,

$$d\theta^* = \gamma_{\theta^*}\left[\frac{\tau I_{\theta^*}}{v_{\theta^*}} + \left(\varepsilon_{\theta^*} - \varepsilon_{\underline{\theta}^*}\right)\frac{\partial \ln\lambda}{\partial \ln\tau}\right] d\ln\tau.$$

where $\frac{1}{\gamma_{\theta^*}} \equiv \left[\frac{\partial \log X_\theta}{\partial \theta}\right]_{\theta=\theta^*}$. □

C Examples of Knowledge Service Trades

Research, Development, and Testing Services

From BioNTech (Germany) to Pfizer (US)

Pfizer and BioNTech entered a detailed research collaboration and license agreement to develop mRNA-based vaccines for the prevention of influenca in 2018. The agreement covered the eligibility of BioNTech to receive up to USD 305 million in potential development, regulatory and commercial milestone payments as well as up to double-digit royalties (BioNTech & Pfizer, 2018a). The amounts of potential development payments are censored in the published agreement (BioNTech & Pfizer, 2018b). However, the list of development milestones provides an example of the import of foreign development services by Pfizer. The milestones covered, inter alia, payments for the initiation of the first, second, and third phase of the vaccine's clinical trials.

Patents, Licences, Inventions, and Processes

From Ballard Power Systems (Canada) to Audi (Germany)

Audi bought a package of patents from Ballard Power Systems in 2015. The trade covered a purchase of fuel cell technology patents from Ballard Power Systems worth EUR 40 million by Audi (dpa, 2015), and demonstrated an example of patent services imports by Audi.

Artistic Copyrights

From Rodd Industrial Design (United Kingdom) to Motorola (United States), Philips (Netherlands), and Panasonic (Japan)

Rodd Industrial Designs is a design studio founded in the United Kingdom in 2000. It delivers design directions to a variety of foreign companies. Examples are designs for phones, monitors, electric razors, and shower heads. Customers listed on their website are, for example, Motorola, Philips, and Panasonic. Rodd Industrial Designs usually retains the copyrights to their design until the payment of their final invoice (UKIPO, 2012). After the payment the copyright is transferred to their customer. The international transfer of copyrights for designs developed by Rodd Industrial Designs represents an import of copyright services by their the customers.

Other Rights, such as Franchise Fees, Trademarks, and Marketing Rights

From Novartis (Switzerland) to Eris Lifesciences (India)

Eris Lifesciences acquired the trademarks Zomelis from Novartis for the Indian market in 2019. Zomelis is used in the treatment of type two diabetes, whereas it belongs to a class of drugs relying on the novel DPP4 inhibitors technology. The acquisition of Eris Lifesciences valued around USD 13 million and represent a trademark service import. It enabled Eris Lifesciences to introduce Novartis in its product portfolio and to sell it on the Indian market starting December 2019. (Vinay, 2019)

D Endogeneity of Access to Foreign Knowledge Services

Potential sources of endogeneity for access to foreign knowledge services are:

1. Reverse Causality: Access to foreign knowledge services might trigger firm innovations due to reducing firms' cost of innovations, and firm innovations might trigger access to foreign knowledge services due to a firm's increasing knowledge sourcing ability.

2. Self-Selection: More innovative firms might actively improve their access to foreign knowledge services as they potentially benefit more from the access than less innovative firms due to its complementarity with existing innovation efforts.

3. Omitted Variable Bias: Firms might be more innovative and have easier access to foreign knowledge services as a result of unobserved firm characteristics, for instance, being a member of a multinational company group.

Borusyak *et al.* (2021) provide conditions under which identification in quasi-experimental shift-share designs is achieved under endogenous exposure of statistical units to presumably exogenous common shocks. In our case, exposure corresponds to the pre-estimation period country import shares of firms, while common shocks are captured by the aggregate knowledge service exports to Germany by country, year, and industry. More precisely, with regard to industry, we exclude knowledge service exports from a firm's own industry when constructing our common shocks. To achieve identification, we assume that the set of common shocks is exogenous to the threats to identification listed above.

We consider our assumption of the exogeneity of our common shocks as plausible. First, our common shocks are most likely not structurally influenced by the innovation activities or the selection of individual firms as an individual firm's industry is removed during shock construction. Moreover, the simultaneous correlation of unobserved characteristics with our aggregated common shocks and firm outcomes is unlikely. Again, firm characteristics are unlikely to influence our common shocks due to the exclusion of a firm's industry. In addition, the fixed effects included in our regressions cover more aggregate characteristics related to both variables, such as German regions, import countries, industries, and time trends.