Trade in Knowledge Services and Innovation

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November 2023

We investigate how the ongoing globalization of services impacts firm innovation and aggregate welfare. Using firm-level data from Germany, we show that access to knowledge service imports, such as R&D, leads to more succesful product and process innovation. To confront this evidence, we develop a theory of innovation offshoring that conceptualizes services trade in terms of tasks. To reason about the aggregate welfare implications of services trade, we embed this theory into a model of multi-product firms with endogenous innovation, variable markups and free entry. Our model yields an analytic decomposition of the welfare gains from services trade into an allocative and technical efficiency effect, as well as into the contribution of product and process innovation. We inform the key elasticities highlighted by our theory using our reduced-form estimates and offer a quantitative exploration of our theoretical results.

1. Introduction

The ongoing globalization of services is shifting the international landscape of innovation and knowledge creation. Technological and regulatory advancements opportunities for research and development world global 10 percent p.a., (WTO 2019) and now account for a sizeable share of 18 percent of total services imports in the U.S. and 13 percent in Germany in 2020.[1] An now leverage services trade as a way to access foreign expertise and know-how,

In this paper, we investigate the impact of services trade for innovation both empirically and theoretically. Empirically, we show that services trade fosters innovation by providing firms with the opportunity to procure foreign knowledge and ideas to use as inputs into their innovation process. Theoretically, we propose a new theory of innovation offshoring that rationalizes these empirical findings and outlines a new source for the welfare gains from trade based on

Our empirical analysis brings to bear firm-level information on services imports and innovation from Germany, which we obtain by merging the Statistics on International Trade in Services (SITS) with the Mannheim Innovation Panel (MIP). We define knowledge services as payments made by firms related to research, development, and testing; patents, licenses, inventions, and processes; artistic copyrights; and other rights, such as franchise fees or trademarks. Additionally, our data provide comprehensive information on firms' innovation activities, encompassing product and process innovation, as well as innovation input like R&D expenditures.

To estimate the causal effect of knowledge imports on innovation, we construct firm-specific export supply shocks, serving as 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 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 Borusyak *et al.* 2021.[2]

Our empirical results provide initial evidence that access to knowledge imports

[1]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.

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

fosters firm innovation. According to our estimates, services results in a 0.4 to 1.8 percentage point increase in its likelihood of introducing new or improved products or processes. These findings are consistent across various innovation outcomes, providing initial evidence that access to knowledge service imports raises a firm's returns to product and process innovation. Our findings also indicate that imports of knowledge services are associated with increased firm expenditures on domestic R&D. Further, we find no evidence that rising opportunities for importing other types of services have a positive impact on firm innovation.

To rationalize these empirical findings and evaluate their aggregate implications, we then develop a theory of innovation offshoring focused on tradable tasks. In the model, profit-seeking firms produce multiple products under conditions of monopolistic competition with variable markups and free entry. Producers have the option to enhance their capacity to introduce new products or processes by investing in knowledge, which involves performing various tasks designed to resolve requisite problems for innovation. Each of these tasks can potentially be outsourced or offshored, provided that a firm can locate an external partners capable of resolving a specific problem. Outsourcing may be attractive, if external partners have a higher productivity or scale efficiency for performing a task, but is also subject to search and - in the case of offshoring - trade costs. In this environment, firms become more likely to outsource innovation activities domestically or abroad as they become more innovative, where the prevalence of offshoring depends on the associated trade costs.

We use the model to characterize the equilibrium response of a decline in services trade costs for innovation and welfare terms of microeconomic statistics. Aggregate shocks to service trade costs have unequal direct and indirect effects on importers and non-importers of knowledge services, shifting the profile of product and process innovation and, ultimately, employment across firms. We trace the associated welfare implications, show how these can be summarized by a few aggregate statistics, and decompose the change in welfare into various channels, isolating the role of process and product innovation.

We then quantify our theoretical results, using our firm-level estimates to recover the model's key structural elasticities, such as pass-through rates of shocks to the costs of innovation into product variety. Quantitatively, the model-implied welfare gains from knowledge services trade are sizeable, suggesting that a one percent decline in trade costs would lead to an increase of welfare of 0.06 percent. The bulk of the welfare gains is due to the entry of new firms and the introduction of new products by existing firms, which respectively account for about 60 and 30 percent of the overall gains. In contrast, falling prices for varieties available prior to the fall in trade costs contribute less than 10 percent to the overall welfare gain. Given that barriers to services trade remain substantial, our results highlight that trade liberalizations in services may be crucial to fully realizing 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). 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 contribute to the literature studying 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 competition and entry for the welfare effects of trade.[3]

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

[3] 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).

2015; Eppinger 2019; Hebous & Johannesen 2021; Bamieh *et al.* 2022). While the potential importance of services trade as a catalyst of international knowledge transfers has been discussed in previous literature, e.g., Francois & Hoekman (2010) and Ariu *et al.* (2019), our paper is the first to provide direct evidence on this channel.

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 trade partners.[4] Our work contributes by exploiting trade in knowledge-related services to obtain systematic insights into the effects of innovation offshoring through external partners.

2. 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

[4] 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.

- 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.[5] 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):

a. Mode 1: Cross-Border trade - A service is provided from a member of country A to a member of country B across borders.
b. 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.
c. Mode 4: Presence of Natural Persons - A natural person from country A provides a service to a member of country B within country B.

2.2. Variable Construction

2.2.1. Firm Innovation

Th MIP data provide numerous measures of firm innovativeness. We use two yearly survey questions define our broadest measure of 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 broadest measure of 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. To distinguish product from process innovations, we construct two analogous indicators using, respectively, only one of the two question.

Capturing 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.[6]

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

[6] 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

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

2.2.2. Knowledge Services

Towe classify four 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 a l examples of international knowledge transfers captured by each of these service 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

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Innovation Capacity. 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 is linked to participation in international markets via, e.g., exports or multinational activity. 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 particular countries from

revenues.The value of cost reductions are proxied by multiplying the stated percentage cost reduction resulting from process innovations by firms' total revenues.

which firms source knowledge services. To do so, we construct a separate "import-country-combination" fixed effect for each unique combination of source countries.[7]

Size, age, and firm structure. A firm's size and age affect its ability to incur potential fixed costs related to innovation activities and trade participation. To account for firm size, we construct a dummy variable indicating whether a firm has than 250 employees and another 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.[8]

Industry and location. To control for unobserved differences in innovation activities and demand for foreign knowledge services between industries and localities, we construct fixed effects for a firms' industry at the three-digit level, and the federal state where it 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, on average, grew by five percent annually between 2005 and 2012. Total annual expenditures on knowledge service imports average €13 billion, corresponding to roughly 10 percent of aggregate innovation and 21 percent of R&D expenditures. Table A1 lists the main source countries and sourcing industries during our sample period. Major source countries, each accounting for more than five percent of total knowledge service exports to Germany, are the United States, the United Kingdom, Switzerland, France, and Austria. Industries accounting for more than five percent of total knowledge service 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."[9]

Among the four services types included in our definition of knowledge services,

[7] 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.

[8] 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.

[9] "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.

import expenditures on services pertaining to “Research, development, and testing” were most substantial, accounting for 46 percent of total knowledge service imports. By import expenditures, the second-largest category are payments related to “patents, licenses, inventions, and processes” (35 percent), while expenditures on services related to “Other rights” (19 percent) and “Artistic copyrights” (5 percent) are less substantial.[10]

Sample Statistics. Our regression sample covers 11,151 firms and 26,512 firm-year observations between the years 2005 and 2012. Table A2 displays descriptive statistics. Around 4 percent of firms in our sample import import knowledge services. Conditional on importing, the average annual expenditures on knowledge service imports are equal to €0.62 million.

The importing of knowledge services is strongly associated with innovation success. At the extensive margin, importers 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, new or significantly improved products accounted for 19 percent of yearly revenues, compared to 8.2 percent among non-importers. Process innovations reduced unit costs, on average, by 2.6 percent among importers, compared to 1.2 percent among non-importers.

Two innovation-related outcomes foreshadow broader systematic differences between importers and other firms. First, importers appear to have a higher capacity for investment, given that 61 percent of knowledge service importers continuously engage in internal R&D, compared to only 18 percent among non-importers. Second, the value of their revenues from product innovations along with their cost savings from process innovations is magnitudes higher, suggesting importers are substantially larger.

Looking directly at other firm characteristics reveals that importers are larger than non-importers; among the former, over 40 percent have more than 250 employees, compared to 7 percent among the latter. Importers are also more frequently part of a multinational company, and their exporter share is about twice as high compared to non-importers. However, other differences with regards to age, occasional internal R&D activities, and memberships in a national company group are less pronounced.

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

3. Acces to knowledge services and firm innovation

This section presents reduced-form evidence on how access to knowledge service imports impacts firm innovation. We outline below our empirical strategy, and present our estimated effects.

3.1. Empirical Strategy

To investigate how access to foreign knowledge services impacts firm innovation, we consider the following empirical specification,

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

Here, Y_{ft} is an innovation outcome of a firm f at time t. S_{ft} is a firm-level export supply for knowledge services, which we describe in detail below, and β is our parameter of interest. X_{ft} is a vector of time-varying firm controls and α a set of year, industry, regions, and import-country-combination fixed effects.[11] ϵ_{ft} is an idiosyncratic error term.

To construct firm-level export supply shocks for knowledge services, we utilize a quasi-experimental shift-share design (Bartik 1991,Goldsmith-Pinkham *et al.* 2020,Borusyak *et al.* 2021), exploiting variation in firm exposure to a set of common shock. More formally, we utilize information on the universe of services trades from the SITS to construct the following shift-share instrumental variable (SSIV)

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

Common Shocks. The shifters $I_{nt,-i(f)}$ reflect industry-country-specific shocks to knowledge service export supply. $I_{nt,-i(f)}$ is the sum knowledge service imports from a country n across all units in the SITS in a given year t, leaving out firm $f's$ industry, $i(f)$.[12] If the the demand for service imports is uncorrelated across industries after con-

[11] We omit firm fixed effects as country-combination fixed effects already absorb about 80 percent of the variation in our export supply shocks. Thus, their inclusion already represents a restrictive specification.

[12] That is, $I_{nt,-i(f)} = \sum_{f' \in SITS, i(f') \neq i(f)} I_{nf't}$, where $I_{nf't}$ denotes expenditures on knowledge services from country n by firm f' in year t, and *SITS* denotes the set of all units that appear in the SITS data, which is significantly larger than our estimation sample. The underlying idea is to purge a mechanical source of bias arising from the fact that unobserved shocks to firms' import demand are mechanically

ditioning on observables, variation in these shocks capture changes in a given source country's export capacity for knowledge services.[13]

Firm Shock Exposure - The exposure weights ω_{fnt_0} quantify firm f's exposure to a change in country n's export supply for services, based on the firm's share of import expenditure knowledge services from country n during a pre-estimation period t_0 that spans the years from 2002 to 2004.[14] We limit shock exposure to a pre-period t_0 as current import shares may be affected by lagged shocks in a way that is correlated with unobservables ϵ_{ft}.

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

Identification . We assume that identification of our parameter of interest β follows from exogenous variation from common shocks $\left\{I_{nt,-i}\right\}_{n,t,i}$, i.e., that shocks are conditionally quasi-randomly assigned, and provide sufficient identifying variation.[15]To corroborate these assumptions, we follow Borusyak *et al.* (2021) and investigate (i) the concentration of exposure weights, (ii) the statistical properties of the shocks, and (iii) the predictive power of our export supply shocks for past dependend variables and the set of controls. It should be noted that our shift-share variable, due to the leave-one-out correction, does not have a convenient shock-level representation.

Exposure Concentration. To calculate shifts $I_{nt,-i(f)}$, we use 62 countries, 43 industries, and eight years. The largest value of average country exposure equals 0.19,[16] and the inverse Herfindahl index (HHI) of country shares within industry equals 16.4; in an equivalent shock-level regression, this would indicate an effective sample size of about 131.[17]

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correlated with aggregate import volumes.

[13]Shocks to export capacity capture, e.g., changes in trade barriers, quality, or factor costs.

[14]Past import shares are 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.

[15]See D for a more detailed discussion of the threats to identification and their relationship with our common shocks.

[16]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.

[17]Monte-Carlos simulations by Borusyak *et al.* (2021) suggest good performance of shock-level shift-share instruments in finite samples at an effective samples size of 20, yielding false rejection rates of true zero nulls of 7.3% at a 5% confidence level. For an effective sample size 50 shocks, the false rejection rate

Shock Variation. The mean of our exposure-weighted country-industry shocks is around 0.3, with a standard deviation of 1.98. Residualizing shocks on years leaves the standard deviation unchanged.

Shock Correlation. The average significance level of all pariwise correlation coefficients between shocks 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.[18]

Quasi-Random Assignment. Table A3 shows that our SSIV has no predictive power over invididual firm controls, corroborating the assumption of quasi-random shock assignment.[19]

3.2. Innovation Propensity

We begin our empirical analysis by assessing how access to foreign knowledge service exports impacts a firm's propsensity to introduce a new product, service, or production processes. Table A4 reports SSIV estimates across parallel specifications.[20] The first column reports the coefficient estimate for β obtained from a specification that includes year fixed effects and no firm controls, with subsequent columns adding industry- (column 2), state- (column 3), and import-country-level fixed effects (column 4). Column 5 adds a set of general firm controls, and column 6 includes innovation-related firm controls.

Across all specifications, we find that an increase access to foreign knowledge services has a positive and statistically significant effect on a firm's propensity to innovate. The estimates imply that doubling a firm's export supply is associated with an increase in the likelihood of introducing a new product or process of 0.6 to 1.8 percentage points.

