// NO.24-056 | 08/2024

DISCUSSION PAPER

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# Trade in Services and Innovation

Leibniz Association

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*August 2024*

## Abstract

We study the implications of services trade for firm innovation. Using a quasi-experimental shift-share design, we find that access to foreign knowledge-related services improves the innovativeness of domestic firms and complements their indigenously sourced R&D. To confront this evidence, we develop a theoretical model. It demonstrates outsourcing can foster firms' innovation efficiency by mitigating decreasing economies of scale in in-house innovation efforts. As a result, firms become more likely to outsource innovation efforts as they become more innovative, whereas the prevalence of offshoring depends on its associated trade costs.

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|---|---|
| **Keywords** | International integration – Service trade – Firm innovation |
| **JEL code** | F14 – F15 – F23 – O31 – O32 |
| **Data access** | Research Visits at the German Federal Bank |
| **Project number** | 2017/0094 |

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**Acknowledgments:** We thank the ZEW Mannheim and the Research Data Center of the German Central Bank for providing access to the Mannheim Innovation Panel (MIP), the Statistics on International Trade in Services (SITS), and their mapping tables. We thank Benjamin Balsmeier, Kyrill Borusyak, Matthew Grant, Gene Grossman, Katrin Hussinger, Oleg Itskhoki, Ezra Oberfield, Bettina Peters, Steve Redding, Esteban Rossi-Hansberg, Meredith Startz, and Laszlo Tetenyi for insightful comments. Furthermore, we thank the participants of the ResPol ECR, IIOC, DRUID, ISS, SIIB ECR, REvaluation, and Transatlantic Doctoral Conference, the participants of the Wharton Innovation Doctoral Symposium, the KID Summer School, the DRUID PhD Academy, the KITZ Workshop, the IPI Webinar, the WICK workshop, as well as the participants of the internal seminars at Princeton, UCSD, Ryerson, ZEW Mannheim, and the University of Luxembourg. Bastian Krieger gratefully acknowledges funding through the INNcentive scholarship of the German Donors' Association for the Promotion of Humanities and Sciences and the University of Bremen, and through the Pierre Werner scholarship of the Fondation Pierre Werner and the University of Luxembourg. Fabian Trottner acknowledges travel funding through the International Economics Section at Princeton. All results have been reviewed to ensure that no confidential information is revealed.

## 1. Introduction

Innovation and international trade are strongly linked, fundamental drivers of economic growth (Akcigit and Melitz, 2022; Melitz and Redding, 2021; Shu and Steinwender, 2019). Trade in services has the potential to foster innovation by providing domestic firms with increased access to foreign knowledge (Burgess, 1995; Francois and Hoekman, 2010). During the last decades, it outgrew the value of goods trade (OECD, 2017; WTO, 2019), accounting for around 23 percent of the total value of international trade in 2020 (UNCTAD, 2021). In addition, trade in services directly related to the import of foreign knowledge accounted for 18 percent of US and 13 percent of German service imports in 2020.[1]

We provide empirical and theoretical evidence on the effects of services trade on innovation. The paper demonstrates service trade promotes firms' introduction of new goods, and processes. Moreover, we find foreign knowledge is complementary to domestically sourced innovation inputs. The analysis leverages detailed data on the population of service trades to Germany provided by the Statistics on International Trade in Services (SITS) and the innovation activities of a representative sample of firms provided by the Mannheim Innovation Panel (MIP). We define services imports related to foreign knowledge as firm payments related to foreign i) research, development, and testing, ii) patents, licenses, inventions, and processes, iii) artistic copyrights, and iv) other rights, such as franchise fees or trademarks.

To estimate the causal effect of knowledge service imports on the innovativeness of firms, we utilize the population information on German service trades in the SITS to construct firm-specific service export supply shocks. Utilizing a quasi-experimental shift-share design (Bartik, 1991; Borusyak et al., 2021; Goldsmith-Pinkham et al., 2020), our shocks leverage variation in countries' aggregate knowledge service exports to Germany and 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 a firm's exposure to each common shock (Borusyak et al., 2021).

Based on our shift-share design, we find that greater access to foreign knowledge services causes firms to be more innovative, significantly increasing their propensity to introduce new or significantly improved products or processes. The finding is consistent across various innovation measures, providing evidence that access to knowledge service imports raises a firm's returns to product and process innovation. Furthermore, improved access to foreign knowledge services raises firms' domestic R&D expenditures, suggesting that foreign knowledge is complementary to domestically sourced innovation inputs. Lastly, the effect of

[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.

services trade on innovation appears to be limited to knowledge services - improved access to services not explicitly related to foreign knowledge has no positive effect on firm innovation.

To rationalize our empirical findings, we develop a theoretical model of innovation offshoring. In the model, profit-seeking firms produce multiple products under monopolistic competition with variable markups and free entry. Producers can enhance their capacity to introduce new products, or processes by investing in knowledge to perform tasks designed to resolve requisite problems for innovation. Each task can be outsourced or offshored, provided that a firm is able to locate an external partner. Outsourcing and offshoring become more attractive if external partners are able to perform a task at lower costs. However, both are subject to search costs, and offshoring adds further trade costs. In this environment, firms become more likely to outsource innovation tasks domestically or abroad as they become more innovative, where the prevalence of offshoring depends on its associated trade costs.

As barriers to services trade remain substantial, our results imply that trade liberalizations in services are crucial to fully realize the potential gains from globalization.

***Contributions to literature*** – This paper is the first to analyze the causal effects of foreign knowledge service access on firm innovations. As a result, it contributes to the following three strands of literature addressing the connections between international trade and innovation:

*Trade and innovation* – Our work relates to a vast body of research about the effects of international trade on innovation (Shu and Steinwender, 2019; Melitz and Redding, 2021; Akcigit and Melitz, 2022). Empirically, much of the work provides evidence of the connection between innovation and exporting (Lileeva and Trefler, 2010; Aw et al., 2011; Bustos, 2011; Lim et al., 2022) or import competition (Bloom et al., 2015; Bombardini et al., 2017; Fieler and Harrison, 2018; Fieler et al., 2018; Autor et al., 2020; Chen and Steinwender, 2021). However, we relate most closely to the empirical work examining how intermediate goods imports affect productivity and innovation, such as Goldberg et al. (2010), Topalova and Khandelwal (2011), Halpern et al. (2015), Ariu et al. (2019), and Eppinger (2019), whereas our work is the first to document a causal relationship between the rapidly growing subset of knowledge services and firm innovation. *Theoretically*, we contribute to the literature studying the static gains from trade in models with product differentiation and imperfect competition described in, for example, Krugman (1979), Helpman and 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 different endogenous changes in competition and entry for the welfare effects of trade.[2]

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

*Trade in services* – Furthermore, the paper adds to the growing literature on services trade (Francois and Hoekman, 2010, Benz et al., 2020). One stream of research investigates the determinants of services trade flows (Mattoo and Sauve, 2007; Lipsey, 2009; Breinlich and Criscuolo, 2011; Jensen, 2011; Borchert et al., 2013; Miroudot et al., 2013; Ariu, 2016, Christen et al., 2019; Eaton and Kortum, 2019), while another studies the effects of service trade on various economic outcomes (Jensen, 2011; Arnold et al., 2011; Ariu, 2016; Lejarraga and Oberhofer, 2015; Eppinger, 2019; Hebous and 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, for example, Francois and Hoekman (2010) and Ariu et al. (2019), our paper is the first to provide direct evidence of this channel.

*External knowledge management* – Finally, we contribute to the literature studying the strategic management of external knowledge (Cassiman and Veugelers, 2006; Grimpe and Kaiser, 2010; Hagedoorn and 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.[3] We contribute by exploiting trade patterns in knowledge-related services to obtain systematic insights into the effects of external innovation offshoring.

## 2. Data preparation

### 2.1. Data sources

We merge data on firms' innovation from the Mannheim Innovation Panel (MIP) and firms' services trade activities from the Statistics on International Trade in Services database (SITS) at the Research and Data Service Centre (RDSC) of the German federal bank using the mapping tables described in Schild et al. (2017).[4] Peters and Rammer (2013) provide an extensive description of the MIP and Biewen and Meinusch (2021) of the SITS.[5]

The MIP is an annual survey of firms conducted by the ZEW - Leibniz Centre for European Economic Research. It is a representative sample of firms in the manufacturing and service industries of Germany with five or more employees and part of the European Community Innovation Surveys. The MIP provides information on firms' introduction of new or significantly improved products, and processes, as well as firms' innovation efforts. Moreover,

[3] Rosenbusch et al. (2019) document a positive relationship between innovation offshoring in general and innovation performance using a meta-analysis across a large set of quantitative studies. Moreover, according to their estimates, there is no statistical difference between the relationships of offshoring via subsidiaries or the purchase of foreign knowledge services.

[4] More precisely, the link of the SITS with the DAFNE database. DAFNE is the German part of the Orbis database of – at that time – Bureau van Dyke. The MIP is directly linked to the firm identifiers of DAFNE as DAFNE is sourcing its information from Creditreform, which is also used to draw the survey sample of the MIP.

[5] We accessed the SITS within sequential research stays at the Research Data Center of the German Federal Bank. We use version 1.0 of the SITS covering the years 2001 to 2016 (SITS, 2017). The version is described in Biewen and Lohner (2017).

the MIP covers information on additional firm characteristics, such as employee numbers, founding year, industry class, and export revenues.

The SITS is administered by the Research and Data Service Center of the German Central Bank and compiles the Balance of Payments Statistics of Germany. The data contain the universe of services trade for all transactions related to Germany 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. The service types follow the Balance of Payments Manuel and cover over 130 categories (Biewen and Meinusch, 2021). Transactions in the SITS cover the following three modes of service trade defined in the General Agreement on Trade in Services in 1995:

- Cross-border service supply - A service is provided from a member of country A to a member of country B across borders.
- Service consumption abroad - A service is provided from a member of country A to a member of country B (or its property) within country A.
- Services by natural persons - A natural person from country A provides a service to a member of country B within country B.

### 2.2. Variable definition

***Firm innovation* –** We utilize two yearly yes-no questions of the MIP for our primary innovation measure: 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. We define our primary measure of innovation as a dichotomous variable equal to one if a firm answered yes to at least one of the two questions and zero otherwise. In addition, we construct variables differentiating between product and process innovations as well as different levels of innovation success. First, we create separate dichotomous variables for product and process innovations. Then, we add additional measures covering the intensive margin of both types of innovations. For product innovations, we extract i) the yearly revenue shares of new or significantly improved products or services and ii) the total yearly revenues with new or significantly improved products or services. For cost-reducing process innovations, we add i) the yearly percentage point reductions in average costs due to process innovations and ii) the total yearly reductions in costs due to process innovations.[6]

***Foreign knowledge services* –** We classify four types of services as knowledge catalysts. Using the most disaggregated classification in the 5th Balance of Payments Manuel, our definition of

[6] Revenue shares, total revenues, average cost reductions, and total cost reductions refer to the current year. The yearly reductions in total costs are estimated by multiplying the percentage cost reductions resulting from process innovations by firms' total revenues. The total yearly revenues with new or significantly improved products or services are calculated by multiplying firms' revenue shares with new or significantly improved products or services with their total revenues.

knowledge services comprises transactions related to i) research, development, and testing (BPM5 511), ii) patents, licenses, inventions, and processes (BPM5 502), iii) artistic copyrights (BPM5 501), and iv) other rights, such as franchise fees, trademarks, and marketing rights (BPM5 503). Each service category is commonly the subject of policy debates around the regulation of international knowledge and intellectual property dissemination (WTO, 2022). We provide examples of international knowledge transfers captured by each of these service types in Appendix A.

***Additional firm characteristics* –** We use the MIP and SITS to extract an array of firm characteristics that are likely determinants of differences in the innovation activities across firms.

*Innovation capacity* – Firms consistently devoting resources to innovation activities are more likely to introduce new or significantly improved products, and processes. Moreover, they presumably have a higher demand for foreign knowledge services due to lower sourcing costs resulting from a higher knowledge stock, and the potential complementarity of their domestic innovation efforts with foreign knowledge services. To control for such differences across firms, we create dichotomous variables for firms' occasional, and continuous engagement in internal R&D activities.

*Foreign market exposure* – Firms profit from foreign market exposure in their innovation activities through, for instance, an increase in market size and learning through exporting. Furthermore, it is reasonable to assume that previous exposure to foreign markets decreases firms' costs of importing knowledge services due to the amortization of fixed costs related to starting international business relationships. We use the MIP and SITS to construct the following firm-level variables: i) a dichotomous variable indicating if a firm has positive export revenues, ii) two dichotomous variables for a firm's membership in a national or multinational company group, and iii) import-country-combination fixed effects.[7]

*Firm structure* – A firm's size and age tend to be negatively associated with the resource constraints it faces. Thus, larger and older firms may be more able to overcome fixed costs associated with innovation activities and trade participation. Therefore, we control for firm size with a dichotomous variable indicating if a firm has 250 employees or more, and for firm age with a dichotomous variable indicating if a firm is 21 years or older.[8]

[7] We identify a firm's source countries of knowledge service imports during our observation period. Each country combination corresponds to a separate fixed effect. Thus, for example, importing from France, France and Spain, or France and Austria corresponds to separate fixed effects. The import-combination fixed effects cover over 3,600 unique country combinations.

