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ESSAYS ON THE EFFECTS OF INTERNATIONAL TRADE ON LABOR MARKETS AND ECONOMIC GROWTH

Trottner, Fabian Guenter Werner

Princeton, NJ : Princeton University

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ESSAYS ON THE EFFECTS OF INTERNATIONAL TRADE ON LABOR MARKETS AND ECONOMIC GROWTH

FABIAN GUENTER WERNER TROTTNER

A DISSERTATION

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OF PRINCETON UNIVERSITY

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Abstract

I study how international trade affects labor market outcomes and economic growth. In the first chapter, I study how international trade affects wage inequality within and between firms. Using matched employer-employee data from Germany, I document that the firm-size wage premium is higher for skilled compared to less-skilled workers and that larger firms disproportionately employ more skilled workers. I show, using a new quantitative framework, that non-homothetic production and monopsonistic competition in labor markets can rationalize these reduced-form findings. To estimate the model, I propose a new econometric method to identify non-homotheticity in the presence of upward-sloping labor supply curves separately. Counterfactual exercises quantitatively show that the mechanism implies sizeable distributional effects of trade.

The second chapter, co-authored with Yann Koby, combines reduced-form evidence with a new model of a dynamic multi-country and multi-sector economy to study the link between trade and structural transformation. The model accounts for major drivers of structural change - including sector-biased technological change and income effects, as well as technological and factor-driven motives for trade. We provide a characterization of the existence and uniqueness of the equilibrium. We quantify the model to the years 1995 to 2011 and then use it to discuss the decline in U.S. manufacturing and the role of service trade in influencing employment in the manufacturing sector.

The third chapter, co-authored with Bastian Krieger, studies the effect of trade in services on firms' innovation activities. We combine unique micro-data from Germany with a simple theory of international trade and innovation to provide causal evidence that trade in innovation services increases innovative activities in firms, accounting for market size and competition effects of trade integration.

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I am thankful to the team of researchers and staff members at the FDZ at the Institute for Employment Research, at the Research and Data Center of the German Bundesbank, and to Christian Rammer and the Leibniz Center for European Economic Research for providing the data infrastructure and research environment that made possible chapters 1 and 3.

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To my parents and brother

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Chapter 1

Who Gains from Scale? Trade and Wage Inequality Within and Between Firms

1.1 Introduction

What are the distributional effects of international trade? Much of the research seeking to answer this question focuses on aggregate returns to skill, e.g., mean wage differences between college and high school educated workers. However, aggregate returns to skill mask systematic variation in skill premia across firms: Larger firms exhibit higher pay inequality between skilled and less-skilled employees. Meanwhile, modern trade theory emphasizes that trade liberalization reallocates economic activity to large firms. This suggests novel mechanisms for trade to impact wage inequality through the reallocation of labor towards firms paying higher skill premia and through changes in pay inequality within firms. Most models of international trade and wage inequality, however, assume a common wage for each type of worker across firms or a firm wage premium that is common across worker types. This chapter develops a

framework featuring variation in skill premia across firms and uses it to reevaluate the distributional consequences of international trade.

I combine German matched employer-employee data with a new heterogeneous firm model of trade and wage inequality to inform and quantify the mechanisms linking trade, wage distributions within firms, and aggregate earnings inequality. The analysis proceeds in four steps. First, I document that relative wages and employment shares of skilled compared to less-skilled workers are higher at larger firms. Second, to account for these features of the data, I develop a model in which firms operate a non-homothetic production technology and face an upward-sloping supply curve for each type of worker. An increase in firm size raises the relative productivity of more skilled workers, thereby changing both their relative wages and employment as the firm moves along the labor supply curve for each type of worker. Third, I develop a new method that separately identifies non-homotheticities from heterogeneous production technologies and labor supplies. Fourth, I conduct counterfactuals showing that trade substantially raises wage inequality both within and between firms, and evaluating how taxes that correct distortions from monopsonistic labor markets affect inequalities and the welfare gains from trade. I now describe each of these steps in greater detail.

I begin by establishing three stylized facts from German matched employer-employee data about relative wages and relative employment for different types of workers across firms. Specifically, the data show that while larger firms pay higher wages to workers of all skill levels, A large empirical literature documents that larger firms pay higher wages (e.g. Brown and Medoff (1989), Oi and Idson (1999)), and that firm-size wage gaps are potentially important for aggregate inequality (e.g. Card et al. (2013), Alvarez et al. (2018), Helpman et al. (2017), Song et al. (2018)). wages of more skilled workers are more strongly associated with firm sales. Within firms, larger firms pay higher relative wages to more skilled employees. Further, the relative employment shares of more skilled workers are positively related to firm size: High skill workers

are more likely to be employed by larger firms. These features suggest that a firm's decision to scale production, e.g., the decision to export,[1] is connected to within-firm distributions of skill and wages.

I develop a model that accounts for these features of the data by combining non-homothetic technologies (Hanoch (1975), Sato (1975)) with an upward-sloping labor supply function for each type of labor. Non-homotheticity in technology implies that a firm's level of output explicitly has effects on the relative productivity of different skill groups.[2] As a result, firms jointly decide the skill composition and their scale,[3] and relative labor demands for skill types differ across firms with different levels of output. An upward-sloping labor supply function for each skill type introduces monopsonistic competition into the labor market. Workers receive heterogeneous preference shocks over non-wage job characteristics that are unobservable to firms. A firm seeking to expand employment has to post higher wages so that more employees choose to accept the job. As firms cannot price-discriminate, all employees benefit from an increase in the wage, and workers earn rents from employment relationships. Consistent with the reduced form facts, the model predicts that skill premia and skill intensity vary systematically with firm size.

In the model, the relationship between firm size, skill composition, and the skill wage premium depends on both the degree of non-homotheticity in production and on the relative curvature of type-specific labor supply curves. Because the elasticity of labor supply determines marginal hiring costs and worker rents, the model predicts

[1] It is a well-established empirical fact that exporters are more skill intensive, and pay higher wages (e.g. Bernard and Jensen (1995), Bernard et al. (2007), Verhoogen (2008)).

[2] I provide several microfoundations for this technology. In particular, I show that the non-homothetic CES captures a continuous generalization of the binary technology choice model in (Bustos (2011a)).

[3] The cross-sectional predictions are similar to models based on skill-bias in technology (Harrigan and Reshef (2015), Burstein and Vogel (2017)). In contrast to these models, here market size is itself a determinant of skill composition. Thus, a firm's production efficiency is jointly determined with its skill composition and output, similar to knowledge-based models of production hierarchies Lucas (1978), Rosen (1981), Garicano (2000), Garicano and Rossi-Hansberg (2015), Eckert et al. (2019)), and models of technology adoption (Yeaple (2005), Atkeson and Burstein (2010), Bustos (2011a)).

that workers in less elastic supply receive disproportionately higher wages at larger employers. Further, firm size determines the relative productivity of skill groups, and thereby impacts the relative wages that skill types earn across employers - skill types whose relative productivity increases in firm size receive relatively higher wages at larger firms. Similar forces determine the relationship between size and workforce skill composition: Ceteris paribus, larger firms hire relatively more skill types who are in more elastic supply, and whose relative productivity is increasing in firm size. The model parsimoniously captures these forces through two sets of structural parameters.