Additional Checks . Before proceeding to presenting results on the response of other innovation outcomes, we conduct a suite of additional checks to solidify the causal

decreases to 5.6%.

[18] 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.

[19] 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.

[20] 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 may have similar residuals.

interpretation of our estimate.

Excluding Non-Importers. Our point estimate is not sensitive to estimating equation (1) on the subsample of firms with positive knowledge service imports in the pre-estimation period.[21] Removing non-importers strenghens the causal interpretion of our SSIV estimate by reducing the inverse Herfindahl index of average shock exposures from 16.4 to 51.6 and maximum average exposure from 0.19 to 0.06. Table A5 shows that the resulting point estimate of β persists at 0.006 and remains statistically significant.

Excluding Multinationals. Table A6 shows that our SSIV estimate of a subsample regression that excludes firms which are part of a multinational company group.[22] Our point estimate for β remains positive and statistically significant, and the point estimate for β increases from 0.006 to 0.012.

Shift-share construction. We explore alternative approaches to constructing our export supply shocks. First, as our baseline set of shocks effectively limits shock exposure to firms founded before the year 2005, we re-define the reference period for shock exposure, t_0, as the first year a firm is observed importing knowledge services in the SITS data. Second, to investigate whether our results are driven by few, high-leverage shocks, we construct two alternative shift-share variables analogous to (2), but limiting the set of source countries to include either only or all except for the major source countries listed in Table A1.[23] Table A5 displays the results of re-estimating specification (1) with these alternative shift-share variables.

Imports of other service types. Our estimates may reflect a broader relationship between service imports and innovation if, e.g., shocks to the supply of knowledge service are highly correlated with shocks to the export supply of other types of services. To address this concern, we to construct shocks analogous to (2) for all service types, excluding knowledge services.[24] As shown by Table A5, re-estimation of specification (1) with these shock yields a small, statisticially insignficant, and negative point estimate for β.

[21]Removing non-importers also raises the effective size of our sample by further reducing the concentration of exposure weights across shocks. All non-importers are exposed to the common placebo shock with an exposure weight of one, which mechanically raises the maximum average exposure and reduces the inverse Herfindahl index.

[22]Due to the intangible nature of services,. multinationals may 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).

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

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

3.3. Product and process innovation

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

Extensive Margin. To study whether access to knowledge service imports differentially impacts a firm's propensity to innovate on products or processes, we re-estimate specification (1) using two alternative outcome variables indicating the introduction of (i) new or significantly improved products or services and (ii) new or significantly improved cost-reducing processes. Table A6 reports the results.

We find that greater access to knowledge service imports has similar effects on a firm's propensity for product and process innovation. Our estimates suggest that doubling a firm's export supply of knowledge services makes it 0.4 percentage points more likely to introduce a new product. propensity for adopting a new production process increase by 0.5 percentage points. Considering that product innovations occur, on average, twice as frequently as process innovations, this suggests that access to knowledge imports has a comparatively

Intensive Margin . To investigate how shocks to a firm's export supply of knowledge services impact its returns to innovation investments at the intensive margin, we re-estimate specification (1) using sales from product and cost reductions from process innovations as a dependent variable.

The estimates displayed in Table A6 show that firms with access to a larger export supply of knowledge services attain higher revenues through new or improved products. Our estimates suggest that a 1 point increase the supply of foreign knowledge services implies a statistically significant 0.11 percent increase in firm revenues attributable to sales of new or significantly improved products. We also find a positive, but statistically insignificant effect on a firm's revenue share of new or improved products.

Turning to the returns from adopting new processes, our results show that access to foreign knowledge services implies more substantial cost savings. Our point estimates imply that a 1 point export supply shock to knowledge services raises the percentage reduction in unit costs attributable to new processes by 0.0001 percent; this translates into an increase in total cost savings from process innovations of 0.08 percent.

3.4. Domestic R&D Expenditures

To shed light on potential complementarities between foreign- and domestically-sourced innovation activities within firms, we assess how changes in access to foreign knowledge services affect expenditures on domestically-sourced R&D services. To measure a firm's 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 A7 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. None of the displayed point estimates for β indicate that access to foreign knowledge services leads to reduced expenditures on domestically sourced R&D. In contrast, we find a positive and statistically significant effect on domestic R&D expenditures in most specifications, where a 1 point increase in export supply 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 on domestic R&D expenditures with a coefficient estimate for β of 0.03.

4. A Model of Innovation and Services Trade

A broad increase in the opportunities for importing knowledge services has three important consequences at the level of firms and within industries: it (i) led to greater cost reductions through process innovations, (ii) increased revenues from new products, and (iii) induced greater innovation expenditures. In this section, we develop a theory of innovation offshoring that rationalizes this evidence qualitatively and quantitatively.

There are two countries, Home and Foreign. The home economy produces a homogeneous final good, an endogenous mass of differentiated consumer products and knowledge services. Before proceeding to describing the demand and market structure of the economy, we begin below by describing the innovation process of a single producer in the differentiated goods industry.

4.1. A Theory of Innovation Offshoring

Production of differentiated varieties requires labor, ℓ, and intangible capital, k, which we refer to as knowledge. Technology is represented by a labor cost function that, conditional on knowledge, exhibits constant marginal and a fixed overhead cost. Labor used is thus linear in output y: $\ell(y,k) = f(k)\cdot\mathbb{1}(y>0) + c(k)\cdot y$, where $\mathbb{1}(\cdot)$ is an indicator function. We assume that overall labor used is decreasing in knowledge ($\ell_k(\cdot,\cdot) < 0$) but at a diminishing rate ($\ell_{kk}(\cdot,\cdot) < 0$).

Innovation Process. We posit a research technology which builds on a firm's existing knowledge capital through investment in innovation. More formally, if a firm with initial knowledge base k invests an amount ι in innovation, its knowledge becomes $k' = k + \iota$. Innovation is the outcome of a process that involves synthesisizing new insights from many distinct knowledge areas, indexed by a type $\omega \in [0,1]$, according to:

$$\iota = \left(\int_0^1 \iota(\omega)^{\chi} d\omega\right)^{1/\chi}, \tag{3}$$

where $\iota(\omega)$ denotes insight quality, and $\chi \leq 1$ governs the elasticity of subsitution between different types of insights.

In each knowledge area, there is a research task. This task yields a random number of insights with random quality. that is drawn from a Poisson distribution with mean one. If the task is performed a total number of $N(\omega)$ times, the number of insights, $n(\omega)$, that will be discovered then follows a Poisson distribution with mean $N(\omega)$. The quality $\iota_i(\omega)$ of each of these insights $i = 1, \ldots, n(\omega)$ is drawn randomly from a Pareto distribution with tail parameter $\zeta > 2$ and scale parameter k^{γ}, $\iota_i(\omega) \sim G(\iota) = 1 - (k^{\gamma}/\iota)^{\zeta}$.

We assume that the best insight is selected for integration into the innovation process. As shown in the Appendix, these assumptions imply the following innovation production function:

$$\iota = A \cdot k^{\gamma/\zeta} \cdot \left(\int_0^1 N(\omega)^{\chi/\zeta} d\omega\right)^{1/\chi}, \tag{4}$$

where $A \equiv \Gamma(1 - \frac{\chi}{\zeta})^{1/\chi}$ is a constant that depends on the Gamma function $\Gamma(\cdot)$. Two points are worth noting. First, innovative investments face diminishing returns due to the randomness of research success, captured by $1/\zeta$. Second, existing knowledge may enhance innovation productivity due to "standing on shoulders" effects ($\gamma > \zeta$) or possibly lower it due to "fishing-out" effects ($\gamma < \zeta$).

Each task can be performed in-house, using labor; or it can be outsourced to an external supplier. In-house execution of tasks suffers from diminishing returns to scale due to limited span-of-control.[25] Hence, outsourcing may be attractive if external

[25] The substantive assumption is that in-house task performance is subject to disceconomies of scale. E.g., we could have, alternatively, posited rent-sharing between workers and firms due to monopsony in the labor market or efficiency wages to generate such disceconomies of scale.

suppliers can handle large volumes of tasks more efficiently, without the diminishing returns that the firm experiences.

Formally, to perform a given task in-house N times requires hiring N^α workers, with $\alpha > 1$ capturing span-of-control. To outsource, the firm procures a competitively supplied knowledge service at Home ($l = H$) or in a foreign market ($l = F$) at a price $\psi \cdot w_l$. Here, the parameter ψ governs the costs of outsourcing. We follow Grossman & Rossi-Hansberg (2008) in assuming that the input requirement for foreign services, $\tau \cdot t(\omega)$, varies by task. The schedule $t(\omega)$ reflects heterogeneity in offshoring costs across tasks, where we index tasks so that $t'(\omega) > 0$.[26] The factor τ represents broader conditions affecting the costs of coordinating international innovation activities.

Optimal offshoring decisions. For a given innovation target, the firm chooses whether to perform each task in-house or through outsourcing, and at which level of intensity, to minimize the cost function $\kappa(\iota; \cdot)$. Let the cost share of tasks offshored be denoted by $\varphi^{\mathcal{O}} \equiv \frac{\partial \ln \kappa(\iota;\cdot)}{\partial \ln \tau}$ and that of tasks outsourced by $1 - \varphi^{\mathcal{I}}$. We characterize the features of these optimal choices below, with details on mathematical derivations relegated to the Appendix.

Let ω^* denote the marginal task that leaves the firm indifferent between either outsourcing arrangement, defined by $\tau \cdot t(\omega^*) = w_H/w_F$.[27] The optimal choice for tasks in $[0, \omega^*]$ is then to offshore if $\tau \cdot t(\omega) \cdot \psi \cdot w_F < w_H \cdot N(\omega)^{\alpha-1}$ and integrate them, otherwise. Conversely, tasks in $[\omega^*, 1]$ are outsourced domestically if $\psi < N(\omega)^{\alpha-1}$; else, they are integrated. Both domestic and foreign outsourcing of tasks, thus, is more attractive when a firm's desired task intensity is higher; this implies selection and a non-homotheticity in outsourcing decision, as shown by the following Proposition.

PROPOSITION 1. *For a firm with knowledge base k,*

a. *there exist two cutoffs $\underline{\iota}^{\mathcal{I}}(k, \tau), \underline{\iota}^{\mathcal{O}}(k, \tau) > 0$ such that $\varphi^{\mathcal{I}}(\iota; k) < 1$ if, and only if, $\iota > \underline{\iota}^{\mathcal{I}}(k)$; and $\varphi^{O}(\iota, k) > 0$ if, and only if, and $\iota > \underline{\iota}^{\mathcal{O}}(k)$.*
b. *the cost elasticity of innovation is given by:*

$$\mathcal{E}(\iota; k, \tau) \equiv \frac{\partial \ln \kappa(\iota; k, \tau)}{\partial \ln \iota} = \zeta \cdot \left[\varphi^{\mathcal{I}} \cdot \alpha + 1 - \varphi^{\mathcal{I}}\right]. \tag{5}$$

[26] This heterogeneity may capture both institutional and technological barriers to innovation outsourcing. An example of the former are the prevalent securiy-driven restrictions on international research collaborations in knowledge areas such as nuclear physics or bio-chemical engineering.

[27] We restrict attention to empirically relevant cases where $\omega^* \in (0, 1]$ throughout the main text. See the Appendix for a complete characterization of all cases.

c. *the response of marginal innovation costs to changes in offshoring costs* τ *is given by:*

$$\frac{\partial \ln \kappa'(\iota; \kappa, \tau)}{\partial \ln \tau} = \varphi^{\mathcal{O}} \cdot \left[1 + \frac{1-\varphi^{\mathcal{O}}}{\mathcal{E}} \cdot \eta^{\mathcal{O}}\right],$$

where $\eta^{\mathcal{O}} \equiv \frac{\partial \ln \varphi^{\mathcal{O}}}{\partial \ln \iota} > 0 \Leftrightarrow \frac{\alpha-1}{\alpha-\chi/\zeta} > \frac{\partial \ln t(\omega^*)}{\partial \omega^*} \int_o^{\omega^*} (\frac{t(\omega)}{t(\omega^*)})^{\frac{\chi/\zeta}{\chi/\zeta-1}} d\omega.$

The intuition underlying Proposition 1 is that firms use outsourcing as a tool to mitigate scale inefficiencies from limited span-of-control: when the size of a firm's desired innovative investment increases, scale inefficiencies become more costly, making outsourcing as well as offshoring more attractive. As a result, firms select into outsourcing based on their innovativeness (part a.), the innovation cost elasticity $\mathcal{E}$ decreases in the cost share of tasks performed in-house $1-\varphi^{\mathcal{I}}$ (part b.), and marginal innovation cost exposure to trade shocks is depends on a firm's offshoring cost share $\varphi^{\mathcal{O}}$, reflecting both a price and scale effect (part c.).

The empirical counterpart to Proposition 1 is a positive correlation between knowledge service imports and innovation expenditures within industries, as observed in our data. Further, Proposition 1 lends theoretical justification to the construction of our SSIV variable (equation (2)).

Going forward, a key implication of Proposition 1 is that changes in the opportunities for importing knowledge services differentially shift the innovation incentives of ex-ante heterogeneous firms. To reason about the associated implications for innovation outcomes and welfare, we now embed our theory of innovation offshoring into a model of monopolistic competition between heterogeneous multi-product firms.