[8] Similarly, our company group variables 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.

*Market environment* – To control for unobserved differences in innovation activities and demand for foreign services between industries and locations, we construct fixed effects for a firm's industry at the Nace Rev. 1 three-digit level, and the federal state of a firm's locations.

### 2.3. Descriptive statistics

***Aggregate statistics on knowledge services trade*** – Following Table B.1, aggregate statistics from the SITS database indicate that Germany's annual knowledge service imports grew on average by four percent annually between 2005 and 2012. Total annual expenditures on knowledge service imports average at €14 billion, corresponding to roughly ten percent of Germany's total innovation expenditures.

Table B.2 lists the main source countries and sourcing industries during our sample period. Moreover, it investigates the distribution of knowledge service imports among its subtypes. Major source countries 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] Moreover, among the four services types included in our definition of knowledge services, import expenditures on services pertaining to "Research, development, and testing" are most substantial, accounting for 46 percent of total knowledge service imports. The second-largest category is payments related to "Patents, licenses, inventions, and processes" with 35 percent, while expenditures on services related to "Other rights" and "Artistic copyrights" are less substantial with 19 and five percent.[10]

***Sample statistics*** – The regression sample covers 11,151 firms and 26,512 firm-year observations between the years 2005 and 2012. Table 1 displays descriptive statistics for our sample. The average share of firms importing knowledge services during this period is four percent. Among importers, the average yearly knowledge service imports equal EUR 0.62 million.

[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.

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

**Table 1. Sample statistics**

| | Knowledge service importers | | Non-importers | | *RDSC export variable name* |
|---|---|---|---|---|---|
| Firm-year observations: | 1,334 | | 25,718 | | *obs_count_imp* |
| Unique firm observations: | 512 | | 10,639 | | *firm_count_imp* |
| Characteristics | Mean | Stand. dev. | Mean | Stand. dev. | |
| **Innovation-related firm characteristics** | | | | | |
| Knowledge service imports (€ millions) | 0.64 | 0.75 | 0 | 0 | *aus500* |
| Product or process innovation (%) | 68.6 | 46.4 | 33.2 | 47.1 | *pdz* |
| Product innovation (%) | 64.5 | 47.9 | 29.8 | 45.7 | *pd* |
| Revenue share of product innovations (%) | 18.6 | 25.5 | 8.2 | 18.6 | *umneu* |
| Revenues of product innovations (€millions) | 60 | 79.5 | 3.1 | 5.4 | *umneu_um* |
| Process innovation (%) | 30.3 | 45.9 | 12.1 | 32.5 | *rek* |
| Unit cost reduction from process innovation (%) | 2.6 | 5.9 | 1.2 | 4.7 | *rekp* |
| Cost savings from process innovations (€millions) | 1.74 | 24.9 | 0.05 | 0.7 | *rekp_um* |
| Occasional internal R&D (%) | 11.1 | 31.5 | 10.1 | 32.9 | *fuegel* |
| Continuous internal R&D (%) | 61.9 | 48.6 | 18.9 | 30.2 | *fuekon* |
| **General firm characteristics** | | | | | |
| Older than 21 years (%) | 53.1 | 49.9 | 42.2 | 49.4 | *old* |
| More than 250 employees (%) | 42.8 | 49.5 | 6.7 | 25 | *large* |
| Domestic Company Group (%) | 13.6 | 34.3 | 12.3 | 29.8 | *ugrup* |
| Exporter (%) | 88.1 | 32.3 | 48.1 | 49.9 | *ex_d* |
| Multinational Company Group (%) | 53.8 | 49.8 | 9.8 | 29.7 | *umulti* |

*Sources: i) Research Data and Service Centre (RDSC) of the German Federal Bank, Statistics on International Trade in Services (SITS), 2005 to 2012; ii) ZEW Mannheim, Mannheim Innovation Panel (MIP), 2005-2012; iii) own calculations. Table was exported from the RDSC as "table_1" on 2023.02.15.*

Imports of knowledge services are strongly associated with innovation success. The share of knowledge service importers reporting the introduction of any kind of innovation is more than twice as high as among non-importers. Furthermore, among knowledge importers, new or significantly improved products account for 19 percent of revenues, compared to 8.2 percent among non-importers. In addition, making the same comparison, process innovations reduced unit costs by 2.6 percent, compared to 1.2 percent.

There seem to be larger systematic differences between knowledge importers and non-importers. First, importers appear to have a higher capacity for innovation investment, given that 61 percent of knowledge service importers continuously engage in internal R&D, compared to only 18 percent among non-importers. Second, knowledge importers' revenues from product innovations along with their cost savings from process innovations are magnitudes higher, suggesting them to be substantially larger.

Investigating further firm characteristics reveals that importers are indeed 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 five times more frequently part of a multinational company, and their exporter share is about twice as high. However, other differences with regard to age, occasional internal R&D activities, and memberships in a national company group are less pronounced.

## 3. Estimating the effects of access to knowledge services on firm innovation

### 3.1. Estimation strategy

To study the effects of access to foreign knowledge services on firm innovation, we estimate the following specification:

$$Y_{f,t} = \beta S_{f,t} + \delta' X_{f,t} + \alpha + \epsilon_{f,t}. \qquad \text{Eq. (1)}$$

$Y_{f,t}$ is an innovation outcome of domestic firm $f$ at time $t$. $S_{f,t}$ is firm-specific export supply shock to foreign knowledge services. Thus, our parameter of interest $\beta$ captures the direct effect of differences in services export supply on firm innovation. $\alpha$ is a set of fixed effects related to years, industries, states, and import-country-combinations.[11] $X_{f,t}$ is a vector of time-varying firm controls, and $\epsilon_{f,t}$ the idiosyncratic error term.

We rely on a quasi-experimental shift-share design (Bartik, 1991; Borusyak et al., 2021; Goldsmith-Pinkham et al., 2020) to construct firm-specific export supply shocks to knowledge services. The shocks exploit two sources of variation: i) variation in a set of shocks common to all firms in a given industry and ii) variation in firms' individual exposure to each common shock. More precisely, we use the information on the universe of German service trades

[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.

provided by the SITS to construct a shift-share variable capturing firm $f$'s exposure to a set of export supply shocks to knowledge services as follows:

$$S_{f,t} = \begin{cases} \sum_n \omega_{f,n,t_0} \log(I_{n,-i(f),t}) & \text{if } f \text{ is a knowledge service importer in 2002-2004,} \\ 0, & \text{if } f \text{ is not a knowledge service importer in 2002-2004.} \end{cases} \quad \text{Eq. (2)}$$

***Common shocks*** – The shocks $I_{n,-i(f),t}$ capture industry-country-year variation in knowledge service export supply. They are defined as the total value of knowledge service exports from country $n$ to Germany in year $t$ in the SITS database from industries other than firm $f$'s industry $i(f)$.[12] We assume the demand for service imports is uncorrelated across industries after conditioning on our fixed effects and controls. Furthermore, given our leave-one-out correction, variation in $I_{n,-i(f),t}$ captures shocks to trading partner's capacity to export knowledge services that are uncorrelated with any unobserved firm-level shocks to import demand.[13]

***Shock exposure*** – The exposure of firm $f$ to an export supply shock $I_{n,-i(f),t}$ is captured by the weight $\omega_{f,n,t_0}$. It is defined as firm $f$'s share of knowledge service imports to country $n$ during the pre-estimation period $t_0$.[14] The pre-estimation period $t_0$ spans from 2002 to 2004. We limit shock exposures to a pre-period as current import shares may be correlated with unobservables of $\epsilon_{f,t}$ via lagged shocks.

***Shift-share variable*** – Following Equation (2), we sum the product of $\omega_{f,n,t_0}$ and $\log(I_{n,-i(f),t})$ across all source countries $n$ for each domestic German firm $f$ during year $t$. The variable takes the value of zero for all firms not importing knowledge services during the pre-estimation period $t_0$, effectively assigning them to a placebo country not exporting any knowledge services.

***Identification*** – The identification of our parameter of interest β follows from the exogeneity of our common shocks $I_{n,-i(f),t}$.[15] Thus, we assume they are conditionally quasi-randomly assigned, and provide sufficient identifying variation. To corroborate our assumptions, we follow Borusyak et al. (2021) and investigate (i) the concentration of exposure weights, (ii) the statistical properties of common shocks, and (iii) the predictive power of our shift-share variable for past dependent variables and our control variables.

***Shock variation*** – The upper part of Column (1) in Table B.3 summarizes our statistics on the estimated common shocks. The shocks $I_{n,t,-i(f)}$ feature variation across 62 countries, 43 industries, and eight years. The mean of our exposure-weighted shocks is around 0.3, with a

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[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. We leave out a firm's industry to purge a mechanical source of bias arising from the fact that unobserved shocks to firms' import demand are mechanically 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 proxy exposure if, for example, knowledge services from different suppliers are imperfectly substitutable for a firm due to search costs, or establishing supplier-buyer relationships is associated with fixed costs.

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

standard deviation of 1.98. Residualizing shocks on years leaves the standard deviation practically unchanged, indicating that our shift-share variable provides sufficient variation.

***Exposure concentration*** – The lower part of Column (1) in Table B.3 summarizes the statistics on our estimated shock exposures. In terms of average shock exposure, $\bar{\omega}_n = \frac{1}{N_f}\sum_f \omega_{f,n,t0}$ where $N_f$ is the number of firms in the sample, the largest value of $\bar{\omega}$ in our data equals 0.19. The inverse Herfindahl index (HHI) of the average shock exposures, $\sum_{n,i} \bar{\omega}^2_{n,1}$, equals 16.4, which, in an equivalent shock-level regression, would indicate an adequate effective sample size of 16.4×8≈131.[16] [17]

***Shock correlation*** – We estimate the significance levels of all pairwise correlations from our set of common shocks. The results are presented in Column (1) of Table B.4. The mean significance level of all pairwise correlation coefficients equals 33 percent, while the first quartile equals 7 percent, the second equals 25 percent, and the third quartile equals 56 percent. Therefore, more than 75 percent of common shock correlations represent only weakly statistically significant or insignificant correlations.[18]

***Quasi-random assignment*** – To examine the conditional quasi-random assignment of shocks, we implement falsification tests proposed by Borusyak et al. (2021). If common shocks are conditionally as-good-as-randomly assigned to firms, the shift-share variable should neither predict firm controls nor firms' past innovation activities. Table B.5 shows the results of separately projecting the shift-share variable on the set of firm-level controls and the lags of our primary innovation indicator. We find no statistically significant relationship for our shift-share variable.

### 3.2. Innovation propensity

We begin our empirical analysis by estimating Specification (1) using our broadest innovation measure as dependent variable: A dichotomous variable indicating whether a firm introduced new or significantly improved products, or processes within the last three years.

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[16] Studying the shift-share instrument proposed by (Autor et al., 2013), Borusyak et al. (2021) show that shock-level shift-share instruments perform well in finite samples at an effective total number of shocks of 20, yielding false rejection rates for a 5% level test of the true null of a zero effect of 7.3%. For an effective total number of 50 shocks, the false rejection rate decreases to 5.6%, and it rises to 9% for an effective total number of 10 shocks.

[17] Within our robustness tests, 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. These results are presented in the second column of Table B.3.

[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 as presented in Column (2) of Table B.4. 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.

**Table 2. Export supply shocks to knowledge services: Effect on firm innovation propensity**

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| **Shift-share variable - $S_{f,t}$** | | | | | | |
| Export supply of knowledge services | 0.027*** | 0.016*** | 0.016*** | 0.007*** | 0.005** | 0.006*** |
| | (0.002) | (0.002) | (0.002) | (0.002) | (0.003) | (0.002) |
| **Controls** | | | | | | |
| Old firm (0/1) | | | | | -0.042*** | -0.019*** |
| | | | | | (0.002) | (0.002) |
| Large firm (0/1) | | | | | 0.163*** | 0.079*** |
| | | | | | (0.004) | (0.003) |
| Exporter (0/1) | | | | | 0.177*** | 0.063*** |
| | | | | | (0.002) | (0.002) |
| Multinational group (0/1) | | | | | 0.100*** | 0.021*** |
| | | | | | (0.010) | (0.002) |
| German group (0/1) | | | | | 0.071*** | 0.036*** |
| | | | | | (0.002) | (0.002) |
| Occasional R&D (0/1) | | | | | | 0.503*** |
| | | | | | | (0.002) |
| Continuous R&D (0/1) | | | | | | 0.621*** |
| | | | | | | (0.005) |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Industry FE | | ✓ | ✓ | ✓ | ✓ | ✓ |
| Ger. state FE | | | ✓ | ✓ | ✓ | ✓ |
| Imp. origin FE | | | | ✓ | ✓ | ✓ |
| R-squared | 0.020 | 0.157 | 0.160 | 0.180 | 0.227 | 0.446 |
| Adjusted R-squared | 0.020 | 0.156 | 0.158 | 0.171 | 0.219 | 0.440 |
| Observations | 26,512 | 26,512 | 26,512 | 26,512 | 26,512 | 26,512 |

Note: The table presents the results of Specification (1). Dependent variable corresponds to "Firm innovated within the last three years (0/1)". Standard errors are displayed in parentheses and clustered at the firm- and import-country-combination-level. P-values correspond to * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Sources: i) Research Data and Service Centre (RDSC) of the German Federal Bank, Statistics on International Trade in Services (SITS), 2005 to 2012; ii) ZEW Mannheim, Mannheim Innovation Panel (MIP), 2005-2012; iii) own calculations. Table was exported from the RDSC as "table_2" on 2023.02.15.