To assess the aggregate distributional consequences of a trade-induced shift in the firm size distribution, it is critical to separately identify the parameters that govern non-homotheticity in labor demand and the elasticity of the labor supply for different skill types. I achieve this by developing an estimation strategy that identifies the elasticities of labor demand independently of the curvature of labor supply. To address the simultaneity bias that arises from upward-sloping labor supply curves and to separately identify non-homotheticities from exogenous differences in labor demand, I build on approaches to partial identification from Leamer (1981) and Feenstra (1994). I show that an exogenous shock to firm demand is sufficient to provide partial identification of the production function's output elasticities and the elasticity of substitution, which in turn fully characterize the elasticities of labor demand. To the extent that regional labor markets (i.e., East and West Germany) are subject to different shocks, the additional cross-regional variation provides full identification of the labor demand elasticities. The estimates of the production technology are then used to infer labor supply elasticities by matching simulated moments of wage distributions to their empirical counterparts.

The resulting parameter estimates imply that more skilled workers earn disproportionately higher wages at larger firms for two reasons. First, their productivity is more complementary to scale. Second, their labor supply curve is less elastic, implying

that finding skilled workers is more costly to firms, and thus, these workers earn higher rents from employment relationships. By allowing for firm-varying returns to skill, the model quantitatively matches many dimensions of earnings inequality not typically featured in frameworks of international trade: Wage inequality between- and within-firms, as well as empirical patterns in within-group wage dispersion. Even though labor demand is estimated on firm-level outcomes and not explicitly targeted in the structural simulations, the model matches aggregate patterns of worker-to-firm sorting in the data well.

To assess the model's aggregate implications, I consider counterfactual changes in trade costs implied by the observed changes in the share of exporting firms, export shares, and total import shares between the periods 1993-2002 and 2003-2014. I find that the associated decrease in trade costs increased wage inequality by 4.2 percent, which captures 22 percent of the total increase in wage inequality observed in the data. I find that trade accounts for 30 percent of the observed changes in aggregate skill premia. In part, this reflects that within-firm effects, which account for 30 percent of counterfactual changes in earnings inequality, amplify the change in aggregate skill premia. Between firms, wages of skilled workers employed at exporting firms see the most significant increase. As a consequence, counterfactual changes in inequality are largest within high skill types and occur predominantly at the top of the wage distribution.

This theoretical mechanism also implies new welfare effects of trade. Imperfect competition in labor markets distorts the equilibrium allocation in both labor and product markets and hence influences the gains from trade. To quantify the associated welfare effects, I analytically derive a set of correcting proportional income taxes. The tax rate varies by skill type and the tax revenue funds wage-bill subsidies that induce firms to ignore rent-sharing concerns when making hiring decisions, to produce at a more efficient scale, and to reduce their profit margins. As a result

of the tax reform, more high skill workers sort into the growing firms upon trade liberalization. As a consequence of the reallocation in the labor market, the tax decreases wage inequality within skill groups by 20 percent, relative to the effect of trade without intervention. Worker welfare rises for all skill types and on average, by 6 percent. These findings highlight the interaction between trade frictions and domestic distortions in influencing the distributional consequences of trade liberalization and the welfare gains from trade.

Related Literature Traditionally, the literature on trade and inequality emphasizes between-sector reallocation and studies changes in mean wages of broadly defined worker groups. While quantitative frameworks based on this approach (Parro (2013), Caron et al. (2014, 2017), Cravino and Sotelo (2017), Burstein et al. (2019), Caliendo et al. (2019), Eckert (2019)) have yielded valuable insights, I depart from this literature by focusing on reallocation between firms, and by allowing for imperfect competition in labor markets.

As part of the recent literature on heterogeneous firms and trade (Melitz (2003)), one line of research highlights the importance of trade liberalization in changing the relative demand for skilled workers within and between firms (Yeaple (2005), Verhoogen (2008), Bustos (2011a), Davis and Harrigan (2011), Harrigan and Reshef (2015), Burstein and Vogel (2017), Fieler et al. (2018)). I contribute to this literature by providing a model of firm-varying labor demand that explicitly accounts for the role of firm size, and remains tractable even with arbitrarily many worker types. Contrary to these papers, I highlight wage dispersion within skill groups, firm-varying skill wage premia, and imperfect competition in labor markets.

Labor market frictions were introduced into models with firm heterogeneity in the form of efficiency wages (Davis and Harrigan (2011)), fair wages (Egger and Kreickemeier (2012, 2009),Amiti and Davis (2012), Egger et al. (2013)) and search

frictions (Davidson and Matusz (2006), Felbermayr et al. (2013, 2011), Helpman and Itskhoki (2010), Ritter (2015), Helpman et al. (2017, 2010)). All of these papers focus on wage dispersion across firms for ex-ante similar workers. In contrast, I provide an integrated framework that also accounts for within-firm wage dispersion and worker-to-firm sorting.

This paper also contributes to the literature studying the gains from trade in heterogeneous firm models (e.g., Arkolakis et al. (2012), Arkolakis et al. (2019)) by quantifying the welfare effects of distortions in worker-to-firm sorting.[4] While previous research has emphasized this channel theoretically (Davidson et al. (2008), Helpman et al. (2010)), and via reduced-form evidence (Davidson et al. (2014, 2012)), this paper is the first to quantify its relevance.

A mechanism not explored in this paper is competitive assortative matching (Ohnsorge and Trefler (2007), Costinot and Vogel (2010), Sampson (2014)). Recent papers in this literature featuring endogenous firm sizes predict that firms match with a single worker type (e.g., Grossman et al. (2017)), and that within-firm wage dispersion is a sign of inefficiencies, i.e., search frictions in the labor market (Eeckhout and Kircher (2018)).[5] Accounting for matching based on unobserved worker ability might constitute an interesting extension of my model.[6]

The non-homothetic CES was first studied by Sato (1975) and Hanoch (1975), and recently re-introduced by Comin et al. (2017) to analyze income effects in preferences in a growth model. Matsuyama (2015) uses the same model of utility in the context of a home market effect model of trade. This paper is the first to use it in production to

[4] To the best of my knowledge, this paper is also the first one to quantify the welfare effects of a correcting tax in the context of imperfectly competitive labor markets and international trade.

[5] Eeckhout and Pinheiro (2014) provide a model with many-to-one matching, where, interestingly, departures from a homothetic CES are necessary to generate different skill mixes across firms.

[6] My paper relates more broadly to the literature on labor market sorting (e.g., Shimer (2005), Gautier et al. (2010), Gautier and Teulings (2015), Lise et al. (2016)). While much of this literature describes worker-to-jobs sorting, I develop a model that determines equilibrium firm size and generates wage inequality, both between firms for a given worker type, and within firms across different worker types.

study wage inequality and labor market sorting. In recent work, Bauer et al. (2019) analyze non-homotheticity in firms' demand for IT, and Blaum et al. (2019) study non-homotheticity in firms' import demand for quality.