4.2. Preferences and Demand

A unit mass of identical domestic households inelastically supplies one unit of labor at the competitive wage w_H. Households hold quasi-linear preferences over consumption of a homogeneous, numeraire good, X, and an aggregate index of differentiated varieties, Y, represented by,

$$U(X, Y) = X + \ln Y + 1. \tag{6}$$

Let P^Y denote the utility-based price index of Y so that consumers optimally purchase differentiated products up to the point where $Y = 1/P^Y$, and devote the remainder of their income to consumption of the homogeneous good.

The consumption index Y is an aggregate over real consumption, y_θ, of composite goods with types indexed by θ. A composite good of type θ comprises h_θ varieties with two characteristics: one that differentiates them from other composite goods and another that renders them pairwise CES-substitutes with an elasticity of substitution $\varepsilon > 1$. Given this formulation of preferences, per-capita consumption expenditures on a variety j equal:

$$p_{\theta j} y_{\theta j} = \left(\frac{p_{\theta j}}{\mathrm{p}_\theta}\right)^{1-\varepsilon} \mathrm{p}_\theta \mathrm{y}_\theta, \tag{7}$$

where $y_{\theta j}$ is the consumption of the variety, $p_{\theta j}$ is its price and p_θ is the CES price index of the composite good: $\mathrm{p}_\theta^{1-\varepsilon} = \int_0^{h_\theta} p_{\theta j}^{1-\varepsilon} dj$.

Following Matsuyama & Ushchev (2017), the preferences represented by P^Y belong to a class termed *Homothetic with a Single Aggregator* (HSA). HSA preferences are defined in terms of a market share function $s(\cdot)$ and a common aggregator P such that

$$\frac{d \ln P^Y}{d \ln p_\theta} = \frac{\mathrm{p}_\theta \mathrm{y}_\theta}{P^Y Y} = s\left(\frac{\mathrm{p}_\theta}{P}\right) \tag{8}$$

and

$$\int_\Theta s\left(\frac{\mathrm{p}_\theta}{P}\right) dF(\theta) = 1, \tag{9}$$

where $dF(\theta)$ is the measure of composites with type θ and Θ the set of all possible types.[28] Equation (8) gives the demand for composite goods in explicit form; the substantive implication is that this demand only depends on its price relative to a common aggregator, P. This aggregator mediates price competition between goods; this is reflected in the price elasticity of demand:

$$\sigma_\theta \equiv \sigma\left(\frac{\mathrm{p}_\theta}{P}\right) = 1 - \frac{\frac{\mathrm{p}_\theta}{P} s'\left(\frac{\mathrm{p}_\theta}{P}\right)}{s\left(\frac{\mathrm{p}_\theta}{P}\right)} > 1. \tag{10}$$

In the special case where the preferences represented by P^Y are CES, where $s(z) = z^{1-\sigma}$, the price elasticity of demand is constant, $\sigma_\theta = \sigma$, and P aligns with the ideal price index P^Y. Away from this special case, the price elasticity of demand varies endogenously with a good's relative price. We adopt

ASSUMPTION 1. *(i) Either* $\sigma(\cdot) = \sigma$ *or* $\sigma'(\cdot) > 0$ *and (ii) in the neighboorhood of any equilibrium,* $\varepsilon > \sigma(\frac{p_\theta}{P})$.

[28] We impose $s'_\theta(z) < 0$ when $s(z) > 0$, $\lim_{z\to 0} s(z) = \infty$, $\lim_{z\to\bar{z}} s(z) \to 0$ for $\bar{z} = \inf\{z > 0 | s(z) = 0\}$. Matsuyama & Ushchev (2017) show that these assumptions guarantee that the demand system in (7) and (9) can be rationalized by a monotone, convex, continuous and homothetic rational preference relation.

The first part of Assumption 1 implies that a good's demand becomes less elastic when its price decreases relative to the common aggregator. As an implication, a composite good's price elasticity of demand is decreasing in its product scope: $\frac{\partial \sigma_\theta}{\partial h_\theta} \leq 0$. The second part posits negative cross-price demand effects within composite goods; this has implications for innovation decisions that we describe next.

4.3. Production

The numeraire good X is competitively produced under constant returns to scale and traded freely. By choice of units and numeraire, this fixes the wage in the home and foreign economy at one in units of the homogeneous good.

Firms in the differentiated goods sector purchase a fixed quantity of F_e units of home labor to enter. Upon entry, each firm receives a draw θ from a distribution $G(\theta)$, granting it monopoly rights over blueprints for many distinct products with a common type θ. The blueprint for a particular product j consists of a knowledge base, $k_{\theta j} \equiv k_\theta$, an innovation cost function, $\kappa(i_j; k_{\theta j}, \tau)$, and a production technology, $C_\theta(y, \iota_j) = c(k_{\theta j} + \iota_j) \cdot y + f(k_{\theta j} + \iota_j)$. The innovation cost function summarizes a firm's underlying decision to outsourcing innovation tasks, following Proposition 1.

Each firm chooses a product range, h_θ, alongside setting a price $p_{\theta j}$, and determining the level of its innovation investment $\iota_{\theta j}$ for each product so as to maximize the following market value function:

$$v_\theta = \int_0^{h_\theta} \pi_{\theta j}(h_\theta, p_{\theta j}, \iota_{\theta j}) dj, \tag{11}$$

where $\pi_{\theta j}$ are the profits generated by product j, $\pi_{\theta j} \equiv [p_{\theta j} - c(k'_{\theta j}] y_{\theta j} - f(k'_{\theta j}) - \kappa(\iota_{\theta j}, k_{\theta j}, \tau)$,

In this environment, firms will choose the same innvation investment and price for each product; henceforth, product-firm subscripts will thus be suppressed. For each good that a firm chooses to supply, the profit-maximizing price equals a markup μ_θ over its marginal costs,

$$p_{\theta j} \equiv p_\theta = \mu(\frac{\mathsf{p}_\theta}{P}) c_\theta, \tag{12}$$

where the optimal markup satsfies Lerner's formula,

$$\mu(\frac{\mathsf{p}}{P}) = \frac{\sigma(\frac{\mathsf{p}}{P})}{\sigma(\frac{\mathsf{p}}{P}) - 1}. \tag{13}$$

Firm internalize the monopoly power they hold over its portfolio of products and, hence, apply a common markup to all products.[29]Their choices of product range, in turn, balance the additional profit from a new product against the profit loss due to diminished sales of existing products, $\pi_\theta + h_\theta \frac{\partial \pi_\theta}{\partial h_\theta} = 0$.[30] Combining this condition with the above pricing rule yields,

$$\frac{p_\theta y_\theta}{\sigma_\theta} - f_\theta - \kappa_\theta = \frac{\varepsilon - \sigma_\theta}{\varepsilon - 1} \cdot \frac{p_\theta y_\theta}{\sigma_\theta}. \tag{14}$$

The right-hand side of equation (14) captures cannibalization effects: a new product reduces the firm price index (p_θ), subsequently reducing the profits of existing varieties (following Assumption 1). A firm's optimal choice of product range, then, ensures that profits from new products on the left offset the profit loss from cannibalization.

The first-order condition for a firm's desired knowledge capital stock is $-y\partial c_\theta/\partial k'_\theta - \partial f_\theta/\partial k'_\theta = \partial \kappa_\theta/\partial \iota_\theta$. A firm invests in knowledge until savings from lower production costs are driven to zero; integrating this optimality condition with a firm's other choices yields:[31]

$$c_\theta y_\theta \cdot \left[-\epsilon^{c_\theta}_{k'_\theta} - \frac{1}{\varepsilon - 1} \cdot \epsilon^{f_\theta}_{k'_\theta} \right] = \kappa_\theta \cdot \left[\frac{k'_\theta}{\iota_\theta} \cdot \mathcal{E}_\theta + \epsilon^{f_\theta}_{k'_\theta} \right], \tag{15}$$

where ϵ^g_x denotes the elasticity of a function $g(x)$ with respect to a variable x.

Equation (15) summarizes the forces that shape firms' innovation incentives. The scope for innovation offshoring (τ) is reflected in the cost (κ_θ) and scale efficiency ($\mathcal{E}_\theta$) of a firm's innovative investments. The term $c_\theta y_\theta$ reflects scale economies: as scale per product rises, innovative investments become more profitable. Scope economies, in turn, are reflected in the term $\epsilon^{f_\theta}_{k'_\theta}$: knowledge accumulation may streamline the introduction of new products ($\epsilon^{f_\theta}_{k'_\theta} < 0$) or make them more complicated ($\epsilon^{f_\theta}_{k'_\theta} > 0$).[32] Intuitively, the importance of scope economies for the profitability of innovation depends

[29]This is a well-known feature of nested demand systems and would also be true if marginal costs were not symmetric within firms. See Hottman *et al.* (2016) for a more detailed discussion.

[30]To simplify notation, we suppress the argument of functions whenever this dependence is clear from the context (e.g., we write σ_θ and κ_θ instead of $\sigma(\frac{\mathrm{p}_\theta}{P})$ and $\kappa_\theta(\iota, \tau)$).

[31]The decomposition follows from rewriting the FOC for h_o as as $f_\theta = \frac{\sigma_\theta - 1}{\varepsilon - 1} \frac{p_\theta y_\theta}{\sigma_\theta} - \kappa_\theta = \frac{c_\theta y_\theta}{\varepsilon - 1} - \kappa_\theta$ to substitute for f_θ in the FOC for innovation.

[32]This formulation flexibly encompasses different types of innovation. When innovative investments reduce variable but raise fixed costs, knowledge capital captures intangibles, as in De Ridder (2022). Alternatively, knowledge capital may catalyze "scalability innovations", e.g., the adoption of business models or technologies with higher upfront but lower unit costs, such as cloud-computing and IT services. Finally, innovation may lower both fixed and variable cost, capturing, e.g., advanced automation and robotics in manufacturing.

the strength of cannibalization effects in demand, captured by ε.

4.4. Equilibrium

As in Melitz (2003), producers of differentiated products face an exogenous exit probability Δ in each period. In steady state, firms will enter until the expected value of entry equals the entry cost:

$$\frac{1}{\Delta} \cdot \int_{\Theta} v_\theta dG(\theta) = F_e. \tag{16}$$

Denoting the equilibrium mass of entrants by M, the measure of type θ firms active in steady state is equal to $dF(\theta) = MdG(\theta)$.

An equilibrium is defined by a number of entrants M and a vector of firm choices $\{\mathrm{p}_\theta, h_\theta, \iota_\theta\}_{\theta\in\Theta}$, so that consumers maximize utility taking prices as given, firms maximize profits, and the free entry condition holds. An equilibrium satisfies equations (7), (9), (10), (11), (13), (14), (15), and (16).

5. The Firm-level and Aggregate Effects of Services Trade Liberalization

In this section we use the model developed in the previous section to study the firm-level and aggregate implications of services trade liberalization.

5.1. Concepts

We first introduce two elasticities related to the shape of demand curves that facilitate the exposition of our theoretical results. The first is a firm's price cost pass-through, which describes how changes in marginal production costs c_θ impact the its desired price. Formally, we define:

$$\rho_\theta \equiv \rho(\frac{\mathrm{p}_\theta}{P}) \equiv \frac{\partial \ln p_\theta}{\partial \ln c_\theta} = \frac{1}{1 - \frac{\frac{\mathrm{p}_\theta}{P}\mu'(\frac{\mathrm{p}_{\theta}}{P})}{\mu(\frac{\mathrm{p}_\theta}{P})}}. \tag{17}$$

Under CES preferences, markups are constant, $\mu'_\theta(\cdot) = 0$, and cost pass-throughs complete, $\rho_\theta(\cdot) = 1$. Away from this special case, assumption 1 implies incomplete pass-through of cost shocks into prices, $\rho_\theta(z) \in (0, 1)$.

The second demand elasticity relevant for welfare analysis is the consumer surplus that a firm create, denoted by $(\delta_\theta - 1)s_\theta(\frac{p_\theta}{P})$. Here δ_θ is the ratio of the area under the demand curve to sales:

$$\delta_\theta \equiv \delta(\frac{p_\theta}{P}) = \frac{\int_0^{y_\theta} p(y_\theta)dy}{s(\frac{p_\theta}{P})} = 1 + \frac{\int_{p_\theta/P}^{\infty} \frac{s(\xi)}{\xi}d\xi}{s(\frac{p_\theta}{P})} \geq 1, \tag{18}$$

where $p(\cdot)$ is the inverse residual demand curve for the firm's composite good. Under CES preferences, δ_θ captures love-of-variety and coincides with the markup, $\delta_\theta = \frac{\sigma}{\sigma-1}$. For other HSA preferences, δ_θ varies with a firm's position on its residual demand curve, p_θ/P.

5.2. Effect on Firm Output and Innovation

We begin our analysis by drawing out the forces that shape the allocational implications of changes in the opportunities for innovation offshoring, $d\ln\tau$. As firms select into a direct and an indirect effect. The direct effect reflects

We show in the Appendix that this increase in competition satisfies

$$d\ln P = \bar{\mu} \cdot \overline{\varphi}^{\mathcal{O}} \cdot d\ln\tau. \tag{19}$$

Here, the average markup $\bar{\mu} = \mathbb{E}_s\left[1/\mu_\theta\right]^{-1}$ reflects the responsiveness of aggregate profits to competition.

PROPOSITION 2. *The change in a firm's relative price caused by a change in services trade costs is given by*

$$d\ln\frac{p_\theta}{P} = \rho_\theta \cdot \left(\Gamma_\theta^c - \Gamma_\theta^h\right) \cdot \varphi_\theta^{\mathcal{O}} \cdot d\ln\tau - \rho_\theta \cdot \frac{1-\sigma_\theta\rho_\theta}{\varepsilon - \sigma_\theta\rho_\theta} \cdot \bar{\mu} \cdot \overline{\varphi}^{\mathcal{O}} \cdot d\ln\tau, \tag{20}$$

where $\Gamma_\theta^c \equiv \frac{\partial \ln c_\theta}{\partial \ln k_\theta}$ *and* $\Gamma_\theta^h \equiv \frac{\partial \ln h_\theta}{\partial \ln \kappa_\theta}$ *are the pass-throughs of shocks to innovation investment costs into unit production costs* (c_θ) *and product variety* (h_θ).