*Main results* – Table 2 reports coefficient estimates from parallel specifications differing in terms of control variables and fixed effects.[19] Column (1) reports results including year fixed effects, Column (2) adds industry fixed effects, Column (3) German state fixed effects, Column (4) import-country-combination fixed effects, Column (5) control variables for firm structure and foreign market exposure, and Column (6) control variables for innovation efforts. The coefficient estimates for $\beta$ are positive and statistically significant across all specifications, suggesting that greater access to foreign knowledge services raises a firm's propensity to innovate. Our estimates indicate that a one-point increase in a firm's access to knowledge services raises the likelihood of introducing product or process innovations by 0.5 to 2.7 percentage points.

***Additional checks*** – Before providing further insights on the implications of foreign knowledge services for innovation, we conduct several additional checks to solidify the causal interpretation of our estimate.

*Excluding multinationals* – Column (1) of Table 3 displays the results of a subsample regression that excludes firms that are part of a multinational company group. 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 and Johannesen, 2021). Our point estimate for $\beta$ remains positive and statistically significant, and the point estimate for $\beta$ increases from 0.006 to 0.012.

*Excluding non-importers* – Due to the small share of knowledge service importers in our sample, a substantial part of the variation in shock exposure across firms stems from differences in the extensive margin of importing. To test whether our results are driven primarily by variation in shock exposure on the extensive margin, we re-estimate Specification (1) for the subsample of firms with positive knowledge service imports in the pre-estimation period. In Column (2) of Table 3, we show that our estimate of $\beta$ persists at 0.006 and remains statistically significant.

[19] Our standard errors are clustered at the firm and import-country-combination level and, thus, allow for residual correlations within individual firms and within the groups of firms importing knowledge services from the same countries. As a robustness test, we use the standard error correction proposed by Adao et al. (2019), which considers residual correlations across firms with similar country exposure shares. The reported levels of statistical significance stay robust.

**Table 3. Export supply shocks to knowledge services: Effect on firm innovation propensity, Excluding multinational firms and non-importers of knowledge services**

| | (1)<br>Non-multinational firms | (2)<br>Knowledge service importers |
|---|---|---|
| **Shift-share variable - $S_{f,t}$** | | |
| Export supply | 0.012*** | 0.006*** |
| of knowledge services | (0.003) | (0.002) |
| **Controls** | | |
| Old firm (0/1) | -0.019*** | 0.081** |
| | (0.001) | (0.034) |
| Large firm (0/1) | 0.083*** | 0.105*** |
| | (0.002) | (0.038) |
| Exporter (0/1) | 0.062*** | 0.111* |
| | (0.002) | (0.061) |
| Multinational group (0/1) | - | 0.023 |
| | - | (0.036) |
| German group (0/1) | 0.034*** | 0.003 |
| | (0.001) | (0.038) |
| Occasional R&D (0/1) | 0.505*** | 0.462*** |
| | (0.001) | (0.044) |
| Continuous R&D (0/1) | 0.626*** | 0.522*** |
| | (0.005) | (0.036) |
| R-squared | 0.422 | 0.627 |
| Adjusted R-squared | 0.418 | 0.530 |
| Observations | 23,308 | 1,330 |

*Note: The table presents the results of Specification (1). Dependent variable corresponds to "Firm innovated within the last three years (0/1)". Each column covers a subsample to test the robustness of our previous results. Fixed effects for years, industries, German states, and import origin country are included. Standard errors are displayed in parentheses and clustered at the firm- and import-country-combination-level. P-values correspond to * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.*
*Sources: i) Research Data and Service Centre (RDSC) of the German Federal Bank, Statistics on International Trade in Services (SITS), 2005 to 2012; ii) ZEW Mannheim, Mannheim Innovation Panel (MIP), 2005-2012; iii) own calculations. Table was exported from the RDSC as "table_3" on 2023.02.15.*

*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 a limited number of high-leverage common shocks, we construct two alternative shift-share variables analogous to Equation (2).[20] For this, we limit our set of source countries i) to the major source countries listed in Table B.1, and ii) to all source countries, but the major source countries listed in Table B.1. Table 4 displays the results of re-estimating Specification (1) with these alternative shift-share variables. They demonstrate the results are neither driven by limiting shock exposure to older firms in Column (1), nor by a set of high-leverage common shocks in Column (2). In Column (3), the shift-share variable focused on major source countries losses its statistical significance. However, as this shift-share variable limits the variation of our common shocks to five countries, this result is not surprising.

*Imports of other services* – It is possible that our estimates reflect a broader relationship between service imports and innovation if, for example, shocks to the supply of knowledge services are highly correlated with shocks to the export supply of other types of services. To address this concern, we construct shocks analogous to Equation (2) for all service types, excluding those we labeled knowledge services. Column (4) of Table 4 shows that when we re-estimate Specification (1) while using these shocks, increasing a firm's export supply of non-knowledge services has a very small, negative effect on innovation propensity.

[20] As Table B.2 shows, sixty-eight percent of the total value of knowledge service exports to Germany stemmed from five countries between 2005 and 2012.

**Table 4. Export supply shocks to knowledge services: Effect on firm innovation propensity, Alternative definitions of shift-share variable**

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| **Shift-share variables - $S_{f,t}$** | | | | |
| Export supply of knowledge services | 0.006*** | | | |
| - Alternative first year of observation | (0.000) | | | |
| Export supply of knowledge services | | 0.015** | | |
| - Minor sourcing countries | | (0.033) | | |
| Export supply of knowledge services | | | 0.003 | |
| - Major sourcing countries | | | (0.111) | |
| Export supply of non-knowledge services | | | | -0.000* |
| - Excluding knowledge services | | | | (0.096) |
| **Control variables** | | | | |
| Old firm (0/1) | -0.019*** | -0.019*** | -0.019*** | -0.019*** |
| | (0.000) | (0.000) | (0.000) | (0.000) |
| Large firm (0/1) | 0.079*** | 0.080*** | 0.079*** | 0.081*** |
| | (0.000) | (0.000) | (0.000) | (0.000) |
| Exporter (0/1) | 0.063*** | 0.063*** | 0.063*** | 0.063*** |
| | (0.000) | (0.000) | (0.000) | (0.000) |
| Multinational group (0/1) | 0.020*** | 0.021*** | 0.021*** | 0.023*** |
| | (0.000) | (0.000) | (0.000) | (0.000) |
| German group (0/1) | 0.036*** | 0.036*** | 0.036*** | 0.037*** |
| | (0.000) | (0.000) | (0.000) | (0.000) |
| Occasional R&D (0/1) | 0.503*** | 0.503*** | 0.503*** | 0.503*** |
| | (0.000) | (0.000) | (0.000) | (0.000) |
| Continuous R&D (0/1) | 0.621*** | 0.621*** | 0.621*** | 0.621*** |
| | (0.000) | (0.000) | (0.000) | (0.000) |
| R-squared | 0.446 | 0.446 | 0.446 | 0.446 |
| Adjusted R-squared | 0.440 | 0.440 | 0.440 | 0.440 |
| Observations | 26,512 | 26,512 | 26,512 | 26,512 |

*Note: The table presents the results of Specification (1). Dependent variable corresponds to "Firm innovated within the last three years (0/1)". Each column covers an alternative definition of our shift-share variable to test the robustness of our previous results. Fixed effects for years, industries, German states, and import origin country are included. Standard errors are displayed in parentheses and clustered at the firm- and import-country-combination-level. P-values correspond to * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.*

*Sources: i) Research Data and Service Centre (RDSC) of the German Federal Bank, Statistics on International Trade in Services (SITS), 2005 to 2012; ii) ZEW Mannheim, Mannheim Innovation Panel (MIP), 2005-2012; iii) own calculations. Table was exported from the RDSC as "table_4" on 2023.02.15.*

### 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 Equation (1) using the introduction of (i) new or significantly improved products, and (ii) new or significantly improved cost-reducing processes as alternative dependent variables. The findings in Column (1) of Table 5 indicate that a one-point increase in the supply of knowledge service exports raises the likelihood of firms introducing new or significantly improved processes by 0.5 percentage points. Similarly, the results in Column (4) of Table 5 show that a one-point increase in knowledge service export supply increases the probability of firms introducing new or significantly improved products by 0.6 percentage points.

***Intensive margin*** – To investigate how shocks to a firm's export supply of knowledge services impact its returns to innovation at the intensive margin, we re-estimate Equation (1) using the revenues from product innovations and cost reductions from process innovations as dependent variables. The estimates displayed in Table 5 show that access to foreign knowledge services implies substantial cost savings. Our point estimate in Column (2) implies that a one-point increase in the export supply to knowledge services raises the percentage reduction in unit costs attributable to new processes by 0.001 percent; whereas this translates into an increase in total cost savings from process innovations of 0.096 percent, as indicated by the estimate in Column (3). Furthermore, firms with access to a larger export supply of knowledge services attain higher revenues through new or improved products. Our estimates in Column (6) suggest that a one-point increase in the supply of foreign knowledge services implies a statistically significant 0.11 percent increase in firm revenues attributable to revenues from new or improved products. Also, we find a positive, but statistically insignificant effect on a firm's revenue share of new or improved products in Column (5).

**Table 5. Export supply shocks to knowledge services: Effect on firm process and product innovation**

| | (1)<br>Process innovation<br>(0/1) | (2)<br>Process innovation<br>% of unit costs | (3)<br>Process innovation<br>Log(total reduction) | (4)<br>Product innovation<br>(0/1) | (5)<br>Product innovation<br>% of revenue | (6)<br>Product innovation<br>Log(total revenue) |
|---|---|---|---|---|---|---|
| **Shift-share var. - $S_{f,t}$** | | | | | | |
| Export supply of | 0.005** | 0.001*** | 0.096** | 0.006** | 0.001 | 0.113** |
| knowledge services | (0.002) | (0.000) | (0.039) | (0.002) | (0.001) | (0.044) |
| **Control variables** | | | | | | |
| Old firm (0/1) | -0.006** | -0.002*** | -0.010 | -0.017*** | -0.019*** | -0.106*** |
| | (0.002) | (0.000) | (0.034) | (0.002) | (0.001) | (0.033) |
| Large firm (0/1) | 0.111*** | 0.003*** | 2.094*** | 0.064*** | -0.013*** | 1.943*** |
| | (0.005) | (0.000) | (0.068) | (0.006) | (0.003) | (0.077) |
| Exporter (0/1) | 0.015*** | 0.002*** | 0.207*** | 0.064*** | 0.021*** | 0.946*** |
| | (0.002) | (0.000) | (0.028) | (0.002) | (0.001) | (0.024) |
| Multi. group (0/1) | 0.055*** | 0.003*** | 0.966*** | 0.019*** | -0.004*** | 0.849*** |
| | (0.005) | (0.000) | (0.071) | (0.003) | (0.001) | (0.053) |
| German group (0/1) | 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 R&D (0/1) | 0.195*** | 0.017*** | 2.475*** | 0.454*** | 0.098*** | 5.892*** |
| | (0.003) | (0.000) | (0.049) | (0.003) | (0.001) | (0.024) |
| Continuous R&D (0/1) | 0.248*** | 0.025*** | 3.305*** | 0.611*** | 0.188*** | 8.464*** |
| | (0.002) | (0.000) | (0.051) | (0.006) | (0.003) | (0.054) |
| R-squared | 0.188 | 0.094 | 0.221 | 0.449 | 0.316 | 0.485 |
| Adjusted R-squared | 0.179 | 0.084 | 0.213 | 0.443 | 0.308 | 0.479 |
| Observations | 26,512 | 26,512 | 26,512 | 26,512 | 26,512 | 26,512 |

*Note: The table presents the results of Specification (1). Each column covers an alternative dependent variable. Fixed effects for years, industries, German states, and import origin countries are included. Standard errors are displayed in parentheses and clustered at the firm- and import-country-combination-level. P-values correspond to * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.*

*Sources: i) Research Data and Service Centre (RDSC) of the German Federal Bank, Statistics on International Trade in Services (SITS), 2005 to 2012; ii) ZEW Mannheim, Mannheim Innovation Panel (MIP), 2005-2012; iii) own calculations. Table was exported from the RDSC as "table_5" on 2023.02.15.*

### 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 6 reports the results of re-estimating Specification (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 $\beta$ 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 one-point increase in export supply increases domestic R&D expenditures by 0.07 to 0.51 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 $\beta$ of 0.04.