This chapter also contributes to a broad literature arguing that employer heterogeneity is important for aggregate wage inequality. The model of the labor supply side is related to Card et al. (2018), Haanwinckel (2018), Lamadon et al. (2019) and Berger et al. (2019), although I consider a different specification for labor demand and output markets. Since my framework features reduced-form wage expressions featuring log-linear interactions between skill and firm effects, it also relates to a large reduced form literature built around two-way fixed effects models of wages (Abowd et al. (1999), Card et al. (2013), Alvarez et al. (2018), Song et al. (2018), Bonhomme et al. (2019), Borovickova and Shimer (2019)).

1.2 Motivating Facts

In this section, I establish three key stylized facts about the relationship between relative wages and relative employment across firms that guide the theoretical model developed below.

1.2.1 Data Description and Definition of Skill Types

This study uses the Linked-Employer-Employee Data (LIAB) (longitudinal model 1993-2014 (LIAB LM 9314)) provided by the Institute for Employment Research (IAB) in Germany.[7] The data contains information on the complete workforce of a subset of German establishments. The sample establishments are the ones selected - at

[7]Data access was provided via on-site use at the Research Data Centre (FDZ) of the German Federal Employment Agency (BA) at the Institute for Employment Research (IAB) and subsequently remote data access. A detailed documentation of the data can be found in Heining et al. (2016),Fischer et al. (2009) and Heining et al. (2014). Data access was provided under project FDZ1440.

least once - in an annually conducted survey between 2000 and 2008. The employee information contains employment biographies from 1993 to 2014 of all individuals, which were, at least one day, employed at one of the sample establishments. I organize the resulting dataset as an annual panel.

The data provides detailed information on individual workers - daily wages, days worked, age, gender, nationality, tenure at the firm, education, and occupation. The information on employers includes revenues, the sector of economic activity, spending on intermediate inputs, and exports. Throughout, I use the term firms to refer to establishments. A more detailed overview of the data is presented in the appendix.

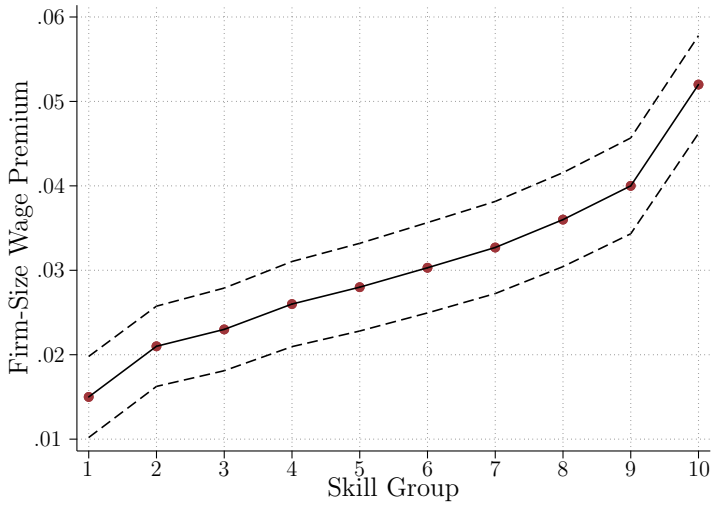
Definition of Skill This chapter associates the skill of a worker with the *average* wage that workers of her type earn. A worker's type corresponds to her sector of employment, occupation, and educational attainment. For each sector, I calculate age- and gender-adjusted average wages across all workers of a given type and rank types according to their average wages. Skill group 1 consists of workers who belong to a type that falls into the first decile, and henceforth until skill group 10.

1.2.2 Facts

Fact 1.1. *Compared to less skilled workers, the wages of more skilled workers are more strongly related to firm size.*

A canonical feature of labor markets is that larger firms pay higher wages to their employees. Here, I document that firm-size wage premia differ across skill types. I regress the wage of an individual worker i in year t, $\log W_{i,t}$, on a vector of worker controls $\boldsymbol{x}_{i,t}$, a vector of employer controls $\boldsymbol{y}_{f(i,t)}$, fixed effects $\boldsymbol{\omega}(i,t)$ for sector of employment, occupation, education, federal state of employment and year, as well as log revenues, $\log REV_{f(i,t)}$:

Figure 1.1: The Relationship Between Firm Sales and Worker Wages by Skill Type



Notes: This figure displays the coefficient estimates β_s in the empirical model in (1.1), which measure the relationship between worker wages and the sales of their employer for different skill groups. Standard errors are clustered at the establishment level. All regressions include fixed effects for a worker's age-group, gender, nationality, occupation, sector of occupation, the federal state of residence and years. Firm controls include the revenue share of intermediate inputs, and average skill intensity of all full-time employees.

$$\log W_{i,t} = \beta_{s(i,t)} \log REV_{f(i,t)} + \boldsymbol{\delta}' \mathbf{x}_{i,t} + \boldsymbol{\gamma}' \boldsymbol{y}_{f(i,t)} + \boldsymbol{\omega}(i,t) + \epsilon_{i,t}, \tag{1.1}$$

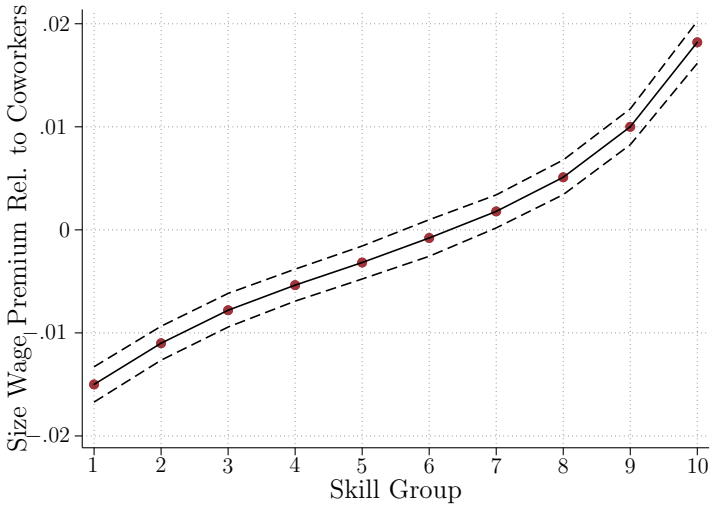
where $s(i,t)$ and $f(i,t)$ denote the skill level and employer of worker i.

Figure 1.1 displays the coefficient estimates for β_s. The results indicate that the earnings of high skill workers are more strongly related to employer revenues. On average, high skill workers are paid five percent more when working for an employer with twice the sales volume. In contrast, among the lowest skill group, a doubling of employer sales is associated with a one percent increase in wages earned.

shows this pattern is robust to using value-added or sales to total worker ratios to measure firm size and performance, as well as to the inclusion of worker and firm fixed effects.