The first on the right-hand side of equation (20) gives the cross-sectional effects of changes in services trade costs on firm competitiveness. Following Proposition 3, innovation expenditures on imported knowledge services, $\frac{\partial \ln \kappa_\theta}{\partial \ln \tau} = \varphi_\theta^{\mathcal{O}}$. $\Gamma_\theta^c = \frac{\partial \ln c_\theta}{\partial \ln \kappa_\theta}$ and $\Gamma_\theta^h = \frac{\partial \ln h_\theta}{\partial \ln \kappa_\theta}$. These elasticities describe the pass-through of shocks to the costs of innovation investments into unit production costs (c_θ) and product range (h_θ).

The indirect effect is mediated through changes in competition. Initially, a decline in trade costs, on average, increases the profits of existing firms by $-\overline{\varphi} d\ln\tau = -\mathbb{E}_s\left[\frac{\kappa_\theta}{s_\theta}\varphi_\theta^{\mathcal{O}}\right] d\ln\tau$. To re-establish the free entry condition in the market, there must subsequently be an increase in competition.

5.3. Welfare Gains from Knowledge Service Imports

Per-capita welfare W in the home country comprises (exogenous) labor income, $\bar{Y}$, plus consumer surplus, $U = \overline{Y} - \log P^Y$. Letting $\mathbb{E}_x[y_\theta] \equiv \int_\Theta \frac{x_\theta y_\theta}{\int_\Theta x_\theta dG(\theta)} dG(\theta)$ denote the x–weighted average of y_θ, given two variables $x_\theta \geq 0$, and y_θ, changes in welfare associated with shocks satisfy:

$$dU = \underbrace{\left(\overline{\delta} - 1\right) d\ln M + \frac{1}{\varepsilon - 1}\mathbb{E}_s\left[d\ln h_\theta\right]}_{\text{Entry/exit of varieties}} - \underbrace{\mathbb{E}_s\left[d\ln p_\theta\right]}_{\text{Divisa Price Index}}, \tag{21}$$

where $\overline{\delta} = \mathbb{E}_s[\delta_\theta]$ is the average consumer surplus.

Welfare changes dW incoporate the consumer surplus brought about by firm entry or exit ($d\ln M$) or created through product introductions of existing firms ($d\ln h_\theta$) via the first two terms on the right-hand-side of (21). Intuitively, the marginal entrant raises consumer surplus in proportion to, $\mathbb{E}_s[\delta_\theta]-1$. Changes in welfare associated with product introductions by existing firms, in turn, are governed by the within-firm elasticity of substitution, $\frac{1}{\varepsilon - 1}$.

The last summand in (21) captures how changes in real GDP affect welfare. If the model did not allow firm entry or product innovation, the first two terms of (21) would be zero and changes in welfare would be captured by measured GDP.

Theorem 1. *In response to a change in service trade barriers, $d\ln\tau$, the change in per-capita welfare U is given by,*

$$dU = \underbrace{-\bar{\mu}\Lambda d\ln\tau}_{\Delta\textit{Technical Gains}} \underbrace{-\mathbb{E}_s\left[\left(1 - \frac{\mathbb{E}_s[\delta_\theta]}{\mu_\theta}\right)\sigma_\theta\rho_\theta \cdot \left\{\left(\Gamma_\theta^c - \Gamma_\theta^h\right)\varphi_\theta - \frac{\varepsilon - 1}{\varepsilon - \sigma_\theta\rho_\theta}\bar{\mu}\Lambda\right\}\right] d\ln\tau}_{\Delta\textit{Allocative Gains}}, \tag{22}$$

where $\lambda = \mathbb{E}_s\left[\frac{\kappa_\theta}{s_\theta}\cdot\varphi_\theta^{\mathcal{O}}\right]$, $\bar{\mu} = \mathbb{E}_s[1/\mu_\theta]^{-1}$, $\Gamma_\theta^h \equiv \frac{\partial\ln h_\theta}{\partial\ln\kappa_\theta}$ *and* $\Gamma_\theta^c \equiv \frac{\partial\ln c_\theta}{\partial\ln\theta}$.

Welfare changes associated with services trade costs stem from two effects. The term labeled technical efficiency captures the change in welfare when the distribution of relative prices $(\frac{p_\theta}{A})_{\theta\in\Theta}$ is held fixed. In an economy with symmetric CES preferences,

$s_\theta(z) = a_\theta z^{1-\sigma}$ and $a_\theta > 0$, this is the only effecti implying that the import share of services in GDP and aggregate markup are sufficient statistics to summarize welfare changes. Through this lense, the technical efficiency effect captures sources of gains from trade analogous to Arkolakis *et al.* (2012).

The second term in equation Equation (22) captures how reallocations of economic activity between firms contribute to welfare. This term equals zero in an economy with homogeneous markups, reflecting that reallocations have no first-order effect on welfare when the initial allocation is efficient. In contrast, heterogeneity in markups spells allocative inefficiencies; in this case, trade-induced shifts in the profile of innovation across firms have ramifications for welfare. Γ_θ^c and Γ_θ^h, only matter for the allocative efficiency effect.

5.4. Changes in other aggregates: Markups and real GDP

We finish this section by characterizing the response of other important aggregates to a decline in the costs of innovation offshoring - the aggregate markup, $\bar{\mu}$, and real GDP.

PROPOSITION 3. *In response to a change in service trade barriers, $d\ln\tau$, the change in the aggregate markup $\bar{\mu} = \mathbb{E}_s\,[1/\mu_\theta]^{-1}$, is given by*

$$d\ln\overline{\mu} = \mathbb{E}_s\left[\left\{\left(1-\frac{\overline{\mu}}{\mu_\theta}\right)(\sigma_\theta-1)\rho_\theta + \overline{\mu}(1-\rho_\theta)\right\}\left\{\left(\Gamma_\theta^c - \Gamma_\theta^h\right)\varphi_\theta + \frac{\varepsilon-1}{\varepsilon-\rho_\theta\sigma_\theta}\bar{\mu}\Lambda\right\}\right] d\ln\tau.$$

The response of real GDP per capita, $d\ln Q \equiv -\mathbb{E}_s\left[d\ln\, p_\theta\right]$, is given by

$$d\ln Q = -\mathbb{E}_s\left[\frac{\varepsilon-1}{\varepsilon-\rho_\theta\sigma_\theta} - \rho_\theta\right]\overline{\mu}\Lambda d\ln\tau - \mathbb{E}_s\left[\left(\Gamma_\theta^c + \Gamma_\theta^h\right)\varphi_\theta\right] d\ln\tau$$

Changes in the aggregate markup reflect

6. Quantification

In this section, we quantify the welfare formula provided in section 5.

6.1. Calibration

6.1.1. Innovation cost pass-throughs: $\Gamma^h_\theta, \Gamma^c_\theta$

We use our reduced-form estimates to inform the structural innovation cost pass-throughs. For unit costs, we use our estimates of the effect of export supply shocks on firms' reductions in unit costs attributable to innovation, which our model maps into the outcome $-\frac{\partial \ln c_\theta}{\partial \ln k_\theta} d \ln k_\theta = -d \ln c_\theta$. For product variety, in turn, we leverage our reduced-form estimates pertaining to firm firm revenues from new products, $\frac{\partial \ln s_\theta}{\partial \ln h_\theta} d \ln h_\theta = \frac{1-\sigma_\theta \rho_\theta}{1-\epsilon} d \ln h_\theta$.

To derive the structural analogue of our empirical shift-share instrument, we extend the model to allow firms to source knowledge services from multiple source countries $n \in \mathcal{N}$ at a fixed cost $f_{I,n}$ and variable cost τ_n. The (cross-sectional or time) variation in innovation costs can then written as follows:

$$- d \ln \kappa_\theta = -\varphi_\theta \sum_{n \in \mathcal{N}} \omega_{\theta n} \frac{d \ln \mathcal{P}_{nI}}{d \ln \tau} d \ln \tau_n + \alpha_f + \epsilon_\theta \tag{23}$$

where $\omega_{\theta n} \equiv \frac{\tau_n I_{\theta n}}{\sum_n \tau_n I_{\theta n}} \mathbf{1}_{\{\varphi_\theta > 0\}}$ is the import expenditure share of firm θ on knowledge services from country n, α_F is a firm fixed effect and ϵ_θ a structural residua.

Our empirical firm-level shocks rely on aggregete import volumes to proxy for changes in structural trade costs. Γ^c_θ via the two-stage IV estimate of the effect of innovation expenditures on unit costs, $\mathbb{E}_f \left[\Gamma^c_\theta\right] = \mathbb{E}_f \left[\widehat{\Gamma^c_\theta}\right] = \frac{d \ln c_\theta / d \ln S_{f,t}}{d \ln \kappa_\theta / d \ln S_{f,t}}$.

6.1.2. Other statistics

We rely on external estimates to calibrate the cross-firm price elasticity of demand σ_θ, the perceived price elasticity of product demand ε, and price cost pass-throughs ρ_θ. Hottman *et al.* (2016) find an average cannibalization rate, defined as the partial elasticity of firm sales of old products with respect to the number of products, equal to -0.5, implying that $\frac{(1-\rho)+\varepsilon\rho}{\sigma} = 0.5$. We set the average markup equal to $\bar{\mu} = 1.15$, in line with existing estimates in the literature.[33] We choose price cost pass-through to be equal to $\rho = 0.7$, following Amiti *et al.* (2019) and Arkolakis *et al.* (2019). Given these choices, we inform the elasticity of substitution σ by imposing a cannibalization rate

[33] Using firm-level markup estimates for German firms by Ganglmair *et al.* (2021), we find an average markup across the firms within our sample of 1.5. Since our sample is biased towards larger firms, this likely overstates the economy-wide markup. Setting a lower markup is a conservative choice, given that our estimated welfare gains increase in the size of the average markup.

of 0.5. Given the sparseness of estimates of the average brand-level consumer surplus $\mathbb{E}_s\left[\frac{\sigma}{\sigma-1}\delta_\theta - 1\right]$ in the literature, we choose a conservative value of $\mathbb{E}_s[\delta_\theta] = 1.05$ for our baseline analysis.

To calculate the ratio of knowledge service imports to sales, we divide the average yearly imports of knowledge services during our sample period by the average yearly revenues reported as part of the core indicators of the Mannheim innovation panel. To calculate the aggregate import share of knowledge services, we divide yearly averages of the total yearly import volumes of knowledge services in the SITS by the total yearly R&D expenditures reported in the MIP core indicators.

6.1.3. Results [Needs Updating]

We summarize our calibrated parameters in table A8. Following proposition 3, we find that the elasticity of aggregate spending on knowledge service imports to trade costs $1-\theta$ equals –0.8. Given the estimate for the trade elasticity, our reduced-form estimates imply that the average firm-level pass-through of knowledge cost shocks into unit costs and the number of products, respectively, equals 0.004, and –0.95. Hence, while theoretically ambigious, our results suggest that reductions in services trade costs cause importers to adopt more cost-effective processes, and to engage in more product innovation.

6.2. Quantitative Results [Still Needs Updating]

Baseline

table A9 displays the gains from knowledge services trade following **??** and 1 under our baseline calibration. The results suggest that the welfare gains from services trade are sizeable, implying that a 1 percent reduction in services trade costs raises consumer welfare by 0.06 percent. The bulk of these welfare gains stems from increasing product variety through the expansion of product lines and brands. In particular, changes in the number of products by existing firms account for 27 percent of the welfare gains, while the entry of new firms accounts for 64 percent. In contrast, reductions in the prices of old products offered by the initial set of firms account for less than 10 percent of the overall welfare effect. These findings underscore the importance of product entry for the welfare gains from trade, highlighting in particular the role of product innovation by existing firms.

Our theoretical results further allow us to disentangle the importance of the direct and indirect effects of trade shocks for aggregate welfare. According to our estimates, rising aggregate competition discourages innovation, which counteracts the welfare gains implied by the direct effects along three margins of welfare gains. In total, the innovation-discouraging effects of rising competition lower welfare by 0.004 percent, or 5.7% percent of the overall gain. Rising competition primiarly impedes firms' incentives to invest in new product lines, lowering the gains materializing through this margin by 18 percent, which corresponds to a reduction in the total gains of 4.8%.

Discussion and robustness

We conclude by discussing the sensititivty of the quantitative results to our calibration choices.

Cost pass-throughs and markups. Following Theorem 1, the cost pass-through ρ, ceteris paribus, affects the economy's adjustment to trade shocks via two channels. On the one hand, a lower cost pass-through ρ implies that firms' perceived demand elasticity responds more to changes in its product range, implying that prices of existing products respond more to product innovation. Second, a lower cost pass-through tends to reduce firm entry by raising the partial elasticity of firm-level prices to aggregate competition. Intuitively, if competition has a larger impact on firms' desired markups, less entry is required to achieve a given increase in competition. The level of markups, on the other hand, affects both the rate of entry, as well as the consumer surplus generated by entrants.

In table we report how our welfare estimates change under alternative assumptions on markups and pass-throughs. Throughout, we maintain that the cannibalization rate equals 0.5, and adjust the between-brand elasticity of substitution σ to be consistent with alternative choices for markups and pass-throughs.