## 4. Economic model of firm innovation and knowledge services trade

We develop a theoretical model to demonstrate how access to foreign knowledge services influences firm innovation. It is described in large detail in Appendices D and E. The model focuses on the mechanisms of outsourcing and offshoring innovation efforts and is structured around the following key components.

***Knowledge creation*** – Firms innovate by solving specific tasks that contribute to knowledge creation. Each task yields insights that follow a Poisson distribution, with the quality of these insights described by a Pareto distribution. The firm's knowledge production function is defined by the aggregation of these insights, influenced by the number of tasks performed and their quality.

***Outsourcing decision*** – Tasks can be performed internally or externally. In-house task performance involves hiring workers and faces decreasing returns to scale, for example, due to management limitations. Moreover, tasks can be outsourced domestically or offshored to foreign service providers and involve search costs for suitable external partners. Moreover, offshoring faces additional trade costs compared to domestic outsourcing.

We introduce a reservation cost framework where firms decide to outsource tasks domestically or abroad based on comparing in-house costs with potential outsourcing costs. The decision to outsource or perform tasks in-house depends on the firm's ability to locate external partners who can perform the tasks at lower costs domestically or abroad.

**Table 6. Export supply shocks to knowledge services:**
**Effect on firms' domestic R&D expenditures**

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| **Shift-share variable - $S_{f,t}$** | | | | | | |
| Export supply of | 0.509*** | 0.337*** | 0.334*** | 0.164*** | 0.0704*** | 0.0382 |
| knowledge services | (0.038) | (0.031) | (0.031) | (0.026) | (0.016) | (0.037) |
| **Control variables** | | | | | | |
| Old firm (0/1) | | | | -0.322*** | 0.0241 | 0.0139 |
| | | | | (0.054) | (0.023) | (0.014) |
| Large firm (0/1) | | | | 2.657*** | 1.052*** | 0.983*** |
| | | | | (0.107) | (0.045) | (0.049) |
| Exporter (0/1) | | | | 2.292*** | 0.300*** | 0.292*** |
| | | | | (0.0510) | (0.0125) | (0.00781) |
| Multinational group (0/1) | | | | 1.944*** | 0.502*** | 0.444*** |
| | | | | (0.083) | (0.054) | (0.026) |
| German group (0/1) | | | | 0.829*** | 0.204*** | 0.196*** |
| | | | | (0.035) | (0.014) | (0.017) |
| Occasional R&D (0/1) | | | | | 8.455*** | 8.456*** |
| | | | | | (0.050) | (0.048) |
| Continuous R&D (0/1) | | | | | 10.90*** | 10.83*** |
| | | | | | (0.096) | (0.041) |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Industry FE | | ✓ | ✓ | ✓ | ✓ | ✓ |
| Ger. state FE | | | | ✓ | ✓ | ✓ |
| Imp. origin FE | | | | | | ✓ |
| R-squared | 0.047 | 0.265 | 0.268 | 0.347 | 0.859 | 0.865 |
| Adjusted R-squared | 0.047 | 0.264 | 0.266 | 0.345 | 0.859 | 0.863 |
| Observations | 26,512 | 26,512 | 26,512 | 26,512 | 26,512 | 26,512 |

Note: The table presents the results of Specification (1). The dependent variable corresponds to "log(Domestic R&D expenditures + 1)". Fixed effects and control variables are included as indicated. Standard errors are displayed in parentheses and clustered at the firm- and import-country-combination-level. P-values correspond to * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.
Sources: i) Research Data and Service Centre (RDSC) of the German Federal Bank, Statistics on International Trade in Services (SITS), 2005 to 2012; ii) ZEW Mannheim, Mannheim Innovation Panel (MIP), 2005-2012; iii) own calculations. Table was exported from the RDSC as "table_6" on 2023.02.15.

***Outsourcing and innovation efficiency*** – As firms innovate more, they are more likely to outsource innovation activities domestically or abroad due to diminishing returns to in-house efforts in our model. Outsourcing allows firms to scale their innovation activities more efficiently, leveraging external knowledge and reducing marginal costs.

***Trade costs and innovation efficiency*** – Service trade costs are crucial in determining the extent to which firms engage in outsourcing innovation tasks abroad via offshoring. Lower service trade costs make offshoring relatively more attractive. Thus, by reducing the costs of offshoring, they enable firms to access a wider pool of external knowledge. As a result, the model demonstrates that trade cost reduction can lead to more a more efficient knowledge production, and enhance firms' innovation capacity.

***Consumer preferences*** – We incorporate household preferences for a homogeneous good and differentiated varieties of products, which influence firm decisions on product offerings and innovation. Households derive utility from consuming a variety of products, driving demand for innovative products.

***Aggregate demand*** – The demand for products is aggregated based on their prices relative to a common aggregator, affecting the firm's pricing and innovation strategies. Firms adjust their innovation efforts to meet consumer demand for differentiated products, balancing costs and potential market rewards.

***Aggregate welfare gains*** – The model indicates that trade in knowledge-intensive services can lead to substantial aggregate welfare gains. By facilitating access to a broader spectrum of external knowledge, firms can innovate more efficiently. This, in turn, drives productivity improvements and economic growth. The increased efficiency in knowledge production reduces costs and enhances the quality and variety of products available to consumers, leading to higher consumer welfare.

***Distributional effects*** – While the aggregate welfare gains from trade in knowledge services might be significant, the distribution of these gains may not be uniform across all firms and industries. More innovative firms are better positioned to capitalize on the opportunities presented by access to foreign knowledge services, potentially widening the gap between more and less innovative firms.

***Opposing effects*** – On the one hand, lower trade costs enhance aggregate welfare as described above. On the other hand, the same reduction in trade costs can intensify competition, potentially leading to the displacement of less competitive domestic firms that are unable to leverage foreign knowledge services as effectively. This can result in welfare losses reducing the described gains.

***Key insights*** – The theoretical model provides a comprehensive framework for understanding the mechanisms through which access to foreign knowledge services influences firm innovation and welfare. It emphasizes the strategic decisions firms make regarding outsourcing and offshoring, and the role of trade costs within these decisions. It shows that trade cost reduction can lead to more a more efficient knowledge production, and enhance firms' overall innovation capacity. However, firms select into importing knowledge services based on their innovation levels. More innovative firms are likelier to engage in offshoring due to a reduction in marginal costs and the decreasing returns to scale of their in-house innovation efforts. Therefore, the model highlights innovation-enhancing effects of trade in service, as well as the importance of firm heterogeneity in determining the benefits of services trade for innovation.

**5. Conclusion**

This paper utilizes detailed data on the population of German service trades and a representative survey about the innovation activities of German firms to analyze how access to foreign knowledge via services trade impacts domestic firm innovation. To disentangle the direction of causality between access to foreign knowledge services and domestic firm innovation, we applied a shift-share design relying on worldwide aggregate shocks in countries' export supply of knowledge-related services, and firms' individual exposure to each shock.

First, we demonstrate that increasing a firm's access to knowledge service imports raises its innovativeness. On the extensive margin, greater access to foreign knowledge services makes a firm more likely to introduce new or significantly improved products and production processes. On the intensive margin, it leads to higher revenues from product and larger cost reductions from process innovation. Second, we show the positive impact on innovation outputs is accompanied by higher expenditures on domestically-sourced R&D, suggesting that foreign- and indigenously-sourced knowledge are complementary inputs into firms' innovation process. Third, we traced the effects of knowledge services trade in a theoretical model with endogenous innovation and competition. Based on the model, we show a potential for sizable welfare gains resulting from easing trade in knowledge services.

Our estimates provide tentative policy advice. Policy makers should be aware of the importance of access to foreign knowledge services within their trade negotiations, in particular considering the increased tendencies towards protectionism worldwide. 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. Furthermore, it is important to address the potential distributional effects of service trade. As less innovative firms theoretically profit less from service trade liberalizations, it is important to consider providing them with alternative support – in particular as Germany is facing an increasing concentration of innovation within its economy that creates risks for the country's resilience towards external shocks in the long run (Rammer and Schubert, 2018). Finally, it is important to consider the potential market exits of firms resulting from increased competition due to reduced service trade costs. Implementing temporary support measures can mitigate these effects, and help to ensure that the benefits of reduced trade costs are broadly shared across the economy, fostering inclusive growth.

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 and 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 A. 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, licenses, 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 customers.

***Other rights, such as franchise fees, trademarks, and marketing rights***

From Novartis (Switzerland) to Eris Lifesciences (India)

Eris Lifesciences acquired the trademark 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 B. Additional tables

**Table B.1. Development of knowledge service imports of Germany by year**

| Year | Total expenditures (€ billion) | Growth rate (%) |
|---|---|---|
| 2005 | 11 | |
| 2006 | 12 | 6% |
| 2007 | 13 | 11% |
| 2008 | 13 | -2% |
| 2009 | 13 | 0% |
| 2010 | 16 | 21% |
| 2011 | 17 | 8% |
| 2012 | 14 | -17% |
| Average | 14 | 4% |

*Notes: Estimates are based on the aggregate value of knowledge service exports to Germany covered by the SITS during the period 2005 to 2012.*
*Sources: i) Research Data and Service Centre (RDSC) of the German Federal Bank, Statistics on International Trade in Services (SITS); ii) own calculations. Table was exported from the RDSC as "table_A_1_4" on 2023.02.15.*

**Table B.2. Knowledge service exports to Germany by major source countries, major sourcing industries, and knowledge service types**

| | Share in total knowledge service import expenditures (%) |
|---|---|
| **Source country** | |
| United States | 36 |
| United Kingdom | 10 |
| Switzerland | 9 |
| France | 8 |
| Austria | 5 |
| | |
| **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 |
| | |
| **Knowledge service types** | |
| Artistic copyrights | 5 |
| Patents, licenses, inventions, and processes | 30 |
| Other rights | 19 |
| Research, development, and testing | 46 |

*Notes: Estimates are based on the aggregate value of knowledge service exports to Germany covered by the SITS during the period 2005 to 2012.*
*Sources: i) Research Data and Service Centre (RDSC) of the German Federal Bank, Statistics on International Trade in Services (SITS); ii) own calculations. Table was exported from the RDSC as "table_A_1_1", "table_A_1_2", and "table_A_1_3" on 2023.02.15.*

**Table B.3. Descriptive statistics of common shocks and exposure shares**

| Statistic | (1)<br>All firms | (2)<br>Knowledge service importers | (3)<br>RDSC export variable name |
|---|---|---|---|
| **Statistics on common shocks** | | | |
| Mean of weighted shocks | 0.30 | 6.45 | *trend_mean* |
| S.d. of weighted shocks | 1.98 | 6.77 | *trend_sd* |
| Inter quartile range of weighted shocks | 0.00 | 13.74 | *trend_iqr* |
| Residualized mean of weighted shocks | 0.00 | 0.00 | *mean_trend_wt* |
| Residualized s.d. of weighted shocks | 1.98 | 6.77 | *sd_trend_wt* |
| Residualized i.q.r. of weighted shocks | 0.00 | 13.76 | *iqr_trend_wt* |
| Covered industry | 43 | 36 | *count_i* |
| Covered countries | 62 | 62 | *count_n* |
| Covered years | 8 | 8 | *count_t* |
| **Statistics on exposure shares** | | | |
| HHI of exposure shares | 16.43 | 51.57 | *HHI* |
| Maximum value of exposure shares | 0.19 | 0.06 | *weights_max* |

*Sources: i) Research Data and Service Centre (RDSC) of the German Federal Bank, Statistics on International Trade in Services (SITS); ii) ZEW Mannheim, Mannheim Innovation Panel (MIP), 2005-2012; iii) own calculations. Table was exported from the RDSC as "table_A_2" on 2023.02.15.*

### B.4. Statistical significance of all pairwise correlations between common shocks

| Significance level statistic | All sample firms | Knowledge services importers |
|---|---|---|
| Mean | 0.34 | 0.43 |
| 10th percentile | 0.01 | 0.03 |
| First quartile | 0.07 | 0.15 |
| Median | 0.26 | 0.41 |
| Third quartile | 0.56 | 0.69 |
| 90th percentile | 0.82 | 0.87 |

*Sources: i) Research Data and Service Centre (RDSC) of the German Federal Bank, Statistics on International Trade in Services (SITS); ii) own calculations. Table was exported from the RDSC as "des_table4_1" and "des_table4_2" on 2022.04.13.*