Fact 1.2. *Within-firm wage inequality between skill groups is systematically related to firm size.*

Figure 1.2: The Relationship Between Firm Size and a Worker's Relative Wage Within the Firm by Skill Type



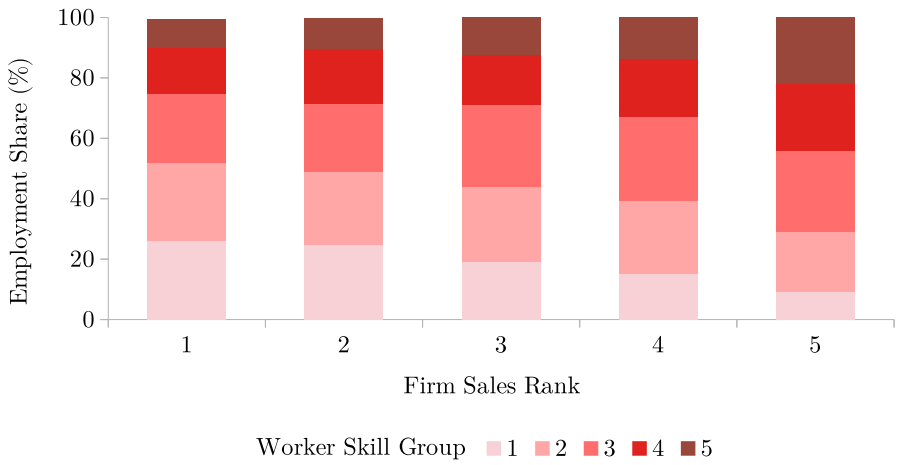
Notes: This figure displays the coefficient estimates β_s in the empirical model in (1.2), which measures the relationship between a worker's pay relative to the mean pay at the establishment and the establishment sales by skill group. Standard errors are clustered at the establishment level. All regressions include fixed effects for a worker's age-group, gender, nationality, occupation, sector of occupation, the federal state of residence, years and control for the revenue share of intermediate inputs.

To show how size relates to the earnings within the firm, I consider the same explanatory variables as before but instead use a worker's wage relative to the average wage $\overline{W}_{f(i,t)}$ paid at her firm as a dependent variable:

$$\log W_{i,t} - \log \overline{W}_{f(i,t)} = \beta_{s(i,t)} \log REV_{f(i,t)} + \boldsymbol{\delta}' \mathbf{x}_{i,t} + \boldsymbol{\gamma}' \boldsymbol{y}_{f(i,t)} + \boldsymbol{\omega}(i,t) + \epsilon_{i,t}. \quad (1.2)$$

Differences in the coefficient β across skill types indicate that within-firm inequality between worker groups is systematically related to firm revenues. Figure 1.2 displays the coefficient estimates and indicates that within firm-pay inequality is increasing in firm sales. High skill workers are paid 2 percent more than their coworkers when working for an employer with double the sales volume. In contrast, low skill workers are paid 1.5 percent less than their coworkers when working for an employer with double the sales volume.

Figure 1.3: Employment Distribution of Skill Groups Across The Establishment Sales Distribution



Notes: This figure displays the distribution of skills across the firm size distribution. Firm sales ranks denote quintiles of sector-specific sales distributions.

Table 1.11 provides detailed regression results and shows that the patterns hold for alternative measures of firm scale and are qualitatively robust to the inclusion of individual firm and worker fixed effects.

Fact 1.3. *Larger firms employ disproportionately more skilled workers.*

Figure 1.3 compares the skill distribution of the workforce across the firm sales distribution distribution and shows that more skilled workers tend to work for larger firms.

To supplement the graphical evidence, I regress an index measuring a firm's skill intensity, $comp_{f,t} = \overline{s(i,t)}_{i \in f(t)}$, on firm revenues, a vector of firm controls $\mathbf{y}_{f,t}$, and fixed effects $\boldsymbol{\omega}_{f,t}$ for industry, geographic location and years:

$$comp_{f,t} = \beta \log REV_{f,t} + \boldsymbol{\gamma}' \mathbf{y}_{f,t} + \boldsymbol{\omega}_{f,t} + \epsilon_{f,t}. \tag{1.3}$$

Table 1.12 displays the estimates. Firm size is positively related to skill intensity, suggesting that the skill composition of labor demand is heterogeneous across firms and systematically related to firm size.

1.3 Theory

This section develops a theoretical framework that rationalizes the reduced form facts in the previous section and highlights a new theoretical mechanism through which international trade affects wage inequality within and between firms.

1.3.1 Economic Environment

A small open economy H (Germany in the application) trades with an aggregate rest of the world F. Foreign variables, denoted with an asterisk, are exogenous. Workers and firms populate the economy, and all agents have CES preferences over differentiated goods with an elasticity of substitution $\eta > 1$. Product markets are monopolistically competitive.

Workers differ in skill $s \in \mathcal{S} = \{1, ..., S\}$, and there is a continuum of workers of each skill type of measure L_s. Workers derive utility from consumption and job-specific amenities. Section 1.3.3 describes the role of amenities and the problem of workers in detail.

As in Melitz (2003), there is a large, unbounded pool of prospective entrants into the industry. Entrants pay a fixed cost F_E to enter and gain monopoly rights over a single differentiated variety. Active firms are indexed by f, and $\mathcal{F}$ denotes the set of active firms. Upon entry, firms draw the demand for their product φ, and non-wage amenities A that they can offer to employees, from a joint cumulative distribution function $G(\varphi, A)$. The draw φ determines the demand schedule faced by the firm. Firms incur a fixed cost F_X to export, and exports are subject to an iceberg trade cost τ.

1.3.2 Technology

Each firm f produces output Q_f by combining labor inputs $l_{s,f}$ according to a non-homothetic CES production function (Hanoch (1975), Sato (1975)):

$$1 = \sum_{s \in \mathcal{S}} \Omega_s^{\frac{1}{\sigma}} l_{s,f}^{\frac{\sigma-1}{\sigma}} Q_f^{\frac{\varepsilon_s - \sigma}{\sigma}}. \tag{1.4}$$

Ω_s denote skill-specific productivity shifters that are common to all firms. σ governs the elasticity of substitution between worker types. The parameter ε_s controls the complementarity of skill type s with firm output Q. As the index Q rises, the productivity of skill type s varies at a rate controlled by parameter ε_s. To see this, consider the relative marginal products of labor MPL_s for two skill types:

$$\log\left(\frac{MPL_{s,f}}{MPL_{s',f}}\right) = \frac{1}{\sigma}\log\left(\frac{\Omega_s}{\Omega_{s'}}\right) - \frac{1}{\sigma}\log\left(\frac{l_{s,f}}{l_{s',f}}\right) + \left(\frac{\varepsilon_s - \varepsilon_{s'}}{\sigma}\right)\log Q_f. \tag{1.5}$$

It is evident that the non-homothetic CES nests both the homothetic CES and Cobb-Douglas functional forms. If $\varepsilon_s = \varepsilon_{s'} = 1$, the production function is equal to the standard CES. Additionally, if $\sigma = 1$, then the production function is Cobb-Douglas. In the general non-homothetic case, the relative productivity of worker types depends explicitly on the size of the firm.