7. 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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Appendix

Appendix A. Tables

Table A1. Knowledge Service Exports to Germany: Major Source Countries and Sourcing Industries

	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: Based on annual averages of total knowledge service imports of all German residents in the SITS database during the period 2005 to 2012. Where applicable, averages taken across industry or source country. Imports of knowledge services are 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).

Table A2. Sample Descriptive Statistics

	Knowledge Service Importers		Non-Importers	
Unique Firm Observations	512		10,639	
Firm-Year Observations	1,334		25,718	
Innovation-related firm characteristics	Mean	Stand. Dev.	Mean	Stand. Dev.
Knowledge Service Imports (€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 of product innovations (%)	18.6	25.5	8.2	18.6
Revenues of product Innovations (€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 savings from process innovations (€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 unweighted averages taken across all firm-year observations during the sample period from 2005 to 2012, and are calculated separately by firm-year importer status. Importers are firms with positive expenditures on foreign knowledge services. Knowledge service imports are calculated from the SITS database, 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 database. Product innovation is defined as the introduction of one or many new or improved products. Process innovation is defined as the introduction of new or improved production processes. Revenue share of product innovations and unit cost reduction from process innovation are measured in percent and multiplied by 100. Averages of all other variables measured in percent correspond to an average across dummy variables multiplied by 100.

Table A3. Quasi-Random Assignment of Common Shocks: Falsification Tests

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dep. Variable	Old	Large	Exporter	Multin. Group	Ger. Group	Occ. R&D	Cont. R&D	Innovation indicator 1-yr lag
S_{ft}	0.005	0.004	−0.002	0.007	−0.004	−0.000	−0.001	0.004
	(0.005)	(0.004)	(0.002)	(0.005)	(0.003)	(0.002)	(0.003)	(0.005)
Old Firm		0.036***	−0.008***	−0.019***	−0.016***	−0.018***	−0.029***	−0.022***
		(0.004)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.002)
Large Firm	0.121***		−0.002	0.254***	0.240***	0.020***	0.142***	0.087***
	(0.007)		(0.006)	(0.008)	(0.012)	(0.004)	(0.006)	(0.004)
Exporter	0.008***	−0.000		0.070***	0.023***	0.082***	0.159***	0.074***
	(0.001)	(0.002)		(0.001)	(0.001)	(0.001)	(0.003)	(0.002)
Multinational	−0.046***	0.182***	0.157***		−0.220***	0.038***	0.123***	0.035***
Group	(0.004)	(0.004)	(0.008)		(0.001)	(0.002)	(0.014)	(0.003)
German	−0.030***	0.136***	0.041***	−0.174***		0.022***	−0.050***	0.043***
Group	(0.002)	(0.002)	(0.002)	(0.016)		(0.001)	(0.002)	(0.002)
Occasional	−0.042***	0.014***	0.157***	0.036***	0.027***		−0.302***	0.411***
R&D	(0.003)	(0.002)	(0.002)	(0.003)	(0.001)		(0.015)	(0.006)
Continuous	−0.051***	0.074***	0.258***	0.089***	0.046***	−0.231***		−0.570***
R&D	(0.007)	(0.002)	(0.005)	(0.008)	(0.002)	(0.008)		(0.007)
R^2	0.23	0.289	0.31	0.27	0.10	0.11	0.36	0.43
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
Industry FE	✓	✓	✓	✓	✓	✓	✓	✓
State FE	✓	✓	✓	✓	✓	✓	✓	✓
Import-Origin FE	✓	✓	✓	✓	✓	✓	✓	✓
Observations	26512	26512	26512	26512	26512	26512	26512	11106

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 A4. Export Supply Shocks to Knowledge Services: Effect on Firm Innovation Propensity

	(1)	(2)	(3)	(4)	(5)	(6)
Export Supply Knowledge Services	0.027***	0.016***	0.016***	0.007***	0.005**	0.006***
	(0.002)	(0.002)	(0.001)	(0.002)	(0.004)	(0.002)
Controls						
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	0.16	0.16	0.18	0.23	0.45
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 firms' export supply of knowledge services correspond to variable S_{ft} defined 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 A5. Export Supply Shocks to Knowledge Services: Effect on Firm Innovation Propensity, Robustness Checks

	(1)	(2)	(3)	(4)	(5)	(6)
Knowledge Service Export Supply: Baseline	0.006***	0.012***				
	(0.002)	(0.003)				
Alternative year t_0 to measure exposure			0.006***			
			(0.000)			
Only main importers				0.003		
				(0.111)		
Excluding main importers					0.015*	
					(0.003)	
Export Supply Other Services						−0.000
						(0.096)
R^2	0.63	0.42	0.44	0.44	0.44	0.44
Year FE	✓	✓	✓	✓	✓	✓
Industry FE	✓	✓	✓	✓	✓	✓
Federal State FE	✓	✓	✓	✓	✓	✓
Import Origin FE	✓	✓	✓	✓	✓	✓
Observations	1330	23308	26512	26512	26512	26512

Notes: Coefficient estimate for β in specification (1) with a dummy indicating product, service, or process innovation as dependent variable. Shocks to firms' export supply of knowledge services correspond to variable S_{ft} defined in (2). Column 1 restricts the estimation sample to firms with positive imports of knowledge-related services during the pre-estimation years 2002-2004. Column 2 restricts the estimation sample to firms not part of a multinational company group. Column 3 constructs export supply shocks as in (2), but sets the reference year for shock exposure t_o to the first year a firm appears in the SITS database. Column 4 constructs $S_{f,t}$ as in (2), but only uses information on imports from the set of major source countries listed in table (A1) to construct shocks and exposure weights. Column 5 constructs $S_{f,t}$ as in (2), but excludes imports from all major source countries. to construct shocks and exposure weights. Column 6 replaces $S_{f,t}$ with shocks to the export supply of service types not included in the definition of knowledge services, following (2) and using information on firm-level and economy-wide imports of all services types from the SITS. 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 A6. Export Supply Shocks to Knowledge Services: Effect on Firm Product/Process Innovation

	Cost Savings from Process Innvation			Product/Service Innovation		
	dummy (0/1)	in % of unit costs	log(total reduction)	dummy (0/1)	in % of revenue	log(total revenue)
Export Supply Knowledge Services	0.005**	0.001***	0.096**	0.006**	0.001	0.113***
	(0.002)	(0.000)	(0.039)	(0.002)	(0.001)	(0.044)
Controls						
Old Firm	−0.006**	−0.002***	−0.010	−0.017***	−0.019***	−0.106***
	(0.002)	(0.000)	(0.045)	(0.002)	(0.001)	(0.033)
Large Firm	0.111***	0.003***	2.094***	0.064***	−0.013***	1.943***
	(0.005)	(0.047)	(0.089)	(0.006)	(0.003)	(0.077)
Exporter	0.015***	0.002***	0.207***	0.064***	0.021***	0.946***
	(0.002)	(0.000)	(0.028)	(0.002)	(0.001)	(0.024)
Multinational Company Group	0.055***	0.002***	0.966***	0.019***	−0.004***	0.849***
	(0.005)	(0.000)	(0.071)	(0.003)	(0.001)	(0.053)
Domestic Company Group	0.036***	0.003***	0.544***	0.022***	0.000	0.560***
	(0.002)	(0.000)	(0.042)	(0.002)	(0.001)	(0.035)
Occasional internal R&D	0.195***	0.017***	2.475***	0.454***	9.809***	5.892***
	(0.003)	(0.000)	(0.049)	(0.003)	(0.101)	(0.024)
Continuous internal R&D	0.248***	0.025***	3.305***	0.611***	0.188***	8.464***
	(0.002)	(0.039)	(0.051)	(0.006)	(0.003)	(0.054)
R^2	0.18	0.10	0.21	0.45	0.32	0.49
Observations	26512	26512	26512	26512	26512	26512

Notes: Coefficient estimates for specification (1) using innovation outcomes capturing product and process innovation as dependent variables. Shocks to firms' export supply of knowledge services correspond to variable S_{ft} defined in (2). 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 A7. Supply Shocks to Knowledge Service Exports: Effect on Firms' Domestic R&D Expenditures

	(1)	(2)	(3)	(4)	(5)	(6)
Export supply knowledge services	0.509***	0.337***	0.334***	0.164***	0.070***	0.038
	(0.038)	(0.031)	(0.031)	(0.026)	(0.016)	(0.037)
Controls						
Old Firm (0/1)				−0.322***	0.024	0.014
				(0.054)	(0.024)	(0.014)
Large Firm (0/1)				2.857***	1.052***	0.983***
				(0.105)	(0.045)	(0.049)
Exporter (0/1)				2.292***	0.300***	0.292***
				(0.050)	(0.012)	(0.008)
Multinational Group				1.944***	0.502***	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***	8.456***
					(0.056)	(0.048)
Continuous R&D					10.90***	10.83***
					(0.095)	(0.041)
R^2	0.05	0.27	0.27	0.35	0.86	0.865
Year FE	✓	✓	✓	✓	✓	✓
Industry FE		✓	✓	✓	✓	✓
Federal State FE			✓	✓	✓	✓
Import-Origin FE						✓
Observations	26512	26512	26512	26512	26512	26512

Notes: Coefficient estimates of specification (1) with log(domestic R&D expenditures+1) as dependent variable. Domestic R&D expenditures are measured as the difference between firms' total R&D expenditures reported in the MIP and expenditures on R&D service imports from the SITS. Shocks to firms' export supply of knowledge services correspond to variable S_{ft} defined in (2). 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 A8. Calibrated Moments

Parameter/Statistic		Estimate	Source/Target
Knowledge import ratios	$\mathbb{E}_s\left[\frac{\tau_\theta I_\theta}{p_\theta q_\theta h_\theta}\right], \mathbb{E}_s[\varphi_\theta]$	0.002, 0.19	Author's calculations
Cannibalization rate	$\frac{1-\rho_\theta+\varepsilon_\theta \rho_\theta}{\sigma}$	0.5	Hottman *et al.* (2016)
Product level surplus	δ	1.05	n.a.
Perceived demand elasticicty	ε	7.6	$\mu = 1.15$
Price cost pass-through	ρ	0.7	Amiti *et al.* (2019)
EoS across firms	σ	11.1	Authors' calculations
Aggregate trade elasticity	$-\frac{\partial \ln \overline{\tau I}}{\partial \ln \tau}$	0.8	Authors' estimates
Innovation cost pass-throughs	γ^c	0.004	Authors' estimates
	γ^h	−0.95	Author's estimates

Table A9. Calibrated Welfare Gains from Services Trade

Welfare Gain	$-\frac{\partial \ln \mathfrak{U}}{\partial \ln \tau}$	0.06
Decomposition		
New Products		27%
New Firms		64%
GDP		9%

Notes: This table presents estimates of the elasticity of welfare with respect to variable trade costs of knowledge service imports following Theorem 1 under the assumption that firms are homogeneous and using the estimates in table A8.

Table A10. Welfare Gains: Robustness

	$\rho = 0.9$	$\mu = 1.25$	$\mu = 1.25, \rho = 0.9$
Welfare Gain	0.10	0.17	0.13
Decomposition			
New Products	29%	32%	33%
New Firms	67%	58%	62%
GDP	5%	10%	5%

Notes: This table presents estimates of the elasticity of welfare with respect to the relative costs of service imports in Theorem 1, using the estimates in Table A8.

Appendix B. Proofs

B.1. Derivation of the knowledge production function

Define $G(\iota) = \Pr\left[\iota(\omega) > \tilde{\iota}\right]$. For a given number of ideas, the probability of a firm acquires less than $\tilde{\iota}$ units of additional expertise in knowledge area ω equals:

$$\Pr\left[\max_{i=0,1,\ldots,n(\omega)-1} \iota(\omega) \leq \tilde{\iota}\right] = (1 - G(\tilde{\iota}))^{n(\omega)}. \tag{A1}$$

Given that the arrival rate of new ideas is distributed Possion with mean $N(\omega)$, $n(\omega) \sim \text{Poisson}(N(\omega))$:

$$\begin{aligned}
\Pr\left[\iota(\omega) \leq \tilde{\iota}\right] &= \sum_{n=0}^{\infty} \frac{e^{-N(\omega)} N(\omega)^n}{n!} (1 - G(\tilde{\iota}))^n \\
&= e^{-N(\omega)} \sum_{n=0}^{\infty} \frac{(N(1 - G(\tilde{\iota}))^n}{n!} \\
&= e^{-N(\omega) G(\tilde{\iota})}
\end{aligned} \tag{A2}$$

For a general distribution $G(\cdot)$, this last equation describes the distribution of expertise in knowledge area ω for a given number of activities completed $N(\omega)$. When the quality of ideas is drawn from a Pareto distribution, $\Pr[\iota_i(\omega) > \tilde{\iota}] = G(\tilde{\iota}) = k_j^{\gamma} \tilde{\iota}^{-\zeta}$, then $\Pr\left[\iota(\omega) \leq \tilde{\iota}\right] = e^{-N(\omega) k_j^{\gamma} (\tilde{\iota})^{-\zeta}}$, where

$$\begin{aligned}
\mathbb{E}\left[(\iota(\omega))^{\chi}\right] &= \int_0^{\infty} (z)^{\chi} d(1 - e^{-N(\omega) k_j^{\gamma} (z)^{-\zeta}}) dz \\
&= \int_0^{\infty} (z)^{\chi} (N(\omega) k_j^{\gamma} \zeta (z)^{\zeta - 1}) e^{-N(\omega) k_j^{\zeta - \gamma} z^{-\zeta}} dz \\
&= \int_0^{\infty} \left[N(\omega) k_j^{\gamma}\right]^{\chi/\zeta} u^{1 - \frac{\chi}{\zeta} - 1} e^{-u} du \\
&= \Gamma\left(1 - \chi/\zeta\right) \left[N(\omega)\right]^{\chi/\zeta} k_j^{\gamma\chi/\zeta},
\end{aligned}$$

where we changed the variable of integration in the third line to $u = N(\omega) k_j^{\gamma} z^{-\zeta}$ so that $z = N(\omega)^{1/\zeta} k_j^{\gamma/\zeta} u^{-1/\zeta}$ and $du = -\zeta N(\omega) k_j^{\gamma} z^{-\zeta-1} dz$. Here, $\Gamma(\cdot)$ denotes the Gamma function. Since $2\chi < 2 < \zeta$ by assumption, the expectation above is well defined, $1 - \chi/\zeta > 0$.