### B.5. Quasi-random assignment of common shocks - Falsification tests

| | (1) Old firm (0/1) | (2) Large firm (0/1) | (3) Exporter (0/1) | (4) Multinat-Ional group (0/1) | (5) German group (0/1) | (6) Occasional R&D (0/1) | (7) Continuous R&D (0/1) | (8) Lagged firm innovation (0/1) |
|---|---|---|---|---|---|---|---|---|
| **Shift-share variable - $S_{f,t}$** | | | | | | | | |
| Export supply of | 0.005 | 0.004 | -0.002 | 0.007 | -0.004 | -0.000 | -0.001 | 0.004 |
| knowledge services | (0.005) | (0.004) | (0.002) | (0.005) | (0.003) | (0.002) | (0.003) | (0.005) |
| **Control variables** | | | | | | | | |
| Old firm (0/1) | | 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 (0/1) | 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 (0/1) | 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 group (0/1) | -0.046*** | 0.182*** | 0.157*** | | -0.220*** | 0.038*** | 0.123*** | 0.035*** |
| | (0.004) | (0.004) | (0.008) | | (0.012) | (0.002) | (0.014) | (0.003) |
| German group (0/1) | -0.031*** | 0.136*** | 0.041*** | -0.174*** | | 0.022*** | 0.050*** | 0.043*** |
| | (0.002) | (0.002) | (0.002) | (0.016) | | (0.001) | (0.002) | (0.002) |
| Occasional R&D (0/1) | -0.042*** | 0.014*** | 0.175*** | 0.036*** | 0.027*** | | -0.302*** | 0.411*** |
| | (0.003) | (0.002) | (0.002) | (0.003) | (0.001) | | (0.015) | (0.006) |
| Continuous R&D (0/1) | -0.051*** | 0.074*** | 0.258*** | 0.089*** | 0.046*** | -0.231*** | | 0.570*** |
| | (0.003) | (0.002) | (0.005) | (0.008) | (0.002) | (0.008) | | (0.007) |
| Adjusted R-squared | 0.233 | 0.282 | 0.300 | 0.262 | 0.093 | 0.101 | 0.353 | 0.419 |
| Observations | 26512 | 26512 | 26512 | 26512 | 26512 | 26512 | 26512 | 11106 |

*Notes: Table B.5 presents the results of using our firm controls and our lagged primary innovation measure as dependent variables. Estimates are based on a linear probability model. Fixed effects included are year, industry, German state, and import origin country fixed effects. Standard errors are displayed in parentheses and clustered at the firm- and import-country-combination-level. P-values correspond to * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.*

*Sources: i) Research Data and Service Centre (RDSC) of the German Federal Bank, Statistics on International Trade in Services (SITS), 2005 to 2012; ii) ZEW Mannheim, Mannheim Innovation Panel (MIP), 2005-2012; iii) own calculations. Table was exported from the RDSC as "table_A_4" on 2023.02.15.*

## Appendix C. Endogeneity of access to foreign knowledge services

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

1) Reverse causality: Access to foreign knowledge services might trigger firm innovations due to reducing firms' cost of innovations, and firm innovations might trigger access to foreign knowledge services due to a firm's increasing knowledge sourcing ability.
2) Self-selection: More innovative firms might actively improve their access to foreign knowledge services as they potentially benefit more from the access than less innovative firms due to its complementarity with existing innovation efforts.
3) Omitted variable bias: Firms might be more innovative and have easier access to foreign knowledge services as a result of unobserved firm characteristics, for instance, being a member of a multinational company group.

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

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

## Appendix D. Deriving a theoretical economic model of service trade and innovation

### D.1. Firms' innovation outsourcing decision

To rationalize the empirical findings, we develop a theoretical model of innovation offshoring . In this model, the home economy produces a homogeneous final good and an endogenous mass of differentiated consumer products. In the differentiated goods sector, firms pay an entry cost to gain access to a technology for producing multiple unique varieties using home labor. If an entrant decides to produce a variety j, it can choose to use the initially obtained technology; or invest in acquiring requisite knowledge for discovering a new technology.

Let $k_j$ denote the amount of knowledge that an entrant has acquired to upgrade its production technology for variety $j$. This knowledge leads the firm to discover a set of technologies capable of producing y units of good $j$ at a minimum labor cost given by: $C_j(k_j) = min_{k \leq k_j} c_j(k_j)y + f_j(k_j)$.

***Knowledge creation*** – Firms create knowledge by drawing insights indexed by a type $\omega \in \Omega_j$. Each type of insight ω can vary. $z(\omega)$ corresponds to the number of specific insights drawn from a Poisson distribution with mean one. When a firm performs task $\omega$ a total number of $N(\omega)$ times, the number of insights $i$ that it will obtain, $n(\omega)$, then follows a Poisson distribution with mean $N(\omega)$. Insights differ in quality, $z_{i(\omega)}$, independently drawn from a Pareto distribution, $z_i(\omega) \sim G(z) = 1 - z^{-1/\zeta}$, where $\zeta \geq 1$.[21]

$$k_j = \left(\int_{\Omega_j} z(\omega)^{\chi}\, d\omega\right)^{1/\chi}, \qquad \text{Eq. (3)}$$

where $\chi \leq 1$ governs the substitutability between requisite problems. We can then readily express a firm's knowledge production function in Equation (3) in terms of the number of research tasks that it performs.

*Proposition 1. Assume that $2\chi \leq \zeta$. When a firm performs a task $\omega \in \Omega_j$ a total number of $N(\omega)$ times, the quality of its solution for problem ω follows a Frechet distribution, $Pr[z(\omega) \leq z \mid N(\omega)] = e^{-N(\omega)z^{-\zeta}}$, and its knowledge almost surely equals $k_j = \bar{k}\left(\int_{\Omega_j} N(\omega)^{\chi/\zeta} d\omega\right)^{1/\chi}$, where $\bar{k} \equiv \Gamma\left(1 - \frac{\chi}{\zeta}\right)^{1/\kappa}$ is a constant that depends on the Gamma function $\Gamma(\cdot)$.*

***Task outsourcing and offshoring*** – Tasks can be performed in-house, using home labor, or outsourced to contractor firms. In-house task performance is subject to decreasing returns to scale. However, to outsource, the firm has to locate a suitable supplier at home or abroad. Specifically, we assume that to perform any task a total of N times in-house, firms must hire a total number of $\ell = N^{\alpha}$ workers. The parameter $\alpha > 1$ governs decreasing returns to scale in internal task performance, capturing, for example, a firm's limited span of control.[22]

[21] This assumption is not crucial for establishing main conclusions.

[22] The key implication for our theory is that the costs of performing tasks in-house are convex. We could, alternatively, assume that the pay of in-house researchers reflects rents due to monopsonistic competition in the labor market.

To outsource a task, the firm must locate a contractor at home or in a foreign market, $i \in \{H, F\}$. Contractor firms in location $i$ supply a homogeneous knowledge service at a competitive price, $p_i$. Service input requirements are uncertain, and would not be known unless the firm pays a screening cost $c_i$. By paying $c_i$, the firm instantaneously learns the realization of an i.i.d. random variable $\varepsilon_{i\omega} \geq 1$ with cdf H(ε) by

$$A_{i(\omega)} = \begin{cases} \varepsilon_{i\omega}, i = H \\ \tau t(\omega)\varepsilon_{i\omega}, i = F \end{cases}. \qquad \text{Eq. (4)}$$

Following equation (4), the expected input requirement is the same for all tasks that are outsourced to a domestic service provider. In contrast, following Grossman and Rossi-Hansberg (2008), the expected costs of offshoring, $\tau t(\omega) \geq 1$, vary systematically across tasks. This heterogeneity is captured by the schedule t(ω), where we let tasks be ordered so that $t'(\omega) > 0$. The parameter τ captures technology- or policy-driven barriers to services trade that uniformly apply to all tasks.

***Offshoring decision*** – A firm's optimal outsourcing strategy minimizes the expected cost of acquiring a given amount of knowledge, $\kappa(k_j, \tau)$. Following Weitzman (1979), this strategy involves a reservation selection and stopping rule. Let $\bar{z}_{i\omega}$ denote the reservation cost for outsourcing task ω to country i.[23] The selection rule is to screen for outsourcing opportunities in the location i with the lowest reservation cost, unless it is cheaper, in expectation, to perform the task in-house, $z_{i\omega} \leq \bar{z}_{\omega} = N(\omega)^{\alpha-1} w_H$. The stopping rule is to outsource, $o^i(\omega) = 1$, to the first location i, where a provider can be hired at a cost lower than $\bar{z}_{i\omega}$; else, the task is performed in-house, $o^H(\omega) = o^F(\omega) = 0$.

This optimal strategy implies two intuitive insights. First, as a firm decides to acquire more knowledge, it becomes more likely to outsource innovation activities, reflecting diminishing returns to internal research activities. Second, when a firm decides to explore opportunities for outsourcing a task ω, it will try to locate a supplier in the location with the lowest expected cost first. We summarize this discussion in the following proposition. The proof of the proposition is provided in Appendix E.1.

*Proposition 2. For each good $j \in J$, task $\omega \in \Omega_j$ and location $i \in \{H, F\}$, there exists a knowledge threshold $\underline{k}_j^i$ such that the firm chooses to outsource task ω to location i with positive probability if, and only if, $k_j \geq \underline{k}_j^i(\omega)$. Further, $\underline{k}_j^H(\omega) \leq \underline{k}_j^F(\omega)$ if, and only if, $p_H \leq \tau t(\omega) p_F$.*

Proposition 2 implies that firms select into importing services based on their innovativeness. The underlying mechanism differs from models that generate selection via fixed costs; in particular, it implies that importing knowledge services enables a firm to scale its knowledge more efficiently.

*Proposition 3. Let $\varphi_j^i(k_j) \equiv \frac{\int_{\Omega_j} 1\{o^i(\omega)=1\} a_i(\omega) p_i N(\omega) d\omega}{\kappa(k_j)}$ denote the expenditure share of tasks outsourced to location $i \in \{H, F\}$. Then $\gamma(k_j) = \frac{\partial \ln k_j}{\partial \ln k_j} = \gamma(\varphi_j^H + \varphi_j^F)$, where $1 < \gamma(1) = \zeta < \gamma(0) = \alpha\zeta$ and $\gamma'(\varphi_j^H + \varphi_j^F) \leq 0$.*

[23] The reservation cost is implicitly defined by $c_i = \int_1^{z_{iw}} [z_{iw} - p_i a_i(\omega)\epsilon] dH(\epsilon)$.

Proposition 3 implies that outsourcing innovation activities enables a firm to scale its knowledge more efficiently. When a firm does not outsource, $\varphi_j(k_j) = 0$, its capacity to acquire knowledge is held back by its limited span of control ($\alpha$). Intuitively, by outsourcing innovation activities, a firm can overcome this limitation and scale innovation efforts at a lower marginal cost.

**D.2. Households' preferences and demand**

The home economy is inhabited by a unit mass of households who inelastically supply one unit of labor. Each household holds quasi-linear preferences over consumption of a homogeneous, numeraire good, X, and an aggregate index of differentiated varieties, Y, represented by,

$$U(X,Y) = X + ln\,Y + 1. \quad \text{Eq. (5)}$$

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

The consumption index Y is an aggregate over real consumption, $y_\theta$, of product lines indexed by the type of their supplier, θ. A product line of type  comprises $h_\theta$ varieties with two characteristics. The first characteristic sets them apart from products from other suppliers. The other characteristic renders every pair in a product line of type θ as CES-substitutes with an elasticity of substitution $\epsilon_\theta > 1$. This implies that per-capita consumption expenditures on product j equal

$$p_{\theta j}\, y_{\theta j} \; = \left(\frac{p_{\theta j}}{p_\theta}\right)^{1-\epsilon_\theta} p_\theta\, y_\theta, \quad \text{Eq. (6)}$$

where $y_{\theta j}$ is the consumption of the variety, $p_{\theta j}$ is its price and $p_\theta$ is the real price of the composite good $y_\theta$, $p_\theta^{1-\epsilon_\theta} = \int_0^{h_\theta} p_{\theta j}^{1-\epsilon_\theta}\, dl$.

Following Matsuyama and Ushchev (2017), we take preferences over the bundle of composite goods Y to belong to a class they term Homothetic with a Single Aggregator (HSA). HSA preferences require the existence of market share functions $s_\theta(\cdot)$ and a common aggregator PPP such that

$$\frac{d\ln P^Y}{d\ln p_\theta} = \frac{\mathrm{p}_\theta y_\theta}{P^Y Y} = s_\theta\left(\frac{\mathrm{p}_\theta}{P}\right) \quad \text{Eq. (7)}$$

and

$$\int_\Theta s_\theta\left(\frac{\mathrm{p}_\theta}{P}\right) dF(\theta) = 1, \quad \text{Eq. (8)}$$

where $dF(\theta)$ is the measure of firms of type $\theta$, and $\Theta$ denotes the set of all possible types.[24] Equation (7) gives the real demand for a composite good in explicit form. This demand only depends on its price relative to a common aggregator, which also determines the price elasticity of demand,

$$\sigma_\theta\left(\frac{\mathrm{p}}{P}\right)=1-\frac{\frac{\mathrm{p}}{P}s_\theta'\left(\frac{\mathrm{p}}{P}\right)}{s_\theta\left(\frac{\mathrm{p}}{P}\right)}>1. \qquad \text{Eq. (9)}$$

Equation (9) makes clear that the common aggregator, $P$, mediates market-wide price competition. Since the price elasticity demand generally depends on a firm's position on its demand curve, so does a firm's exposure to competition; the exception to this is the special case of CES preferences, where $s_\theta(z)=\omega_\theta z^{1-\sigma_\theta}, \omega_\theta>0.3$.[25] Only in the special case of symmetric CES preferences, the aggregator $P$ coincides with the ideal price index, $P^Y$. We adopt

*Assumption 1. For all $\theta\in\Theta$, (i) either $\sigma_\theta(\cdot)=\sigma_\theta$ or $\sigma_\theta'(\cdot)>0$ and (ii) in the neighboorhood of any equilibrium, $\varepsilon_\theta>\sigma_\theta\left(\frac{p_\theta}{P}\right)$.*

The first part of Assumption 1 postulates that firm market power is weakly increasing in its product scope, $\frac{\partial\sigma_\theta}{\partial h_\theta}\leq 0$. The second part imposes that cross-price demand effects among a firm's products are negative. As an implication, product introductions reduce the sales of a firm's existing products, $\frac{\partial \ln p_{\theta j}y_{\theta j}}{\partial \ln h_\theta}=(\varepsilon_\theta-\sigma_\theta)\frac{\partial \ln \mathrm{p}_\theta}{\partial \ln h_\theta}$; this has implications for innovation decisions, which we describe next.