Appendix 1.B.2 provides two microfoundations for the technology. The link between output and relative productivities of workers is implied by any model where, in order to expand production, firms make costly investment decisions in new technologies with differing relative productivities of skill types. In particular, I show that a generalization of the technology-choice framework in Bustos (2011b) provides a microfoundation for the non-homothetic CES functional form.[8] Further, non-homotheticity

[8]Specifically, I demonstrate that the technology-choice model implies the same cost function as the general class of non-homothetic CES functions (Sato (1975)).

in firms' labor demands for skilled workers arises in the context of a task-assignment model, where it captures the extent to which scale affects the relative comparative advantages of skill types in performing a given task.[9]

The following parametric restrictions ensure that the production quantity index defined by equation (1.4) is strictly increasing and quasi-concave in all labor inputs. Appendix 1.B.1 provides a detailed overview of the properties of the non-homothetic CES production function.

Assumption 1*For all* $s \in \mathcal{S}$, $(\sigma - \varepsilon_s)(\sigma - 1) > 0$.

1.3.3 Labor Supply to Individual Firms

Workers derive utility from consumption and non-wage amenities offered by jobs. They view jobs as imperfect substitutes and have random utility over employment opportunities, which generates upward-sloping labor supply functions to firms because a higher wage induces more workers to accept a job (Card et al. (2018)).

The utility of worker i working at job f is given by:

$$U_i(f, s) = \log C_i + \log A_f + \frac{1}{\beta_s}\epsilon_{i,f}, \tag{1.6}$$

where $C_i = \left(\sum_{f \in \mathcal{F}} (\varphi_f c_{f,i})^{(\eta-1)/\eta} + (c_i^*)^{(\eta-1)/\eta}\right)^{\eta/(\eta-1)}$ is a CES consumption index defined over domestic varitieties, c_f, and foreign varieties, c^*. A_f denotes non-wage amenities that are enjoyed by all employees of the firm. $\epsilon_{i,f}$ is an extreme-value distributed taste shock with variance 1.

The idiosyncratic taste shock gives rise to horizontal employer differentiation as workers differ in their preferences over the same set of job opportunities. Individual

[9]Beyond these particular microfoundations, several models in the literature provide qualitatively similar predictions. Models of organizational hierarchy (Lucas (1978),Rosen (1981), Garicano (2000), Garicano and Rossi-Hansberg (2015)), or CEO-compensation (e.g. Gabaix and Landier (2008)) feature environments where the relative productivity of different worker groups varies with the scale of a firm.

workplace preferences $\epsilon_{i,f}$ are private information to workers. Thus, firms cannot price-discriminate and offer wages $W_{s,f}$ conditional on worker type s, but not on realizations of $\epsilon_{i,f}$.

To characterize the labor supply to a firm offering wage $W_{s,f}$, note that (1.6) implies the following indirect utility:[10]

$$U_i(f,s) = \log(W_{s,f}/P) + \log A_f + \frac{1}{\beta_s}\epsilon_{i,f}, \tag{1.7}$$

where P is the standard CES price index $P = \left(\sum_{f\in\mathcal{F}} \varphi_f^{\eta-1} p_f^{1-\eta} + (P^*)^{1-\eta}\right)^{1/(1-\eta)}$.

Firms post wages, and each worker i chooses a job opportunity f_i^* to maximize her indirect utility in (1.7). The labor supply to an individual firm is proportional to the probability $\lambda_{s,f}$ that workers of type s chooses to work for f. Provided that $\beta_s > 1$, $\lambda_{s,f}$ depends on the wage offered by the job, on wages offered by all other jobs as well as firm-level amenities:[11]

$$\lambda_{s,f} \equiv \mathbb{P}\left(f_{i,s}^* = f \middle| \{W_{s,f'}, A_{f'}\}_{f'\in\mathcal{F}}\right) = \frac{(W_{s,f}A_f)^{\beta_s}}{\sum_{f'\in\mathcal{F}}(W_{s,f'}A_{f'})^{\beta_s}}. \tag{1.8}$$

The labor supply to a firm equals the mass of workers that choose to accept its job offer:

$$\log \mathcal{L}_s(W;A) = \log(\lambda_{s,f}L_s) = \beta_s \log W + \beta_s \log A + \log \Lambda_s, \tag{1.9}$$

where $\Lambda_s \equiv \left(\sum_{f\in\mathcal{F}}(A_f W_{s,f})^{\beta_s}\right)^{-1} L_s$ captures aggregate labor demand.

Firms view themselves as infinitesimal within the market and compete monopsonistically for workers. The elasticity of the labor supply to an individual firm thus equals $\frac{d\log \mathcal{L}_s}{d\log W_s} = \beta_s$. β_s captures the degree of competitiveness of the labor market. If $\beta_s \to \infty$, the labor market for skill type s is perfectly competitive, and firms can

[10] See Section 1.B.3 for the derivation.
[11] See Appendix 1.B.3 for the derivation.

hire any number of workers at a fixed wage. Lower values of β_s, in turn, capture less competitive labor markets.[12]

The information asymmetry between workers and firms gives rise to rent-sharing between workers and firms, and rents $R_{s,f}$ measure workers' average willingness to pay to remain employed at job f (Rosen (1987)):

$$R_{s,f} \equiv \mathbb{E}\left\{R : U_i(f,s) - \log R/P = \max_{f' \in \mathcal{F}\setminus f} U_i(f',s) \,|i{:}f^*_{i,s} = f\right\}, \tag{1.10}$$

The following proposition illustrates that worker rents are inversely related to the elasticity of labor supply.

Proposition 1.1. *The average rents earned by employees of type s at firm f equal* $R_{s,f} = \frac{1}{1+\beta_s} \cdot W_{s,f}$.

Proof. See Lamadon et al. (2019). □

For intuition, consider a firm wanting to expand production. The firm cannot observe the idiosyncratic workplace preferences of its current employees and, therefore, has to raise wages for all workers to increase hiring. An increase in wages raises the value of the job for workers that already enjoyed working at the firm. If labor supply is less elastic, then to increase production, firms have to raise wages, and hence the value of jobs to workers, by more.

[12] Manning (2003) notes that upward-sloping labor supply curves to the firm arise within models of directed search or convex vacancy posting cost. Appendix 1.B.4 illustrates that upward-sloping labor supply curves can be microfounded through a model with search frictions (e.g. Burdett and Mortensen (1998)). This illustrates that β_s is conceptually related to the job-finding to job-destruction ratio in search models of the labor market. Further, Appendix 1.B.4 shows that a model with random matching in labor markets, convex vacancy posting cost, and multilateral bargaining between workers and employers (Stole and Zwiebel (1996)) gives rise to similar implications for wages.