To derive the knowledge production function, let the set of feasible input combinations that, in expectation, yield innovation output ι be defined as:

$$\boldsymbol{N}(\iota_j) \equiv \{N(\omega)_{\omega\in\Omega} : k_j^{\gamma/\zeta}\Gamma\left(1-\chi/\zeta\right)^{1/\chi}\left(\int_\omega \left[N(\omega)\right]^{\chi/\zeta} d\omega\right) = \iota^\chi\}$$

Under the parametric restriction $2\kappa \leq \zeta$, the following term has a finite variance for $\forall \boldsymbol{N} \in \left\{\boldsymbol{N}(dk_i) : dk_j \geq 0\right\}$,

$$\int_{\Omega_j} \text{Var}\left[z(\omega)\middle|N_j(\omega)\right] d\omega = k_j^{\frac{\gamma}{\zeta}}\left[\Gamma\left(1-2\cdot\chi/\zeta\right) - \Gamma^2\left(1-\chi/\zeta\right)\right]\int_{\Omega_i} N(\omega)^{2\chi/\zeta} d\omega < \infty,$$

We impose that there exist an an extension of the Kolmogorov measure which ensures that all paths $\boldsymbol{N}(\cdot)$ are measurable. The strong law of large numbers for independently distributed random variables then gives the innovation production function:

$$\iota_j \overset{a.s.}{=} k_j^{\gamma/\zeta} A^{1/\chi}\left(\int_{\Omega_j} \left[N(\omega)\right]^{\chi/\zeta} d\omega\right)^{1/\chi},$$

where $A \equiv \Gamma\left(1-\chi/\zeta\right)$. The knowledge production function, then, satisfies

$$\frac{k_j' - k_j}{k_j} = \iota_j/k_j = A^{1/\chi} k_j^{\gamma/\zeta-1}\left(\int_{\Omega_j} \left[N(\omega)\right]^{\chi/\zeta} d\omega\right)^{1/\chi}.$$

B.2. Derivation of the Innovation Cost Function

Let the offshoring cutoff ω^* be implicitly defined by $\frac{q_H}{q_F\tau} = t(\omega^*)$ so that tasks in $\omega \in [0, \omega^*]$ are either performed in-house, using labor; or offshored, using a foreign contractor. The monotonicity of $t(\cdot)$, then, implies that tasks up to a cutoff $\omega_o^* \leq \omega^*$ are offshored, with this cutoff being implicitly defined by:

$$N(\omega_o^*) = \left(\frac{\alpha\tau t(\omega_o^*) q_F}{w_H}\right)^{1/(\alpha-1)}.$$

The remaining tasks $\omega \in [\omega_o^*, \omega^*]$ will be produced in-house.

Cost-symmetry between tasks that are outsourced domestically implies that all tasks in the set $[\omega^*, 1]$ must be performed in-house if $w_H N(\omega^*)^{\alpha-1} < q_H$; else, they are optimally outsourced to domestic contractors.

These considerations imply that the firm's cost-minimization problem can be written as:

$$\kappa(\iota,\tau) = \min_{\substack{N_d(\omega),\, N(\omega),\, N_i(\omega)\\ \omega^*,\, \omega_o^*,\, \omega_i^*}} \quad q_H \int_{\omega_i^*}^{1} N_d(\omega) d\omega + \tau q_F \int_{o}^{\omega_o^*} N(\omega) t(\omega) d\omega + q_H \int_{\omega_o^*}^{\omega_i^*} N_i(\omega)^{\alpha} d\omega \Big\}$$

$$+ \lambda \left[\iota - k^{\gamma/\zeta} \left((1-\omega_i^*) N_d^{\chi/\zeta} + \int_0^{\omega_0^*} N(\omega)^{\chi/\zeta} d\omega + (\omega_i^* - \omega_o^*) N_i^{\chi/\zeta} \right)^{1/\chi} \right]$$

$$+ \lambda^{\mathcal{O}} \left[\left(\frac{\alpha \tau t(\omega_o^*) q_F}{w_H} \right)^{1/(\alpha-1)} - N(\omega_o^*) \right]$$

$$+ \lambda^{\mathcal{I}} \left[t(\omega^*) \tau q_F - q_H \right]$$

$$+ \lambda^{D} \left[w_H N(\omega^*)^{\alpha} - q_H N(\omega_i^*)^{\alpha} \right].$$

The optimal intensity $N_i(\omega) \equiv N_i$ for tasks performed in-house satisfies the following FOC:

$$w_H N_i^{\alpha} \alpha = \lambda \iota^{1-\chi} N_i^{\chi/\zeta} \frac{1}{\zeta},$$

By the envelope theorem, $\frac{\partial \kappa}{\partial \iota} = \lambda, \frac{\tau}{\kappa} \frac{\partial \kappa}{\partial \tau} = \varphi_O$. Defining $\mathcal{E} \equiv \frac{\partial \ln \kappa(\iota,\tau)}{\partial \ln \iota}$, we can then express the cost share of tasks performed in-house, $\varphi^{\mathcal{I}} \equiv (\omega_i^* - \omega_o^*) w_H N_I^{\alpha}$ as:

$$\varphi^{\mathcal{I}} \alpha \equiv (\omega_i^* - \omega_o^*) \mathcal{E} \frac{N_i^{\chi/\zeta}}{\iota^{\chi}} \frac{1}{\zeta}.$$

Following similar steps, the FOCs determining the intensity of outsourced tasks can be written as:

$$\varphi^{\mathcal{O}} = \mathcal{E} \frac{\int_0^{\omega_o^*} N(\omega)^{\chi/\zeta}}{\iota^{\chi}} \frac{k^{\gamma/\zeta}}{\zeta}, \; \varphi^{D} = \mathcal{E} \frac{\left(1-\omega_i^*\right) N_D^{\chi/\zeta}}{\iota^{\chi}} \frac{1}{\zeta}.$$

Rearranging and substituting into the constraint, we obtain:

$$\mathcal{E} = \zeta \left[\varphi^{\mathcal{I}} \alpha + 1 - \varphi \right].$$

Noting that $\frac{\partial \mathcal{E}}{\partial \ln \tau} = \frac{\partial^2 \ln \iota}{\partial \ln \tau \partial \ln \iota} = \frac{\partial \varphi^{\mathcal{O}}}{\partial \ln \iota}$, the cross-elasticity of the cost elasticity $\mathcal{E}$ with respect to the cost parameter τ equals:

$$\frac{\partial \ln \mathcal{E}}{\partial \ln \tau} = \varphi_O \times \frac{(1-\varphi^{\mathcal{O}})}{\mathcal{E}} \times \eta^{\mathcal{O}},$$

where we defined the output elasticity of the offshoring share as $\eta^{\mathcal{O}} \equiv \frac{\partial \ln \varphi^{\mathcal{O}}(\iota,\tau)}{\partial \ln \iota}$. Given that marginal cost are equal to: $\frac{\partial \kappa}{\partial \iota} = \frac{\kappa}{\iota} \times \mathcal{E}$, we can then express the elasticity of marginal cost with respect to innovation scale and offshoring cost as:

$$d \ln \frac{\partial \kappa}{\partial \iota} = \varphi^{\mathcal{O}} \times \left[1 + \frac{1-\varphi^{\mathcal{O}}}{\mathcal{E}} \cdot \eta^{\mathcal{O}}\right] \times d \ln \tau + \left[\mathcal{E} + \frac{\partial \ln \mathcal{E}}{\partial \ln \iota}\right] \times d \ln \iota.$$

Differentiating the optimal input demands, we can further show that

$$\left(1 - \frac{\varphi^{\mathcal{O}}(1-\varphi^{\mathcal{O}})}{\zeta\left[\varphi^{\mathcal{I}}\alpha + 1 - \varphi^{\mathcal{I}}\right]}\right) \cdot \eta_{\mathcal{O}} = -\chi + \frac{\int_o^{\omega_o^*} N(\omega_o^*)^{\chi/\zeta} d\omega}{\int_0^{\omega_o^*} N(\omega)^{\chi/\zeta} d\omega} \frac{\partial \ln \omega_o^*}{\partial \ln \iota},$$

and, since $(t(\omega_o^*) q_H \tau)^{\frac{\alpha - \chi/\zeta}{\alpha - 1}} = \frac{\kappa \times \mathcal{E}}{\iota^{\chi} \times \zeta}$,

$$\frac{\partial \ln \omega_0^*}{\partial \ln \iota} = \frac{\alpha - 1}{\alpha - \chi/\zeta} \frac{\partial \ln \omega_o^*}{\partial \ln t(\omega_o^*)} \cdot \left(\mathcal{E} - \chi + \frac{\varphi^{\mathcal{O}}(1-\varphi^{\mathcal{O}})}{\zeta\left[\varphi^{\mathcal{I}}\alpha + 1 - \varphi^{\mathcal{I}}\right]}\right),$$

which implies

$$\eta_{\mathcal{O}} > 0 \Leftrightarrow \chi \frac{1 - T(\omega_o^*)}{T(\omega_o^*)} < \left(\mathcal{E} + \frac{\varphi^{\mathcal{O}}(1-\varphi^{\mathcal{O}})}{\zeta\left[\varphi^{\mathcal{I}}\alpha + 1 - \varphi^{\mathcal{I}}\right]}\right)$$

where

$$T(\omega_o^*) \equiv \frac{\alpha - 1}{\alpha - \chi/\zeta} \frac{\partial \ln \omega_o^*}{\partial \ln t(\omega_o^*)} \frac{\int_o^{\omega_o^*} N(\omega_o^*)^{\chi/\zeta} d\omega}{\int_0^{\omega_o^*} N(\omega)^{\chi/\zeta} d\omega}.$$

Since $N(\omega) = \left(\frac{t(\omega)}{t(\omega_o^*)}\right)^{1/\chi/\zeta - 1} N(\omega_o^*)$, a sufficient condition for $\eta^{\mathcal{O}} > 0$ is hence given by:

$$\frac{\alpha - 1}{\alpha - \chi/\zeta} \frac{t(\bar{\omega})^{\frac{1}{1-\chi/\zeta}}}{\int_o^{\omega_o^*} t(\omega)^{\frac{\chi/\zeta}{\chi/\zeta - 1}} d\omega} > \frac{\partial t(\bar{\omega})}{\partial \bar{\omega}}.$$

To derive the threshold innovation investment for offshoring, note that no tasks will be offshored if

$$t(\omega_o^*) = \left(\frac{\mathcal{E}/\zeta}{\iota^{\chi}}\right)^{\frac{\alpha-1}{\alpha-\chi/\zeta}} (\tau q_F)^{-1} < t(0)$$

Since $1 \le \mathcal{E}/\zeta \le \alpha$, $\exists \underline{\iota}^{o}$s.t. $\forall \iota < \underline{\iota}_{\mathcal{O}}$, $t(0) > \left(\frac{\alpha}{\iota^{\chi}}\right)^{\frac{\alpha-1}{\alpha-\chi/\zeta}} (\tau q_F)^{-1}$ and hence $\omega_o^* = 0$. Similarly, $\exists \underline{\iota}^{D}$, s.t. $\forall \iota < \iota^{D}$, $1 - \omega_I^* = 0$ and no domestic offshoring occurs.

B.3. Problem of the Firm

A firm of type θ can build k' units of knowledge capital for a particular product j at a total innovation cost of $\kappa_\theta(k') \equiv \kappa(k' - k_\theta)$. The derivations in the text, then, imply that

$$\frac{\partial \ln \kappa}{\partial \ln k'} = \frac{\partial \ln \kappa}{\partial \ln \iota_\theta} \times \frac{k'}{\iota_\theta} = \frac{\partial \ln \kappa}{\partial \iota_\theta} = \frac{k'}{\kappa_\theta} \times \frac{\partial \kappa}{\partial \iota_\theta}$$

This section provides detailed derivations of optimal firm decisions. Conditional on an importing regime $\mathbf{1}_I$, the problem of a firm θ can be written:

$$\Pi_\theta(\mathbf{1}_I) = \max_{h, p_j, k, \mathrm{p}, \lambda} \begin{Bmatrix} \int_0^h \left\{ [p_j - c_\theta(k)] p_j^{-\varepsilon} \mathrm{p}^{\varepsilon-1} s_\theta(\frac{\mathrm{p}}{P}) - \eta_\theta(\iota) - \kappa_\theta^\kappa \right\} dj \\ + \lambda \left((\int_0^h p_j^{1-\varepsilon} dj)^{1/(1-\varepsilon)} - \mathrm{p} \right) \end{Bmatrix},$$

In the following, we establish the existence and uniqueness of a solution to this problem. Throughout, we treat a firm's product range h as a continuous variable.