### D.3. Firms' production decision

The numeraire good $X$ is competitively produced under constant returns to scale, and freely traded with a foreign country, $F$. 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 must purchase a fixed quantity, $F_e$, of home labor to enter. Upon entry, a firm receives a draw from a distribution $\theta\sim G(\theta)$, granting it a technology for supplying a product line of type $\theta$ comprised of unique varieties, $j$. The firm chooses the range of its product line, $h_\theta$, and, whether to acquire requisite knowledge for upgrading to a better technology, $k_j$, for each variety $j$ it chooses to supply.

[24] 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 $\bar{z}=\inf\{z>0\mid s(z)=0\}$. Matsuyama & Ushchev (2017) show that these assumptions guarantee that the demand system in (6) and (8) can be rationalized by a monotone, convex, continuous and homothetic rational preference relation.

[25] An appealing feature of HSA preferences is that they allow to introduce endogenous markups, while maintaining the tractability of the monopolistic competition setup. Unlike oligopolistic multiproduct models (e.g., Feenstra and Ma, 2008, Eckel and Neary, 2010, Hottman et al., 2016), this allows us to tractably account for the implications of free entry, which turn out to be essential for our welfare results. As another appealing feature, these preferences do not violate homotheticity, unlike other common multiproduct extensions of directly explicitly additive preferences, described in, e.g., Mayer et al. (2014, 2021).

Conditional on these choices, the firm can supply $y$ units of good $j$ at a total labor cost given by $C_\theta(y, k_j) = c_\theta(k_j)y + f_\theta(k_j)$. The functions $c_\theta(\cdot)$ and $f_\theta(\cdot)$ satisfy restrictions sufficient to ensure that marginal profits are decreasing in knowledge.[26] Knowledge acquisition follows the process described earlier, which is summarized by a cost function $\kappa_\theta(k_j; \tau)$ that encapsulates the firm's optimal outsourcing and offshoring strategies. Putting this together, each firm then chooses its product range, $h_\theta$, along with its knowledge investments, $k_j$, and prices, $p_j$, for each product to maximize the following market value function

$$v_\theta \equiv \max_{h, p_j, k_j} \int_0^h \pi_{\theta j}(h, p_j, k_j) dj \qquad \text{Eq. (10)}$$

where $\pi_{\theta j}$ denotes profits per product, $\pi_{\theta j} \equiv [p_j - c_\theta(k_j)] y_{\theta j} - f_\theta(k_j) - \kappa_\theta(k_j)$.

Appendix E.2 provides detailed derivations of firm decisions. For conciseness, we begin by noting that firms optimally choose the same knowledge and price for each product, implying that product-firm subscripts can be suppressed. A firm's profit-maximizing price for each supplied good equals a markup $\mu_\theta$ over its marginal costs,

$$p_\theta = \mu_\theta\left(\frac{\mathrm{p}_\theta}{P}\right) c_\theta, \qquad \text{Eq. (11)}$$

where optimal markups satisfy Lerner's formula,

$$\mu_\theta\left(\frac{\mathrm{p}}{P}\right) = \frac{\sigma_\theta\left(\frac{\mathrm{p}_\theta}{P}\right)}{\sigma_\theta\left(\frac{\mathrm{p}_\theta}{P}\right) - 1}. \qquad \text{Eq. (12)}$$

To gain an intuition for the role of product innovation, note that markups depend on the relative price of a firm's entire product line, $\mathrm{p}_\theta / P$. This is because firms will cboose their product range $h_\theta$ so as to internalize any cross-price demand effects between their products. More formally, we can rewrite the optimally condition for a firm's product range, $\pi_\theta - h\frac{\partial \pi_\theta}{\partial h} = 0$,

In particular, this requires $\frac{\partial \ln\left(-\frac{\partial \ln c_\theta}{\partial \ln k_\theta} - \frac{1}{\varepsilon_\theta - 1}\frac{\partial \ln}{\partial \ln k_\theta}\right)/\gamma_\theta}{\partial \ln k_\theta} + \frac{\partial \ln(f_\theta + \kappa_\theta)}{\partial \ln k_\theta} - \gamma_\theta < 0$, where $\gamma_\theta = \frac{\partial \ln \kappa_\theta}{\partial \ln k_\theta}$ as follows[27]

$$\frac{p_\theta y_\theta}{\sigma_\theta} - f_\theta - \kappa_\theta = \frac{\varepsilon_\theta - \sigma_\theta}{\varepsilon_\theta - 1} \frac{p_\theta y_\theta}{\sigma_\theta}. \qquad \text{Eq. (13)}$$

Equation (13) shows that the firm sets its optimal product range so as to ensure that the profits created by the marginally added product on the left exactly offset the associated profit loss due to the cannibalization of sales for old products on the right.

[26] In particular, this requires $\frac{\partial \ln\left(-\frac{\partial \ln c_\theta}{\partial \ln k_\theta} - \frac{1}{\varepsilon_\theta - 1}\frac{\partial \ln}{\partial \ln k_\theta}\right)/\gamma_\theta}{\partial \ln k_\theta} + \frac{\partial \ln(f_\theta + \kappa_\theta)}{\partial \ln k_\theta} - \gamma_\theta < 0$, where $\gamma_\theta = \frac{\partial \ln \kappa_\theta}{\partial \ln k_\theta}$.

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

Finally, a firm invests in knowledge until the marginal profits from discovering better technologies equals the corresponding marginal cost, $-c_\theta'(k)y - f_\theta'(k) = \leq_\theta' (k)$, which implies[28]

$$-\left[\frac{k_\theta c_\theta'}{c_\theta} + \frac{1}{\varepsilon_\theta - 1}\frac{k_\theta f_\theta'}{f_\theta}\right] c_\theta y_\theta - \kappa_\theta \left[\frac{k_\theta \kappa_\theta'}{\kappa_\theta} + \frac{k_\theta f_\theta'}{f_\theta}\right] = 0. \qquad \text{Eq. (14)}$$

We follow Melitz (2003) in assuming that each firm in the differentiated goods industry faces an exogenous probability $\Delta$ of being forced to exit each period. Firms then enter until their expected market value equals the entry cost:

$$\int_\Theta v_\theta dG(\theta) = F_e \qquad \text{Eq. (15)}$$

Denoting the equilibrium mass of entrants by $M$, the mixture of firms of type $\theta$ is given by $dF(\theta) = MdG(\theta)$.

### D.4. Equilibrium

Consumers maximize utility taking prices as given, firms maximize profits, and the free entry condition holds. An equilibrium satisfies Equations (6), (8), (9), (10), (12), (13), (14), and (15).

***Notation*** – For two variables $x_\theta \geq 0$, and $y_\theta$ we denote the $x$-weighted average of $y_\theta$ by $\mathbb{E}_x[y_\theta] \equiv \int_\Theta \frac{x_\theta y_\theta}{\int_\Theta x_\theta dG(\theta)} dG(\theta)$.

### D.5. Concepts

We are interested in characterizing the response of innovation and welfare to changes in services trade costs, $\tau$. To that end, we introduce a number of elasticities related to the shape of demand curves that will later play an important role.

***Price cost pass-through and consumer surplus*** – A firm's price cost pass-through describes how changes in its marginal costs, $c_\theta$, impact the price of its products, $p_\theta$. As usual, this pass-through depends on the elasticity of its markup in (12),

$$\rho_\theta\left(\frac{p}{P}\right) \equiv \frac{\partial \ln p_\theta}{\partial \ln c_\theta} = \frac{1}{1 - \frac{\frac{p}{P}\mu_\theta'\left(\frac{p}{P}\right)}{\mu_\theta\left(\frac{p}{P}\right)}}. \qquad \text{Eq. (16)}$$

Under CES preferences, markups are constant, $\mu_\theta'(z) = 0$, and cost pass-through is complete, $\rho_\theta(\cdot) = 1$. Away from this special case, Assumption 1 implies incomplete price cost pass-throughs, $\rho_\theta(z) \in (0,1)$, reflecting markups if its market share increases.

The consumer surplus created by a firm equals $(\delta_\theta - 1)s_\theta\left(\frac{p_\theta}{P}\right)$, where $\delta_\theta$ is the ratio of the area under the demand curve to sales for a firm's product line,

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[28] The decomposition follows from rewriting Equation (13) as $f_\theta = \frac{\sigma_\theta - 1}{\varepsilon_\theta - 1}\frac{p_\theta y_\theta}{\sigma_\theta} - \kappa_\theta = \frac{c_\theta y_\theta}{\varepsilon_\theta - 1} - \kappa_\theta$ to substitute for $f_\theta$ in Equation (14).

$$\delta_\theta\left(\frac{\mathrm{p}}{P}\right) = \frac{\int_0^{y} \mathrm{p}_\theta(y)dy}{\mathrm{p}_\theta y_\theta} = 1 + \frac{\int_{\mathrm{p}/P}^{\infty} \frac{s(\xi)}{\xi}d\xi}{s\left(\frac{\mathrm{p}}{P}\right)} \geq 1, \qquad \text{Eq. (17)}$$

where $\mathrm{p}_\theta(\mathrm{y})$ is the inverse residual demand curve for product line $\theta$. Under CES preferences, $\delta_\theta$ captures the love-of-variety effect and coincides with the markup, $\delta_\theta = \frac{\sigma}{\sigma-1}$. For other HSA preferences, $\delta_\theta$ is a function of a firm's type and its competitiveness (determined by $\mathrm{p}_\theta/P$ ).

***Welfare*** – Per-capita welfare $W$ in the home country comprises (exogenous) labor income, $\bar{Y}$, plus consumer surplus, $W = \bar{Y} - \log P^Y$. We can then apply the envelope theorem to obtain insights into the various channels through which changes in fundamentals impact welfare,

$$dW = \underbrace{(\mathbb{E}_s[\delta_\theta] - 1)d\ln M + \mathbb{E}_s\left[\frac{1}{\varepsilon_\theta - 1}d\ln h_\theta\right]}_{\text{Entry / exit of varieties}} - \underbrace{\mathbb{E}_s[d\ln p_\theta]}_{\Delta \text{ Divisa Price Index}}. \qquad \text{Eq. (18)}$$

Welfare changes $dW$ incoporate the consumer surplus brought about by firm entry $d\ln M$ or created when an existing firm introduces a new product $d\ln h_\theta$ via the first two terms on the right-hand side of Equation (18). Intuitively, as a marginal entrant provides consumers with access to new product lines, consumer surplus increases in proportion to the average consumer surplus, $\mathbb{E}_S[\delta_\theta] - 1$. Product innovations by existing firms, in turn, represent another form of market expansion. Here, the welfare effect depends on how much consumers value variety within a particular product line, $\frac{1}{\varepsilon_\theta - 1}$.

The last summand in Equation (18) captures how changes in real GDP affect welfare. If the model did not allow firm entry or product innovation, the first two terms of (18) would be zero and changes in welfare would be captured by measured GDP.