1.3.4 The Relationship Between Firm Scale, Wages and Employment Composition

Cost-Minimization

To derive the relationship between a firm's scale, its wages, and workforce composition, I solve for the (variable) cost function $\mathcal{C}(Q_f, A_f)$, which minimizes labor cost at any given target level of output Q :

$$\mathcal{C}(Q_f, A_f) \equiv \min_{\{l_{s,f}\}} \sum_s W(l_{s,f}, A_f) l_{s,f} \quad \text{s.t. } 1 = \sum_{s \in \mathcal{S}} \Omega_s^{\frac{1}{\sigma}} l_{s,f}^{\frac{\sigma-1}{\sigma}} Q_f^{\frac{\varepsilon_s - \sigma}{\sigma}} , \quad (1.11)$$

where $W(l, A)$ denotes the inverse of the labor supply curve in equation (1.9). Under assumption 1.1, this problem has a well-defined interior solution.

Cost-minimization implies that wages equal a mark-up over the marginal product of labor, MPL_s, and marginal cost:

$$\log(W_{s,f}) = \log\left(\frac{\beta_s}{\beta_s + 1}\right) + \log(MC(Q_f, A_f) MPL_s(Q_f)) . \quad (1.12)$$

In equilibrium, a monopolist maximizes profits by equating marginal cost and marginal revenues. Hence, wages correspond to a mark-down over the marginal revenue product of labor, as in classical Monopsony Theory (e.g., Robinson (1933)). The mark-down $\beta_s/(\beta_s + 1)$ is decreasing in the elasticity of the labor supply faced by the firm. Further, proposition 1.1 and the solution for wages in (1.12) jointly imply that skill types who are in less elastic labor supply earn higher rents, relative to their marginal product of labor.[13]

[13] Denoting marginal revenue products by $MRPL_s$, worker rents equal: $R_{s,f} = \frac{\beta_s}{(1+\beta_s)^2} \cdot MRPL_s(Q_f, A_f)$.

The Determinants of Wage Outcomes

A key outcome of the analysis is how firm size determines the wages paid to different skill types. The following proposition illustrates the channels that determine this relationship.

Proposition 1.2. *Denote logged variables by lower-case letters.*

1. *Wages are given by:*

$$w_{s,f} = \chi_s + \frac{\varepsilon_s}{\sigma + \beta_s} \times q_f + \frac{\sigma}{\sigma + \beta_s} \times \psi_f - \frac{\beta_s}{\sigma + \beta_s} \times a_f,$$

where $\chi_s \equiv \frac{1}{\sigma+\beta_s} \log\left(\Omega_s / \left(L_s \Lambda_s\right)\right)$ *and* $\psi_f \equiv \log\left(MC_f / \left(\sum_s \Omega_s^{1/\sigma} l_{s,f}^{(\sigma-1)/\sigma} Q_f^{(\varepsilon_s-\sigma)/\sigma \frac{\varepsilon_s-\sigma}{1-\sigma}}\right)\right)$.

2. *If* $\beta_s = \beta$, *and* $\varepsilon_s = \varepsilon$, *then wages are given by:*

$$w_{s,f} = \chi_s + \frac{\sigma}{\sigma + \beta} \times \widetilde{\psi}_f - \frac{\beta}{\sigma + \beta} \times a_f,$$

where $\widetilde{\psi}_f = \log\left(MC_f \cdot Q / \left(\sum_s \Omega_s^{1/\sigma} l_{s,f}^{(\sigma-1)/\sigma \frac{\varepsilon-\sigma}{1-\sigma}}\right)\right)$.

3. *If* $\beta_s \to \infty$, *then wages are given by:*

$$w_{s,f} = \chi_s - a_f.$$

Proof. The result follows from inserting (1.9) into (1.12). □

Statement 1 shows that two intuitive channels determine the effect of firm size on relative wage outcomes within skill groups and firms. First, firm size directly impacts relative productivity of skill groups. Workers whose relative productivity is increasing in firm size receive larger firm-size wage premia and receive a relatively larger firm-size wage premium. Second, proposition 1.2 shows that workers that are in less elastic labor supply receive a higher firm-size wage premium and receive relatively higher wages than their coworkers when working for larger firms.

Proposition 1.2 further highlights that the model accommodates the standard model with a firm-size wage premium common to all skill types and homogeneous skill wage premia across firms as a special case (statement 2). If the labor supply curve for each skill type has the same elasticity, and if skill types are equally complementary to output, then firm wage effects are common to all skill groups, and relative wages between skill types are equal across firms.[14] If labor markets are perfectly competitive (statement 3), then wage differentials between firms are only driven by compensating differentials and, in particular, invariant to firm size.

Firm Size and the Skill Composition of the Workforce

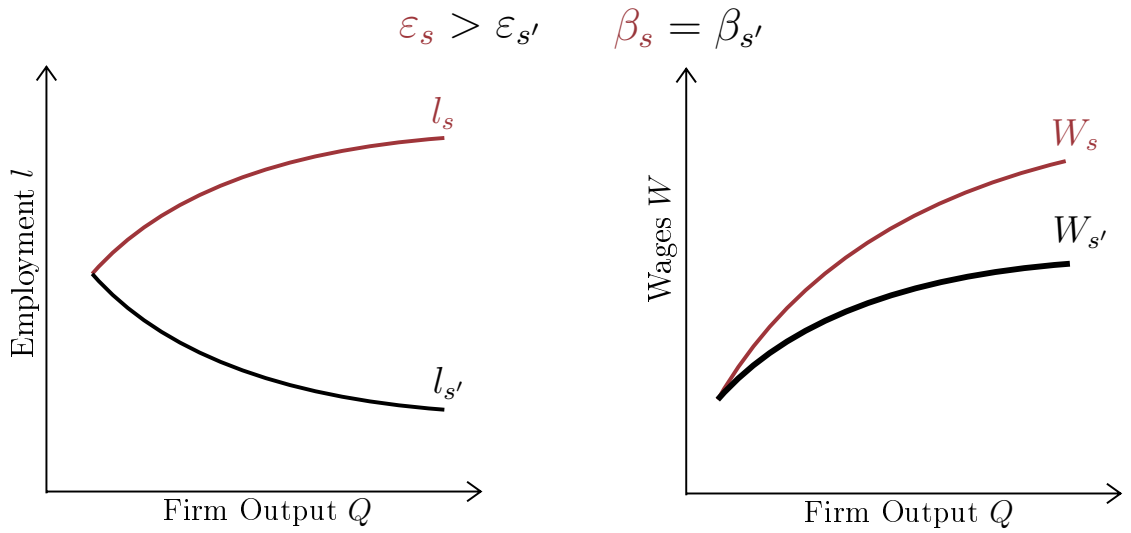
In a perfectly competitive labor market, firms can hire any number of workers at a given wage. In this case, differences in workforce skill composition indicate relative productivity differences of workers across firms. In the presence of upward-sloping labor supply curves, however, workers command rents, and hiring decisions by firms are subject to two concerns. First, firms wish to hire the most productive workers, given their scale. Second, firms prefer to hire workers that are in more elastic labor supply. The relationship between skill composition and output depends on how firm size changes the relative productivity of workers, as well as on the rents that skill types command.