Prices and product range range . The firm chooses $(p_j) \in \mathcal{P} \equiv \bigcup_{j \in [0,h]} \mathcal{P}_{[0,h]}$ where $\mathcal{P}_{[0,h]}$ denotes all smooth, strictly positive price allocations on $[0, h]$. The FOC with respect to p_j is given by,

$$[(1-\varepsilon) p_j + \varepsilon c_j] \frac{p_j y_j}{\mathrm{p}_\theta^\varepsilon} + \lambda p_j^{1-\varepsilon} = 0, \tag{A3}$$

which implies:

$$\int_0^h [(1-\varepsilon) p_j + \varepsilon c_j] p_j y_j dj = \lambda \mathrm{p}_\theta$$

Given h, k and p, it is easy to verify that the second-order condition is satisfied globally since $\frac{1}{p_j}\left(\lambda \mathrm{p}^\varepsilon p_j^{-\varepsilon} \frac{p_j \partial y_j}{y_j \partial p_j} + (1-\varepsilon) y_j\right) < 0$, which establishes a global maximum $p_j(h, \mathrm{p}, k)$, Next, the FOC with respect to h is given by

$$[p_i - c_i] y_i - f_i - \kappa_i + \frac{1}{1-\varepsilon} \lambda p_i^{1-\varepsilon} (\int_0^h p_j^{1-\varepsilon} dj)^{\frac{\varepsilon}{1-\varepsilon}} = 0. \tag{A4}$$

Applying the envelope theorem, we obtain $\frac{\partial [p_i - c_\theta] y_i}{\partial p_i} = -\lambda p_i^{1-\varepsilon} \mathrm{p}^\varepsilon < 0$. Evoking the implicit function theorem and Assumption 1, we can show that

$$\frac{\partial p_j(h,\mathsf{p},k)}{\partial h} = \frac{\varepsilon-\sigma_\theta}{1-\varepsilon}\frac{1}{\mathsf{p}}\cdot\frac{\lambda\mathsf{p}^\varepsilon p_j^{-\varepsilon}\frac{\sigma_\theta}{\varepsilon-\sigma_\theta}}{1-y_j\frac{1}{p_j}\left(\lambda\mathsf{p}^\varepsilon p_j^{-\varepsilon}\frac{p_j\partial y_j}{y_j\partial p_j}+(1-\varepsilon)y_j\right)} < 0,$$

which implies that the left-hand-side of (A4) is strictly decreasing since

$$\lambda p_i^{1-\varepsilon}\mathsf{p}^\varepsilon\left[\frac{1}{p_i}\frac{\partial p_i}{\partial h}+\frac{1}{1-\varepsilon}\frac{1}{\mathsf{p}}p_i^{1-\varepsilon}+\frac{1}{\mathsf{p}}\int_0^h\frac{\partial p_j}{\partial h}dj\right] < 0.$$

Hence, there exist global maxima for any given p and ι, $p_j(\mathsf{p},\iota)$ and $h(\mathsf{p},\iota)$.

The FOC for p is given by

$$(\varepsilon-\sigma_\theta)\int_0^h[p_i-c_i]y_i di = \mathsf{p}_\theta\lambda. \tag{A5}$$

By the envelope theorem, $\frac{\partial h[p_i-c_\theta]y_\theta}{\partial p_i} = -\lambda p_i^{1-\varepsilon}\mathsf{p}^\varepsilon h < 0$, $\frac{\partial h[p_i-c_\theta]y_\theta}{\partial h} = \frac{1}{\sigma-1}\lambda p_i^{1-\varepsilon}\mathsf{p}^\varepsilon$,and $\frac{\partial h}{\partial \mathsf{p}} \propto \frac{\partial y_j}{\partial \mathsf{p}} < 0$,implying that, $\frac{\partial p_i}{\partial \mathsf{p}} > 0$. It is then easy to check that the left-hand-side of (A5) is strictly decreasing. Hence, there exists a unique product range and price that solves the firm's problem at a given level of innovation investment.

Combining these first-order conditions, we obtain the characterization of prices and quantities stated in the main text.

$$\int_0^h[(\sigma_\theta-1)p_j+\sigma_\theta c_j]p_j y_j dj = (\varepsilon-\sigma_\theta)\int_0^h[p_i-c_i]y_i di$$

$$p_{\theta j} = \frac{\sigma_\theta}{\sigma_\theta-1}c_{\theta j}, \quad \mathsf{p}_\theta^{1-\varepsilon} = \mu_\theta\int_0^{h_\theta}c_{\theta j}^{1-\varepsilon}dj.$$

This implies:

$$\int_0^{h_\theta}\left[(p_{\theta j}-c_{\theta j})y_{\theta j}-f_{\theta j}\right]dj = \int_0^{h_\theta}\left[\frac{1}{\sigma_\theta-1}c_{\theta j}y_{\theta j}-f_{\theta j}\right]dj$$

From the FOC for h_θ :

$$\int_0^{h_\theta}\left[\frac{1}{\sigma_\theta}p_{\theta\bar{j}}y_{\theta\bar{j}}-f_{\theta\bar{j}}-\kappa_{\theta\bar{j}}\right]dj = \int_0^{h_\theta}\left[p_{\theta j}y_{\theta j}\frac{\varepsilon-\sigma_\theta}{\varepsilon-1}\right]dj$$

Knowledge. The FOC with respect to innovation is given by

$$\left[-\frac{k_\theta' c'(k_\theta')}{c_\theta} y_\theta c_\theta - \frac{k_\theta' f'(k_\theta')}{f_\theta} f_\theta\right] - \kappa_\theta \frac{\partial \ln \kappa_\theta}{\partial \iota_\theta} = 0. \tag{A6}$$

Further below, we derive the determinant of the Hessian of the firm's market value function, given by:

$$\det\left[\mathcal{H}_{v_\theta}\right] = \left\{\frac{\partial \ln(-\frac{\partial \ln c_\theta}{\partial \ln \iota_\theta} - \frac{1}{\varepsilon-1}\frac{\partial \ln f_\theta}{\partial \ln \iota_\theta})/\mathcal{E}_\theta}{\partial \ln \iota_\theta} + \frac{\partial \ln(f_\theta + \kappa_\theta)}{\partial \ln \iota_\theta} - \mathcal{E}_\theta\right\}.$$

where $\mathcal{E}_\theta$ is the innovation scale elasticity defined in Proposition 1. The following, then, gives a sufficient condition that guarantees the existence and uniqueness of a well-defined solution to the firm's problem:

$$\frac{\partial \ln \mathcal{E}_\theta}{\partial \ln \iota_\theta} < \frac{\partial \ln(-\frac{\partial \ln c_\theta}{\partial \ln \iota_\theta} - \frac{1}{\varepsilon_\theta-1}\frac{\partial \ln f_\theta}{\partial \ln \iota_\theta})}{\partial \ln \iota_\theta} + (\frac{\partial \ln f_\theta}{\partial \ln \iota_\theta} - \mathcal{E}_\theta) \cdot \frac{f_\theta}{f_\theta + \kappa_\theta} \quad .$$

B.4. Log-linearized model

In this part, we log-linearize the model. We expand all equilibrium conditions to the first order in shocks. We repeatedly use the following elasticities: $-\frac{\partial \ln \mathrm{y}_\theta}{\partial \ln \mathrm{p}_\theta} = \sigma_\theta$, $-\frac{\partial \ln \mathrm{y}_\theta}{\partial \ln h_\theta} = \frac{\sigma_\theta}{\varepsilon_\theta - 1}$, and $\frac{\partial \ln \mathrm{y}_\theta}{\partial \ln P} = \sigma_\theta - 1$. As in the main text, we suppress product subscripts throughout the derivations, $y_\theta \equiv y_{\theta j}$.

Markups

Noting that $d \ln \mathrm{p}_\theta = d \ln p_\theta + \frac{1}{1-\varepsilon} d \ln h_\theta$, changes markups are given by

$$d \ln \mu_\theta = \frac{\rho_\theta - 1}{\rho_\theta} d \ln \frac{\mathrm{p}_\theta}{P} = \frac{1-\rho_\theta}{\rho_\theta}\left(\frac{1}{\varepsilon-1} d \ln h_\theta + d \ln P - d \ln p_\theta\right) . \tag{A7}$$

Prices and Quantities

The changes in product-level and firm-level prices equal

$$\begin{aligned} d \ln p_\theta &= d \ln {}_\theta + d \ln c_\theta \\ &= (1-\rho_\theta)\left(d \ln P + \frac{1}{\varepsilon-1} d \ln h_\theta\right) + \rho_\theta d \ln c_\theta \end{aligned} . \tag{A8}$$

$$d \ln \mathrm{p}_\theta = (1-\rho_\theta) d \ln P + \rho_\theta d \ln c_\theta - \frac{\rho_\theta}{\varepsilon - 1} d \ln h_\theta, \tag{A9}$$

Given these changes in prices, the corresponding changes in product quantity and firm market share equal,

$$d\ln y_\theta \;=\; \tfrac{\sigma_\theta\rho_\theta-\varepsilon_\theta}{\varepsilon_\theta-1}d\ln h_\theta - \sigma_\theta\rho_\theta d\ln c_\theta + (\sigma_\theta\rho_\theta-1)d\ln P\;. \tag{A10}$$

$$d\ln s_\theta = (1-\sigma_\theta)d\ln\frac{\mathrm{p}_\theta}{P} = (\sigma_\theta-1)\rho_\theta\left(d\ln P + \frac{1}{\varepsilon_\theta-1}d\ln h_\theta - d\ln c_\theta\right) \tag{A11}$$

Innovation

To differentiate the first-order conditions for innovation, we first evoke Proposition 1 to show tht

$$\frac{\partial\ln\kappa_\theta\left[\epsilon_k^f+\mathcal{E}_\theta\frac{\iota_\theta}{k'_\theta}\right]}{\partial\ln\tau} = \varphi_\theta\cdot\left[1+\tilde{\Omega}_\theta\frac{1-\varphi_o}{\mathcal{E}}\cdot\eta_o\right]\cdot d\ln\tau \tag{A12}$$

where $\tilde{\Omega}=\frac{k'_\theta}{\iota_\theta}\mathcal{E}_\theta/\left[\epsilon_k^f+\mathcal{E}_\theta\frac{\iota_\theta}{k'_\theta}\right]$. The total derivative of the FOC for innovation investments then equals:

$$\gamma_\theta^{cc}d\ln c_\theta = \varphi_\theta\cdot\left[1+\tilde{\Omega}\frac{1-\varphi_\theta^{\mathcal{O}}}{\mathcal{E}_\theta^{\mathcal{O}}}\eta_o\right]d\ln\tau + (1-\sigma_\theta\rho_\theta)d\ln P + (\varepsilon_\theta-\sigma_\theta\rho_\theta)\frac{d\ln h_\theta}{\varepsilon_\theta-1}, \tag{A13}$$

where

$$\gamma_\theta^{cc} = 1-\sigma_\theta\rho_\theta + \left[\frac{\partial\ln(-\epsilon_\theta^c-\frac{1}{\varepsilon_\theta-1}\epsilon_\theta^f)}{\partial\ln k'_\theta} - (\mathcal{E}_\theta+\tilde{\Omega}_\theta\frac{\partial\ln\mathcal{E}}{\partial\ln\iota_\theta})\times\frac{k'_\theta}{\iota_\theta}-1\right]\frac{\partial\ln c^{-1}(k')}{\partial\ln c_\theta}.$$

Differentiating the FOC for h_θ, we can show that:

$$\frac{d\ln h_\theta}{\varepsilon_\theta-1} = \frac{1-\sigma_\theta\rho_\theta}{\rho_\theta\sigma_\theta-\varepsilon_\theta}d\ln P + \frac{\gamma_\theta^{hc}}{\rho_\theta\sigma_\theta-\varepsilon_\theta}d\ln c_\theta + \frac{1-\Omega_\theta}{\rho_\theta\sigma_\theta-\varepsilon_\theta}{}^{\mathcal{O}}d\ln\tau \tag{A14}$$

where $\gamma_\theta^{hc}\equiv\sigma_\theta\rho_\theta-1+\frac{\partial\ln(f_\theta+\kappa_\theta)}{\partial\ln k_{\theta j}}\frac{\partial\ln c^{-1}(k_\theta)}{\partial\ln c_\theta}$ and $\Omega_\theta\equiv\frac{f_\theta}{f_\theta+\kappa_\theta}$ denotes the share of product sunk costs attributable to innovation investment.