### D.6. Identifying the welfare channels of service trade

We identify the channels through which changes in the opportunities to import knowledge services affect the innovation and production decisions of firms in the differentiated goods industry. Differentiating the system of zero-profit and firm optimality conditions with respect to the innovation offshoring cost shifter $\tau$, we obtain the following lemma.[29]

*Lemma 1. In response to a change in the costs of importing services, $dln\,\tau$,*

*a) the change in market-wide competition $dln\,P$ equals*

$$dln\,P = \bar{\mu}\Lambda dln\,\tau \qquad \text{Eq. (19)}$$

*where $\bar{\mu} = \mathbb{E}_S[1/\mu_\theta]^{-1}$ is the aggregate markup and $\Lambda = \mathbb{E}_S\left[\frac{\kappa_\theta}{s_\theta}\varphi_\theta\right]$ the GDP import share of knowledge services.*

*b) the change in firm $\theta'$ s total output, $y_\theta$, is given by,*

[29] In Appendix E.3, we log-linearizes the model.

$$dln\, y_\theta = \underbrace{-\sigma_\theta \rho_\theta \left(\Gamma_\theta^c - \Gamma_\theta^h\right)\varphi_\theta dln\, \tau}_{\text{Direct Effect}} + \underbrace{\left(1 - \sigma_\theta \rho_\theta \frac{\varepsilon_\theta - 1}{\varepsilon_\theta - \sigma_\theta \rho_\theta}\right) \bar{\mu} \Lambda dln\, \tau}_{\text{Indirect Effect}} \qquad \text{Eq. (20)}$$

*where $\varphi_\theta$ is a firm's the innovation cost share of knowledge service imports. $\Gamma_\theta^c \equiv \frac{\partial ln\, c_\theta}{\partial ln\, \kappa_\theta}$ and $\Gamma_\theta^h \equiv \frac{\partial ln\, h_\theta}{\partial ln\, \kappa_\theta}$ are structural elasticities given in Appendix E.4, capturing the pass-throughs of innovation cost shocks into unit costs and product variety.*

Part (a) of Lemma 1 characterizes the response of market-wide competition to changes in services trade barriers ($d\ln \tau < 0$). Intuitively, a decline in trade costs ($d\ln P < 0$) lowers the innovation costs of importers, inducing aggregate profits to increase in proportion to the aggregate import share of knowledge services in industry sales, Λ. Competition must then increase to ensure that the free entry condition continues to hold. This effect scales with the aggregate markup, which indicates how responsive aggregate profits are to rising competition $\left(\frac{d\ln \mathbb{E}[v_\theta]}{d\ln P} = \bar{\mu}^{-1}\right)$.

The direct effect, in turn, shows that a change in the barriers to services trade disproportionately impacts firms that offshore innovation activities. Intuitively, the innovation costs of firms that do not rely on foreign partners are not directly impacted by a change in the costs of offshoring. In contrast, the knowledge acquisition costs of firms relying heavily on knowledge imports, captured by a high import share $\varphi_\theta$,respond strongly to a change in trade costs. The associated implications for product and process innovation are summarized by two structural elasticities, $\Gamma_\theta^c$ and $\Gamma_\theta^h$, capturing how shocks to innovation costs impact innovation activities. We discuss the properties of these pass-throughs in greater detail in the Appendix E.4.

**D.7. Characterizing the welfare gains from services trade**

The following characterizes the response of per-capita welfare to a change in the price of imported innovation inputs. The proof of the following theorem is provided in Appendix E.5.

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

$$d\mathcal{U} = \underbrace{-\bar{\mu}\Lambda dln\, \tau}_{\Delta \text{ Technical Efficiency}} \quad \underbrace{- \mathbb{E}_s\left[\left(1 - \frac{\mathbb{E}_s[\delta_\theta]}{\mu_\theta}\right)\sigma_\theta \rho_\theta \left\{\left(\Gamma_\theta^c - \Gamma_\theta^h\right)\varphi_\theta - \frac{\varepsilon_\theta - 1}{\varepsilon_\theta - \sigma_\theta \rho_\theta}\bar{\mu}\Lambda\right\}\right] dln\, \tau}_{\Delta \text{ Allocative Efficiency}} \qquad \text{Eq. (21)}$$

*where $\lambda = \mathbb{E}_S\left[\frac{\mathcal{P}_I I_\theta}{s_\theta}\right]$ and $\bar{\mu} = \mathbb{E}_S[1/\mu_\theta]^{-1}$. The pass-throughs of innovation cost shocks into innovation outcomes, $\Gamma_\theta^h \equiv \frac{\partial ln\, h_\theta}{\partial ln\, \kappa_\theta}$ and $\Gamma_\theta^c \equiv \frac{\partial ln\, c_\theta}{\partial ln \leq_\theta}$, are given in Lemma 1 .*

Theorem 1 shows that the welfare gains from falling import prices can be decomposed into two effects. The term labeled technical efficiency captures the change in welfare when the distribution of relative prices $\left(\frac{p_\theta}{A}\right)_{\theta \in \Theta}$ 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 effect; implying that the import share of services in GDP and aggregate markups are sufficient statistics to summarize welfare changes; in other words, we recover a version of the welfare formula of the gains from trade for efficient economies derived in Arkolakis et al. (2012).

The second term in equation Equation (21) captures how reallocations of economic activity between firms contribute to welfare. This term equals zero in an economy with homogeneous markups; otherwise, it may be positive or negative, depending on whether the induced changes in product and process innovation induce welfare-enhancing reallocations.

## Appendix E. Proofs

### E.1. Proof of Proposition 2

If the firm undertakes $N(\omega)$ research endeavors to solve a problem $\omega$, it obtains a solution with quality,

$$\Pr\left[\max_{i=0,1,\dots,n(\omega)-1} z_i(\omega) \leq \tilde{z}\right] = (1 - G(\tilde{z}))^{n(\omega)}.$$

Given that the arrival rate of new ideas follows a Poisson distribution, $n(\omega) \sim \text{Poisson}(N(\omega))$, we can readily calculate this probability:

$$\begin{aligned}\Pr[z(\omega) \leq \tilde{z}] &= \textstyle\sum_{n=0}^{\infty} \frac{e^{-N(\omega)}N(\omega)^n}{n!}(1 - G(\tilde{z}))^n \\ &= e^{-N(\omega)} \textstyle\sum_{n=0}^{\infty} \frac{(N(1-G(\tilde{z}))^n}{n!} \\ &= e^{-N(\omega)G(\tilde{z})}.\end{aligned}$$

For a general distribution $G(\cdot)$, this last equation describes the distribution of the quality of ideas for resolving a specific problem $\omega$ when the cumulative research effort directed at resolving it is $N(\omega)$. We now assume that ideas are drawn from a Pareto distribution, $\Pr[z_i(\omega) > \tilde{z}] = G(z) = k_j^{\zeta-k} z^{\zeta}$. Combining this with the above equation, yield the result that the random variable $z(\omega)$ follows a Frechet distribution, $\Pr[z(\omega) \leq \tilde{z}] = e^{-N(\omega)k_j^{\kappa-\zeta}z^{-\zeta}}$, which has an expected value of

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

where we changed the variable of integration in the third line to $u = N(\omega)k_j^{\zeta-\kappa}z^{-\zeta}$, implying that $z = N(\omega)^{1/\zeta}k_j^{\frac{\zeta-\kappa}{\zeta}} u^{-1/\zeta} du = -\zeta N(\omega)k_j^{\zeta-\kappa}z^{-\zeta-1}dz$, and $\Gamma(\cdot)$ denotes the Gamma function. The expectation above is well defined since our assumption that $2\kappa < \zeta$ ensures that $1 - \kappa/\zeta > 0$.

To derive the knowledge production function, define $N(k_i) \equiv \{N(\omega)_{\omega\in\Omega}: \Gamma(1 - \kappa/\zeta)^{1/\kappa}(\int_{\omega} [N(\omega)]^{\kappa/\zeta} du\, k_j^{k/\zeta}\}$ to be the set of feasible input combinations that in expectation yield a knowledge level equal to $k_j$. Imposing that $2\kappa \leq \zeta$ guarantees that the variance of the following term is finite for $\forall \ell \in \{\ell(k_i): k_i \geq 0\}$,

$$\int_{\Omega_j} \text{Var}[z(\omega) \mid \ell_i(\omega)]d\omega = \left[\Gamma\left(1 - \frac{2\kappa}{\zeta}\right) - \Gamma^2\left(1 - \frac{\kappa}{\zeta}\right)\right] \int_{\Omega_i} (N(\omega))^{\frac{2\kappa}{\zeta}} d\omega < \infty,$$

and hence, the strong law of large numbers for independently distributed random variables implies:

$$k_j \overset{\text{a.s.}}{=} \Gamma(1-\kappa/\zeta)^{1/\kappa}\left(\int_{\Omega_j} [N(\omega)]^{\kappa/\zeta} d\omega\right)^{\zeta/\kappa}$$

where we assume that we work with an extension of the Kolmogorov measure which ensures all paths $N(\cdot)$ are measurable so that the law of large numbers holds.

**E.2. Problem of the firm**

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

$$\Pi_\theta(1_I) = \max_{h,p_j,k,\mathrm{p},\lambda}\Big\{\int_0^h \Big\{[p_j - c_\theta(k)]p_j^{-\varepsilon}\mathrm{p}^{\varepsilon-1}s_\theta\left(\tfrac{\mathrm{p}}{P}\right) - \eta_\theta(k)\Big\} dj - \mathcal{C}_\theta^\kappa(k)$$
$$+\lambda\left(\left(\int_0^h p_j^{1-\varepsilon}dj\right)^{1/(1-\varepsilon)} - \mathrm{p}\right)\Big\}.$$

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.

***Product prices and range*** – The firm chooses $(p_j) \in \mathcal{P} \equiv \cup_{j\in[0,h]}\mathcal{P}_{[0,h]}$ 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,

$$\left[(1-\varepsilon) + \varepsilon\frac{c_\theta}{p_j}\right]y_j + \lambda\left(\frac{p_i^{1-\varepsilon}}{\int_0^h p_j^{1-\varepsilon}dj}\right)^{-\frac{\varepsilon}{1-\varepsilon}} = 0. \qquad \text{Eq. (23)}$$

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

$$[p_i - c_\theta]y_i - \eta_\theta + \frac{1}{1-\varepsilon}\lambda p_i^{1-\varepsilon}\left(\int_0^h p_j^{1-\varepsilon}dj\right)^{\frac{\varepsilon}{1-\varepsilon}} = 0. \qquad \text{Eq. (24)}$$

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

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

which implies that the left-hand-side of (24) is strictly decreasing since

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

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

The FOC for $p$ is given by

$$h[p_i - c_\theta]y_\theta \mathrm{P}^{-1}(\varepsilon - \sigma_\theta) - \lambda = 0. \qquad \text{Eq. (25)}$$

By the envelope theorem, $\frac{\partial h[p_i - c_\theta]y_\theta}{\partial p_i} = -\lambda p_i^{1-\varepsilon} p^\varepsilon h < 0, \frac{\partial h[p_i - c_\theta]y_\theta}{\partial h} = \frac{1}{\sigma - 1} \lambda p_i^{1-\varepsilon} p^\varepsilon$, and $\frac{\partial h}{\partial \mathrm{p}} \propto \frac{\partial y_j}{\partial \mathrm{p}} < 0$, implying that, $\frac{\partial p_i}{\partial p} > 0$. It is then easy to check that the left-hand-side of (25) is strictly decreasing. Hence, there exists a unique product range and price that solves the firm's problem at a given level of knowledge.

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

$p_\theta = \frac{\sigma_\theta}{\sigma_\theta - 1} c_\theta, \, , c_\theta y_\theta = (\varepsilon - 1)\eta_\theta. \ \mathrm{p}_\theta^{1-\varepsilon} = h_\theta p_\theta^{1-\varepsilon}$

***Knowledge*** – The FOC with respect to knowledge is given by

$$h\left[-\frac{kc'_\theta}{c_\theta} y_\theta c_\theta - \frac{k\eta'_\theta}{\eta_\theta}\eta_\theta\right] - k(\mathcal{C}_\theta^\kappa)' = 0. \qquad \text{Eq. (26)}$$

Substituting the solutions derived above, we obtain:

$$\left(-\frac{kc'_\theta}{c_\theta} - \frac{1}{\varepsilon - 1}\frac{k\eta'_\theta}{\eta_\theta}\eta_\theta\right) c_\theta y_\theta = k(\mathcal{C}_\theta^\kappa)'.$$

### E.3. 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 $\frac{\partial \ln y_\theta}{\partial \ln P} = \sigma_\theta - 1$. 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

$$d\ln \mu_\theta = \frac{\rho_\theta - 1}{\rho_\theta} d\ln \frac{\mathrm{p}_\theta}{P} = \frac{1-\rho_\theta}{\rho_\theta}\left(\frac{1}{\varepsilon - 1} d\ln h_\theta + d\ln P - d\ln p_\theta\right) \qquad \text{Eq. (27)}$$

***Prices and quantities*** – The changes in product-level and firm-level prices equal

$d\ln p_\theta = d\ln \preceq_\theta + d\ln c_\theta$.