To illustrate the productivity channel, Figure 1.4a assumes that skill types only differ in their complementarity to output. In this case, the *relative* employment for different skill types is not affected by rent sharing concerns. Due to their relative technological advantage, the relative labor demand for skill types more complemen-

[14] The model does not feature wage effects on the individual worker level and, therefore, does not directly relate to common reduced-form empirical models that are log-additive in worker and firm fixed effects (e.g. Abowd et al. (1999)). In Appendix 1.B.4, I consider an extension of the model that introduces heterogeneous efficiency units for a given type of worker. Armed with this simple extension, the model rationalizes a log-additive wage model with *individual* and firm effects under the parametric restrictions provided in statement 3. of Proposition 1.2.

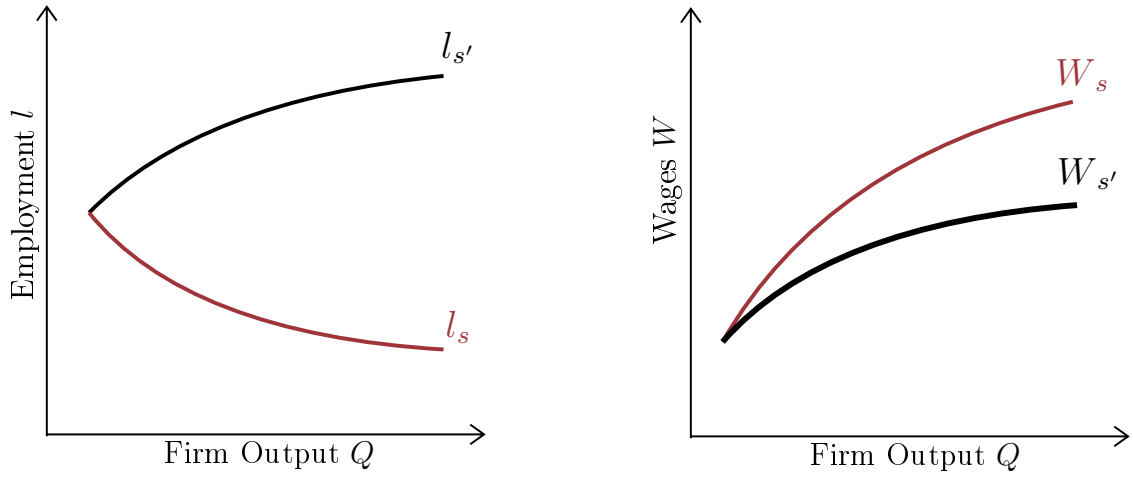
Figure 1.4: Workforce Composition and Firm Size

(a) The Role of Technology



Notes: This figure illustrates the model-implied relationship between employment, wages, and firm size when labor supply elasticities are equal across skill types. Worker types that are more complementary with firm scale are hired relatively more by larger firms and receive relatively higher wages at larger firms.

(b) The Role of Labor Supply



Notes: This figure illustrates the model-implied relationship between employment, wages, and firm size when labor supply elasticities differ across skill types. Workers that command larger rents (lower labor supply elasticities) are hired relatively less by larger firms, but receive higher relative wages at larger firms.

tary to scale increases in firm size. Relative wages paid by firms reflect differences in relative worker productivity only and, therefore, also increase in firm size.

Figure 1.4b focuses on the alternative case when the relationship between skill composition and firm size is driven only by the rent-sharing channel. Workers that command higher rents become increasingly expensive to larger firms, which reduces their employment shares.

1.3.5 Closing the Model

Thus far, the analysis took a firm's output as given. This subsection closes the model by characterizing firms' profit-maximizing choices of output, as well as the equilibrium conditions for market-clearing.

Profit-Maximization

Domestic and foreign demands, $Q_H(p;\varphi)$ and $Q_F(p;\varphi)$, at price p, are given by:

$$Q_H(p;\varphi) = \varphi^{\eta-1}p^{-\eta}P^{\eta-1}Y, \qquad Q_F(p;\varphi) = \varphi^{\eta-1}p^{-\eta}Y^*, \tag{1.13}$$

where Y denotes domestic consumption expenditures, P is the CES price index, and Y^* is the foreign demand shifter.

Firms choose whether to enter foreign export markets and how much to produce in order to maximize operating profits π:

$$\begin{aligned} \pi(\varphi_f, A_f) \;=\; & \max_{p_H,p_F,1_X} \{\{Q_H(p_H;\varphi)\} + 1_x Q_F(p_F;\varphi) - \mathcal{C}(Q_f, A_f) - 1_X F_X\} \\ & \text{s.t.} \quad Q_f = Q_H(p_H;\varphi) + \tau Q_F(p_F;\varphi) \end{aligned} \tag{1.14}$$

where p_H and p_F denote prices charged in the domestic and foreign markets. $\mathcal{C}(Q_f, A_f)$ denotes the total operating cost that solves the cost-minimization problem described in (1.11).

Optimal pricing implies that firms charge a constant mark-up over their marginal cost. In the domestic market, a firm therefore charges:

$$p_{H,f} = \frac{\eta}{\eta - 1} MC(Q_f, A_f). \tag{1.15}$$

The price of a firm exporting to market F is given by:

$$p_{F,f} = \tau \frac{\eta}{\eta - 1} MC(Q_f, A_f) \tag{1.16}$$

Marginal costs are non-constant and depend on the overall quantity produced. Hence, the decision to export affects the cost of production of the goods sold in the domestic market. In contrast to the standard model, an exporter chooses its overall output to maximize profits in all markets jointly.[15] Appendix 1.B.3 shows that marginal costs depend directly on output and are equal to a wedge $\mathcal{W}_f$ over average cost:

$$MC(Q_f, A_f) = \frac{\mathcal{C}(Q_f, A_f)}{Q_f} \left\{ \sum_s \omega(s, f) \frac{\beta_s + 1}{\beta_s} \frac{\varepsilon_s - \sigma}{1 - \sigma} \right\} \equiv \frac{\mathcal{C}(Q_f, A_f)}{Q_f} \mathcal{W}_f, \tag{1.17}$$

where $\omega(s, f) = W_{s,f} l_{s,f} / C(Q_f, A_f)$ denotes the wage bill share of skill group s. Appendix 1.B.3 derives sufficient parameteric restrictions that ensure convexity of costs in output.

[15] This is the case in any model featuring non-constant marginal costs of production (e.g. Caliendo and Rossi-Hansberg (2012a), Almunia et al. (2018)).

Operating profits $\pi(\varphi_f, A_f)$ are increasing in the demand shifter φ_f and increasing in firm amenities A_f. Exporting increases operating profits, and as a result, there is selection into exporting. The following proposition summarizes these properties.