Substituting for $\frac{h_\theta}{\varepsilon_\theta-1}$ in the total derivative of the FOC for knowledge, we obtain:

$$d\ln c_\theta = \varphi_\theta^{\mathcal{O}}\cdot\frac{\Omega_\theta-\tilde{\Omega}_\theta\frac{1-\varphi_\theta^{\mathcal{O}}}{\mathcal{E}}\cdot\eta_o}{\gamma_\theta^{cc}+\gamma_\theta^{hc}}d\ln\tau \equiv \varphi_\theta^{\mathcal{O}}\cdot\Gamma_\theta^c\cdot d\ln\tau$$

$$\frac{d\ln h_\theta}{\varepsilon_\theta - 1} = \frac{1-\sigma_\theta\rho_\theta}{\rho_\theta\sigma_\theta - \varepsilon_\theta} d\ln P + \varphi_\theta^{\mathcal{O}} \cdot \frac{\Gamma_\theta^c \cdot \gamma_\theta^{hc} + \Omega_\theta}{\rho_\theta\sigma_\theta - \varepsilon_\theta} d\ln\tau$$

Free Entry

We denote a firm's total expenditures on imported knowledge services by $\tau I_\theta \equiv h_\theta \int_0^1 1\{\mathcal{O}(\omega) = 1\}\tau w_F \psi t(\omega) N(\omega) d\omega \equiv h_\theta \kappa_\theta \varphi_\theta$. Applying the envelope theorem to differentiate the free entry condition, we then obtain:

$$\int_\Theta \left[h_\theta(p_\theta - c_\theta) y_\theta \frac{P\partial y_\theta}{y_\theta \partial P} d\ln P - h_\theta \kappa_\theta \varphi_\theta d\ln\tau\right] dG(\theta) = 0 \tag{A15}$$

Budget constraint

Differentiating the budget constraint, we find:

$$0 = d\ln M + \mathbb{E}_s\left[(1-\sigma_\theta) d\ln \frac{\mathrm{p}_\theta}{P}\right] \tag{A16}$$

Welfare

By virtue of the envelope theorem, changes in consumer surplus are given by

$$- \ d\ln P^Y = dW = \ \mathbb{E}_s\left[\delta_\theta - 1\right] d\ln M + \mathbb{E}_s\left[d\ln \mathrm{p}_\theta\right] \tag{A17}$$

B.5. Derivation of firm-level effects of Services Trade costs

To derive the change in the common aggregator, note that $(p_\theta - c_\theta) \cdot h_\theta \cdot y_\theta \cdot \frac{P}{y_\theta} \cdot \frac{\partial y_\theta}{\partial P} = \frac{\sigma_\theta - 1}{\sigma_\theta} \cdot p_\theta \cdot y_\theta \cdot h_\theta = \frac{1}{\mu_\theta} s_\theta$ to rewrite equation A15 as:

$$\begin{aligned}
&\int_\Theta \left[h_\theta(p_\theta - c_\theta) y_\theta \frac{P\partial y_\theta}{y_\theta \partial P} d\ln P - h_\theta \kappa_\theta \varphi_\theta d\ln\tau\right] dG(\theta) = 0 \\
\Leftrightarrow &\mathbb{E}_s\left[\frac{1}{\mu_\theta}\right] d\ln P - \mathbb{E}_s\left[\frac{h_\theta\kappa_\theta}{s_\theta}\varphi_\theta\right] d\ln\tau = 0 \\
\Leftrightarrow &d\ln P = \overline{\mu} \times \overline{\varphi} \times d\ln\tau,
\end{aligned}$$

where we denoted the average markup by $\overline{\mu} \equiv \mathbb{E}_s\left[1/\mu_\theta\right]^{-1}$, and the cost share of imported services in aggregate sales by $\overline{\varphi} \equiv \mathbb{E}_s\left[\frac{h_\theta\kappa_\theta}{s_\theta}\varphi_\theta\right]$.

To derive the direct effect, we begin by solving for changes in marginal costs $d\ln c_\theta$ and product variety $d\ln h_\theta$ as functions of changes in trade costs $d\ln\tau$ and competition $d\ln P$. Using equations (A14) and (A13) we obtain:

$$d\ln c_\theta = \Gamma_\theta^c \varphi_\theta^{\mathcal{O}} d\ln\tau, \tag{A18}$$

$$\frac{1}{\varepsilon_\theta - 1} d\ln h_\theta = \Gamma^h_\theta \varphi^{\mathcal{O}}_\theta d\ln\tau + \frac{1-\sigma_\theta\rho_\theta}{\rho_\theta\sigma_\theta - \varepsilon_\theta} d\ln P. \tag{A19}$$

The structural pass-through of knowledge cost shocks into unit costs, Γ^c_θ, is given by

$$\Gamma^c_\theta \equiv \frac{\partial \ln c_\theta}{\partial \ln \kappa_\theta} = \frac{\Omega_\theta - \tilde{\Omega}_\theta \frac{1-\varphi_\theta}{\mathcal{E}_\theta} \eta^{\mathcal{O}}_\theta}{\det\left[\mathcal{H}_{v_\theta}\right]}.$$

Here,$\mathcal{H}_{v_\theta}$ is the Hessian of the firm's logged market value function, which is negative

$$\det\left[\mathcal{H}_{v_\theta}\right] = \left\{ \frac{\partial \ln(-\frac{\partial \ln c_\theta}{\partial \ln \iota_\theta} - \frac{1}{\varepsilon_\theta - 1}\frac{\partial \ln f_\theta}{\partial \ln \iota_\theta})/\mathcal{E}_\theta}{\partial \ln \iota_\theta} + \frac{\partial \ln(f_\theta + \kappa_\theta)}{\partial \ln \iota_\theta} - \mathcal{E}_\theta \right\} < 0.$$

Hence, $\Gamma^c_\theta > 0$ if, and only if, $\frac{\partial c_\theta}{\partial \iota_\theta} < 0$.

Proof. The pass-through of knowledge cost shocks into a firm's product range, in turn, equals:

$$\Gamma^h_\theta \equiv \frac{\partial \ln h_\theta}{\partial \ln \kappa_\theta} \equiv \frac{\gamma^{hc}_\theta \Gamma^c_\theta + (1-\Omega_\theta)}{\rho_\theta\sigma_\theta - \varepsilon}, \tag{A20}$$

where

$$\gamma^{hc}_\theta = 1 - \sigma_\theta\rho_\theta - \left(\Omega_\theta \frac{\partial \ln f_\theta}{\partial \ln \iota_\theta} + (1-\Omega_\theta)\mathcal{E}_\theta\right) \frac{\partial \ln c^{-1}(k_\theta)}{\partial \ln c_\theta} \tag{A21}$$

Rising innovation cost induce less product innovation if $\gamma^{hc}_\theta \Gamma^c_\theta + \omega^{f_\theta + \kappa_\theta}_{\kappa_\theta} > 0$. Restricting attention to the empirically relevant case where $\Gamma^c_\theta > 0$, this implies that the pass-through of cost shocks into product scope Γ^h_θ is negative if

$$\frac{\kappa_\theta}{\kappa_\theta + f_\theta} \cdot \mathcal{E}_\theta \cdot \left(-\frac{\partial \ln c^{-1}(\iota_\theta)}{\partial \ln c_\theta}\right) > \frac{1}{\varepsilon - 1}\frac{p_\theta y_\theta}{\mu_\theta}(\sigma_\theta\rho_\theta - 1) - \frac{1}{\Gamma^c_\theta} - \frac{f_\theta}{\kappa_\theta + \varepsilon_\theta}\frac{\partial \ln f_\theta}{\partial \ln \iota_\theta},$$

and positive otherwise. The left-hand-side is unambigiously positive since $\Gamma^c_\theta > 0$ implies that unit costs are decreasing in knowledge. The sign and magnitude of the term on the right depends on structural elasticities related to demand (markups, pass-through), technology and innovation.

Finally, to characterize the change in a firm's normalized price $d\ln\frac{\mathrm{p}_\theta}{P}$ in terms of changes in trade costs, we can substitute the above expressions for $d\ln P$, $d\ln c_\theta$ and $d\ln h_\theta$ into equation (A9),

$$d\ln\frac{\mathrm{p}_\theta}{P} = \rho_\theta d\ln c_\theta - \rho_\theta d\ln P - \frac{\rho_\theta}{\varepsilon_\theta - 1} d\ln h_\theta$$

$$= \rho_\theta \left[\left(\Gamma^c_\theta - \Gamma^h_\theta \right) \varphi_\theta - \frac{\varepsilon_\theta - 1}{\varepsilon_\theta - \rho_\theta \sigma_\theta} \bar{\mu} \Lambda \right] d \ln \tau.$$

□

B.6. Proof of Theorem 1

Proof. Using equation (A16) to substitute for $d \ln M$ in equation (A17), we obtain:

$$\begin{aligned}
dW &= (\mathbb{E}_s[\delta_\theta] - 1)\, \mathbb{E}_s \left[(\sigma_\theta - 1) d \ln \frac{p_\theta}{P} \right] - \mathbb{E}_s \left[d \ln p_\theta \right] \\
&= -d \ln P + \mathbb{E}_s \left[(\sigma_\theta - 1) \mathbb{E}_s[\delta_\theta] - \sigma_\theta \right] d \ln \frac{p_\theta}{P} \\
&= -d \ln P - \mathbb{E}_s \left[\left(1 - \frac{\mathbb{E}_s[\delta_\theta]}{\mu_\theta} \right) \sigma_\theta d \ln \frac{p_\theta}{P} \right], \\
&= -\bar{\mu} \Lambda d \ln \tau - \mathbb{E}_s \left[\left(1 - \frac{\mathbb{E}_s[\delta_\theta]}{\mu_\theta} \right) \sigma_\theta \rho_\theta \left[\left(\Gamma^c_\theta - \Gamma^h_\theta \right) \varphi_\theta - \frac{\varepsilon_\theta - 1}{\varepsilon_\theta - \rho_\theta \sigma_\theta} \bar{\mu} \Lambda \right] \right] d \ln \tau,
\end{aligned}$$

where we evoked Lemma **??** to solve for $d \ln P$ and $d \ln \frac{p_\theta}{P}$ and go from the third to the fourth line.

Using Lemma **??**, we can then change in real GDP:

$$\begin{aligned}
d \ln Q &\equiv -\mathbb{E}_s \left[d \ln p_\theta \right] \\
&= -\mathbb{E}_s [1 - \rho_\theta]\, d \ln P - \mathbb{E}_s \left[\frac{1}{\varepsilon_\theta - 1} d \ln h_\theta + \rho_\theta d \ln c_\theta \right] \\
&= \mathbb{E}_s \left[-\frac{1 - \rho_\theta \sigma_\theta}{\rho_\theta \sigma_\theta - \varepsilon_\theta} - 1 + \rho_\theta \right] d \ln P - \mathbb{E}_s \left[\left(\Gamma^c_\theta + \Gamma^h_\theta \right) \varphi_\theta \right] d \ln \tau \\
&= -\mathbb{E}_s \left[\frac{\varepsilon_\theta - 1}{\varepsilon_\theta - \rho_\theta \sigma_\theta} - \rho_\theta \right] \overline{\mu} \Lambda d \ln \tau - \mathbb{E}_s \left[\left(\Gamma^c_\theta + \Gamma^h_\theta \right) \varphi_\theta \right] d \ln \tau
\end{aligned}$$

To characterize changes in the aggregate markup, we totally differentiate $\overline{\mu} = \mathbb{E}_s \left[\frac{1}{\mu_\theta} \right]^{-1}$ to obtain

$$d \ln \overline{\mu} = -\mathbb{E}_s \left[\frac{\overline{\mu}}{\mu_\theta} \left(d \ln M s_\theta - d \ln \mu_\theta \right) \right].$$

We use firm-level markups are given by

$$d \ln \mu_\theta = \frac{\rho_\theta - 1}{\rho_\theta} d \ln \frac{p_\theta}{P}.$$

The change in total sales of firms of type θ, in turn, is given by

$$d \ln Ms_\theta = \mathbb{E}_s \left[(\sigma_\theta - 1) d \ln \frac{p_\theta}{P} \right] - (\sigma_\theta - 1) d \ln \frac{p_\theta}{P}.$$

Putting this together, we obtain:

$$\begin{aligned} d \ln \overline{\mu} &= - \mathbb{E}_s \left[(\sigma_\theta - 1) d \ln \frac{p_\theta}{P} \right] - \bar{\mu} \mathbb{E}_s \left[\frac{1}{\mu_\theta} (1 - \sigma_\theta - \frac{\rho_\theta - 1}{\rho_\theta}) d \ln \frac{p_\theta}{P} \right] \\ &= \mathbb{E}_s \left[\left\{ \left(1 - \frac{\overline{\mu}}{\mu_\theta} \right) (\sigma_\theta - 1) \rho_\theta + \overline{\mu}(1 - \rho_\theta) \right\} \cdot \left\{ \left(\Gamma_\theta^c - \Gamma_\theta^h \right) \varphi_\theta + \frac{\varepsilon_\theta - 1}{\varepsilon_\theta - \rho_\theta \sigma_\theta} \bar{\mu} \Lambda \right\} \right] d \ln \tau \end{aligned}$$

□

B.7. General equilibrium formulation

To frame our analysis in general equilibrium, we fully specify the problem of contractor firms and assume that H is a small open economy.

Knowledge services sector

We fully specify the problem of contractors in the services sector. Contractors have the same span-of-control for performing innovation tasks as firms in the heterogeneous good sector. More formally, if a contractor wants to supply N units of knowledge services it must hire $\ell = \frac{1}{\psi} \times N^\alpha$ workers. We assume that knowledge services Here, the parameter ψ governs the relative cost-efficieny of contractors.

We assume that contractors place bids for the right to supply knowledge services to a final good producer at a competitive price q_l. A bid takes the form of a binding offer to supply services at a discount d. The profits of a contractor that submits a bid to win the auction to supply N knowledge services are given by

$$\pi_c^N(N) = q_l N - \frac{1}{\psi} N^\alpha w_l - d(N).$$

Equilibrium bids ensure that profits are independent of N, which implies that $d(N)$ solves the following differential equation

$$\frac{\partial d(N)}{\partial N} = q_l - \frac{\alpha}{\psi} N^{\alpha - 1} w_l.$$

Equilibrium profits are equal to zero, which implies that $q_l = \frac{1}{\psi} N^{\alpha-1} w_l - \frac{d(N)}{N}$

Under perfect competition and free entry, the aggregate supply curve for knowledge services in location l equals:

$$S\left(q_l, M_l^s\right) = M_l^s \times N = M_l^s \left(\frac{\psi q_l}{\alpha w_k}\right)^{1/(\alpha-1)}$$

Hence, the knowledge services industry

Appendix 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)

Appendix D. Endogeneity of Access to Foreign Knowledge Services

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

a. 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.
b. 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.
c. 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.

Appendix E. Theoretical Extensions