Given these changes in prices, the corresponding changes in variety-level quantities and firm market shares equal,

$$d\ln y_\theta = \frac{\sigma_\theta \rho_\theta - \varepsilon_\theta}{\varepsilon_\theta - 1} d\ln h_\theta - \sigma_\theta \rho_\theta d\ln c_\theta + (\sigma_\theta \rho_\theta - 1) d\ln P \qquad \text{Eq. (28)}$$

$$d\ln s_\theta = (1 - \sigma_\theta) d\ln \frac{\mathrm{p}_\theta}{P} = (\sigma_\theta - 1)\rho_\theta \left(d\ln P + \frac{1}{\varepsilon_\theta - 1} d\ln h_\theta - d\ln c_\theta\right) \qquad \text{Eq. (29)}$$

***Innovation outcomes*** – Differentiating the FOC for $h_\theta$, we obtain:

$$\frac{d\ln h_\theta}{\varepsilon_\theta - 1} = \frac{1-\sigma_\theta\rho_\theta}{\rho_\theta\sigma_\theta-\varepsilon_\theta} d\ln P + \frac{\gamma_\theta^{hc}}{\rho_\theta\sigma_\theta-\varepsilon_\theta} d\ln c_\theta + \frac{\omega^{\kappa_\theta}}{\rho_\theta\sigma_\theta-\varepsilon_\theta}\varphi_\theta d\ln\tau \qquad \text{Eq. (30)}$$

where $\gamma_k^{hc} \equiv \sigma_\theta\rho_\theta - 1 + \frac{\partial\ln(f_\theta+\kappa_\theta)}{\partial\ln k_\theta}\frac{\partial\ln c^{-1}(k_\theta)}{\partial\ln c_\theta}$ and $\omega^{\kappa_\theta} \equiv \frac{\kappa_\theta}{f_\theta+\kappa_\theta}$ denotes the share of innovation expenditures in total product entry costs.

To differentiate the FOC for $k_\theta$, recall that Equation 3 implies that a firm's knowledge cost elasticity depends on its import share, $\gamma_\theta \equiv \frac{\partial\ln\kappa_\theta(k)}{\partial\ln k} = \zeta\alpha + \varphi_\theta\zeta(1-\alpha)$. By virtue of the envelope theorem, the change in total innovation costs satisfies: $d\ln\kappa_\theta(k) = \varphi_\theta d\ln\tau + \gamma_\theta d\ln k_\theta$. The total derivative of the right-hand side of equation (14) then equals,

$$d\ln\gamma_\theta\kappa_\theta \equiv \frac{\zeta(1-\alpha)}{\zeta\alpha+\varphi_\theta\zeta(1-\alpha)}\varphi_\theta d\ln\varphi_\theta + \varphi_\theta d\ln\tau + \gamma_\theta d\ln k_\theta. \qquad \text{Eq. (31)}$$

Let $\tilde{\chi}_\theta - 1 \equiv \left[\frac{d\ln\frac{1-\varphi_\theta}{\varphi_\theta}}{d\ln\tau}\right]_{k\text{ constant}}$ denote the elasticity between knowledge service and domestic innovartion expenditures with respect to trade costs, holding a firm's level of knowledge fixed. Then,

$$d\ln\frac{1-\varphi_\theta}{\varphi_\theta} = -\frac{1}{1-\varphi_\theta}d\ln\varphi_\theta = (\tilde{\chi}_\theta - 1)d\ln\tau + \frac{\partial\ln\frac{1-\varphi_\theta}{\varphi_\theta}}{\partial\ln k_\theta}d\ln k_\theta$$

$$\Leftrightarrow d\ln\varphi_\theta = (1-\varphi_\theta)(1-\chi_\theta)d\ln\tau - (1-\varphi_\theta)\frac{\partial\ln\frac{1-\varphi_\theta}{\varphi_\theta}}{\partial\ln k_\theta}d\ln k_\theta\,.$$

Using this expression to simplify (31), we obtain:

$$\begin{aligned} d\ln\gamma_\theta\kappa_\theta =& \left[1 - \frac{\zeta(1-\alpha)\varphi_\theta}{\zeta\alpha+\varphi_\theta\zeta(1-\alpha)}\frac{\partial\ln\varphi_\theta}{\partial\ln\tau}\right]\varphi_\theta\cdot d\ln\tau \\ &+ \left[\gamma_\theta - \frac{\zeta(1-\alpha)(1-\varphi_\theta)}{\zeta\alpha+\varphi_\theta\zeta(1-\alpha)}\frac{\partial\frac{1-\varphi_\theta}{\varphi_\theta}}{\partial\ln k_\theta}\varphi_\theta\right]d\ln k_\theta \\ \equiv& \chi_\theta\varphi_\theta d\ln\tau + \tilde{\gamma}_\theta d\ln k_\theta\,. \end{aligned}$$

Totally differentiating the first order condition for knowledge, we then obtain:

$$\gamma_\theta^c d\ln c_\theta = \chi_\theta\varphi_\theta d\ln\tau + (1-\sigma_\theta\rho_\theta)d\ln P + (\varepsilon_\theta - \sigma_\theta\rho_\theta)\frac{d\ln h_\theta}{\varepsilon_\theta - 1}, \qquad \text{Eq. (32)}$$

where $\gamma_\theta^c = 1 - \sigma_\theta\rho_\theta + \left\{\frac{\partial\ln\left(-\frac{\partial\ln c_\theta}{\partial\ln k_\theta} - \frac{1}{\varepsilon_\theta-1}\frac{\partial\ln f_\theta}{\partial\ln k_\theta}\right)}{\partial\ln k_\theta} - \tilde{\gamma}_\theta\right\}\frac{\partial\ln c_\theta^{-1}(k)}{\partial\ln c_\theta}$.

***Free Entry*** – We denote a firm's total expenditures on imported knowledge services by $I_\theta \equiv h_\theta\int_{\Omega_\theta} 1\{o(\omega)=1\}\tau p_F t(\omega)N(\omega)d\omega \equiv h_\theta\kappa_\theta\varphi_\theta$. Applying the envelope theorem to differentiate the free entry condition, we then obtain:

$$\int_{\Lambda} \left[h_\theta(p_\theta - c_\theta)y_\theta \frac{P}{y_\theta}\frac{\partial y_\theta}{\partial P} \text{dln} P - h_\theta \kappa_\theta \varphi_\theta \text{ dln} \tau\right] dG(\theta) = 0. \quad \text{Eq. (33)}$$

***Budget constraint*** – Differentiating the budget constraint, we find:

$$0 = d \ln M + \mathbb{E}_s\left[(1 - \sigma_\theta) \text{ dln} \frac{\text{p}_\theta}{P}\right]. \quad \text{Eq. (34)}$$

***Welfare*** – By virtue of the envelope theorem, the change in consumer surplus is given by

$$-d \ln P^Y = dW = \mathbb{E}_s[\delta_\theta - 1]d \ln M + \mathbb{E}_s[\text{dln p}_\theta]. \quad \text{Eq. (35)}$$

**E.4. Proof of Lemma 1**

For part (a), we note that $(p_\theta - c_\theta)h_\theta y_\theta \frac{P}{y_\theta}\frac{\partial y_\theta}{\partial P} = \frac{\sigma_\theta - 1}{\sigma_\theta} p_\theta y_\theta h_\theta = \frac{1}{\mu_\theta} s_\theta$ to rewrite equation (33) as:

$$\int \left[h_\theta(p_\theta - c_\theta)y_\theta \frac{P}{y_\theta}\frac{\partial y_\theta}{\partial P} \text{dln} P - h_\theta \kappa_\theta \varphi_\theta \text{dln} \tau\right] dG(\theta) = 0$$
$$\Leftrightarrow \mathbb{E}_s\left[\frac{1}{\mu_\theta}\right] d\ln P - \mathbb{E}_s\left[\frac{h_\theta \kappa_\theta}{s_\theta}\varphi_\theta\right] d\ln \tau = 0$$
$$\Leftrightarrow d \ln P = \bar{\mu}\Lambda d \ln \tau \,,$$

where we denoted the average markup by $\bar{\mu} \equiv \mathbb{E}_s[1/\mu_\theta]^{-1}$, and the GDP import share in aggregate sales by $\Lambda \equiv \mathbb{E}_S\left[\frac{h_\theta \kappa_\theta}{s_\theta}\varphi_\theta\right]$.

To show part (b), 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 (30) and (32) we obtain:

$$d\ln c_\theta = \Gamma_\theta^c \varphi_\theta d\ln \tau \quad \text{Eq. (36)}$$

$$\frac{1}{\varepsilon_\theta - 1} d \ln h_\theta = \Gamma_\theta^h \varphi_\theta d \ln \tau + \frac{1 - \sigma_\theta \rho_\theta}{\rho_\theta \sigma_\theta - \varepsilon_\theta} d \ln P. \quad \text{Eq. (37)}$$

The structural pass-throughs of knowledge cost shocks into unit costs, $\Gamma_\theta^c$, is given by

$$\Gamma_\theta^c \equiv \frac{\partial \ln c_\theta}{\partial \ln \kappa_\theta} = \frac{\chi_\theta - \frac{\kappa_\theta}{f_\theta + \kappa_\theta}}{\det\left[\mathcal{H}_{v_\theta} \cdot \frac{\partial \ln c_\theta^{-1}(k)}{\partial \ln c_\theta}\right]},$$

where Proposition 2 implies that $\chi_\theta \equiv \frac{\partial \ln \gamma_\theta \kappa_\theta}{\partial \ln \kappa_\theta} = 1 - \frac{\zeta(1-\alpha)\varphi_\theta}{\zeta\alpha + \varphi_\theta \zeta(1-\alpha)} \frac{\partial \ln \varphi_\theta}{\partial \ln \tau} > 1$. $\mathcal{H}_{v_\theta}$, in turn, is the Hessian of the firm's logged market value function. Evaluated at the firm's optimal choices, the determinant of $\mathcal{H}_{v_\theta}$ is given by:

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

For the firm's profit problem to be well-defined, the determinant must be negative, $\det \mathcal{H}_{v_\theta} < 0$ , and hence $\Gamma_\theta^c > 0$ if, and only if, $\frac{\partial c_\theta}{\partial k_\theta} < 0$.

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

$$\Gamma_\theta^h \equiv \frac{\partial \ln h_\theta}{\partial \ln \kappa_\theta} \equiv \frac{-\gamma_\theta^{hc}\Gamma_\theta^c - \omega_{\kappa_\theta}^{f_\theta+\kappa_\theta}}{\varepsilon_\theta - \rho_\theta\sigma_\theta}, \qquad \text{Eq. (38)}$$

where

$$\gamma_\theta^{hc} = 1 - \sigma_\theta\rho_\theta - \frac{\partial \ln(f_\theta+\kappa_\theta)}{\partial \ln k_\theta}\frac{\partial \ln c^{-1}(k_\theta)}{\partial \ln c_\theta} = 1 - \sigma_\theta\rho_\theta - \frac{\partial \ln\left(\frac{\sigma_\theta - 1}{\varepsilon_\theta - 1}\frac{p_\theta y_\theta}{\sigma_\theta}\right)}{\partial \ln k_\theta}\frac{\partial \ln c^{-1}(k_\theta)}{\partial \ln c_\theta}. \qquad \text{Eq. (39)}$$

A fall in trade costs induces firms to increase variety through the direct effect if primitives satisfy $\gamma_\theta^{hc}\Gamma_\theta^c + \omega_{\kappa_\theta}^{f_\theta+\kappa_\theta} > 0$. Restricting attention to the empirically relevant case where $\Gamma_\theta^c > 0$, this implies that the pass-through of cost shocks into product scope $\Gamma_\theta^h$ is negative if

$$\frac{\partial \ln \kappa_\theta}{\partial \ln k_\theta} \cdot \left(-\frac{\partial \ln c^{-1}(k_\theta)}{\partial \ln c_\theta}\right) > \frac{\kappa_\theta + f_\theta}{\kappa_\theta}(\sigma_\theta\rho_\theta - 1) - \frac{1}{\Gamma_\theta^c} - \frac{f_\theta}{\kappa_\theta}\frac{\partial \ln f_\theta}{\partial \ln k_\theta}$$

and positive otherwise. The left-hand-side is unambiguously positive since $\Gamma_\theta^c > 0$ 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 (27),

$$\begin{aligned} d\ln \frac{\mathrm{p}_\theta}{P} &= \rho_\theta d\ln c_\theta - \rho_\theta d\ln P - \frac{\rho_\theta}{\varepsilon_\theta - 1} d\ln h_\theta \\ &= \rho_\theta \left[\left(\Gamma_\theta^c - \Gamma_\theta^h\right)\varphi_\theta - \frac{\varepsilon_\theta - 1}{\varepsilon_\theta - \rho_\theta\sigma_\theta}\bar{\mu}\Lambda\right] d\ln\tau\,. \end{aligned}$$

### E.5. Proof of Theorem 1

Using equation (34) to substitute for $d\ln M$ in equation (35), we obtain:

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

where we evoked Lemma 1 to solve for $d\ln P$ and $d\ln \frac{\mathrm{p}_\theta}{P}$ and go from the third to the fourth line.

Using Lemma 1, we can then change in real GDP:

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

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

$$
d\ln\bar{\mu} = -\mathbb{E}_s\left[\frac{\bar{\mu}}{\mu_\theta}\left(\mathrm{d}\ln Ms_\theta - \mathrm{d}\ln\mu_\theta\right)\right].
$$

Firm-level markups are given by

$$
d\ln\mu_\theta = \frac{\rho_\theta - 1}{\rho_\theta} d\ln\frac{\mathrm{p}_\theta}{P}.
$$

The change in total sales of firms of type $\theta$, in turn, is given by

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

Putting this together, we obtain:

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

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