Proposition 1.3. *Operating profits $\pi(\varphi, A)$ are (i) strictly concave in output Q, (ii) increasing in a firm's demand φ, and (iii) increasing in amenities A. Given expenditures and aggregate labor demands for all skill types, the partial equilibrium in product markets is unique.*

Proof. See appendix 1.B.3. □

Domestic expenditures

Fixed costs use a separate factor of production that is in perfectly elastic supply at a price that is normalized 1. Domestic expenditures Y equal the aggregate income from wages, profits, and fixed cost payments:[16]

$$Y = \sum_{s \in \mathcal{S}} \left[\int_{f \in \mathcal{F}} W_{s,f} l_{s,f} df \right] + \mathbf{F}_X + \int_{f \in \mathcal{F}} \pi(\varphi_f, A_F) df, \tag{1.18}$$

where $\mathbf{F}_X = \int_{f \in \mathcal{F}} 1_{X,f} F_X df$ denotes aggregate spending on fixed cost.[17]

Free Entry

Free entry implies that equilibrium expected profits for entrants equal the fixed cost of entry F_E. The free entry condition determining the equilibrium number of active

[16] I assume that the aggregate factor used for the production of fixed cost is owned by an anonymous agent that has the same CES preferences. An alternative assumption that would leave the distributional implications of the model for wages unchanged is to distribute ownership of this factor equally among skill types according to their relative measures (e.g., as in Fieler et al. (2018)). As the counterfactual trade-liberalization considered later leads to an increase in entry and exports, this alternative assumption implies larger, yet proportional, gains from trade for skill groups than the ones presented in the main text.

[17] Labor market clearing, $L_s = \int_{\mathcal{F}} l_{s,f} df$, is ensured by the fact that firms' optimal choices of wages need to be consistent with labor supply.

firms is given by:

$$F_E = \mathbb{E}_G \left[\pi \left(\varphi, A \right) \right]. \tag{1.19}$$

1.3.6 Pass-Through of Foreign Demand Shocks into Wages

Not all firms export, and therefore an aggregate change in foreign demand constitutes a heterogeneous demand shock across firms. To accommodate an idiosyncratic demand shock, a firm increases employment and therefore raises wages for all its employees. However, the rate at which a demand shock affects wages differs across worker types. In general, a change in trade costs has different effects on within-firm inequality for employers that expand, and for employers that contract, upon trade liberalization.

The following proposition considers the effect of a change in the variable trade cost τ to characterize the forces that shape the response of within-firm inequality to a change in a firm's output demand.

Proposition 1.4. *Consider a reduction in variable trade cost,* $d \log \tau < 0$.

1. *If* $\varepsilon_s = \varepsilon$ *and* $\beta_s = \beta$*, then within-firm inequality changes proportionally across all firms:*

2. *If* $\beta_s = \beta$ *and* $\varepsilon_s > \varepsilon_{s'}$ *, then* $\frac{d \log W_{s,f}}{d \log \tau} - \frac{d \log W_{s',f}}{d \log \tau}$ *is increasing in* $\frac{d \log Q_f}{d \log \tau}$.

3. *If* $\varepsilon_s = \varepsilon$ *and* $\beta_s < \beta_{s'}$ *then* $\frac{d \log W_{s,f}}{d \log \tau} - \frac{d \log W_{s',f}}{d \log \tau}$ *is increasing in* $\frac{d \log Q_f}{d \log \tau}$.

Proof. See Appendix 1.B.3. □

The first part of proposition 1.4 implies that idiosyncratic shocks to firm product demand have no direct effect on within-firm inequality between skill groups in the particular case where labor demand is homothetic, and labor supply functions are equally elastic for all skill types.

Statements 2. and 3. show that, in general, skill types whose relative productivity increases in output, or whose labor supply is less elastic receive relatively higher wages at firms that expand after trade liberalization.[18] As a result, a change in trade costs has heterogeneous effects on within-firm wage distributions across firms that trade, and those that do not.

1.3.7 Policy

Differences in scale create relative productivity differences for worker skill types across employers. In a competitive labor market, differences in skill composition across firms would only reflect differences in productivity. However, if labor supply curves are upward-sloping, and if their elasticities differ across types, the relative costs posed by rent sharing factor into firms' hiring decisions. Instead of hiring the most productive workers, given their scale, firms have an additional incentive to hire workers that demand lower rents. Therefore, hiring at the firm-level is distorted, relative to a competitive allocation, and there is misallocation in labor markets.

Simultaneously, upward-sloping labor supply curves raise marginal costs, consumer prices and therefore reduce the equilibrium scale at which firms operate:

$$MC\left(Q_f, A_f\right) = \frac{\mathcal{C}\left(Q_f, A_f\right)}{Q_f}\left\{\sum_s \omega\left(s, f\right)\frac{\beta_s + 1}{\beta_s}\frac{\varepsilon_s - \sigma}{1 - \sigma}\right\} \equiv \frac{\mathcal{C}\left(Q_f, A_f\right)}{Q_f}\mathcal{W}_f.$$

Upward-sloping labor supply curves increase the wedge between average and marginal cost, which, relative to an economy with competitive labor markets, reduces the average firm size, and increases the average share of profits in national income.[19]

[18] Through the lens of my model, heterogeneous pass-throughs of firm-specific demand and productivity shocks into wages across worker types, as documented by Cho and Krueger (2019) and Chan et al. (2019), thus can be rationalized through both labor demand or labor supply related channels.

[19] This effect is similar to the distortion caused by imperfect competition in product markets (e.g., Arkolakis et al. (2019)). Indeed, in both cases, firms operate at a higher profit to revenue ratio than in the respective perfectly competitive benchmark.

If labor supply elasticities differ across skill types, monopsonistic competition in labor markets also affects the relative sizes of firms and, therefore, the shape of the firm size distribution.

Therefore, the model leaves room for policy to improve upon the allocations in product and labor markets. The following proposition shows that under a specific set of employer wage subsidies, funded by proportional income taxes, wages are equal to compensating differentials.

Proposition 1.5. *An employer payroll subsidy* $\tau_s = \frac{1}{1+\beta_s}$*, funded by proportional wage income taxes, eliminates the monopsonistic wedges between marginal revenue products and wages.*

Proof. See appendix 1.B.3. □

An employer wage subsidy incentivizes employers to hire more workers and undoes the effect of rent-sharing concerns on relative hiring decisions between worker groups. To fund the subsidy, the government levies higher proportional taxes on skill groups that command larger rents. While the subsidy is not firm-specific by design, since firms differ in workforce composition, and allocate different wage bill shares to different workers, the subsidy is de-facto firm-specific.[20]

Assessing the net welfare consequences of such a tax reform from the perspective of workers requires weighing the potentially adverse welfare effects from labor income taxes against the welfare gains from improved allocations in product and labor markets.

[20]The logic is reminiscent of the literature in economic geography that argues that place-based hiring subsidies can help alleviate the adverse effects of hiring cost on unemployment (e.g., Kline and Moretti (2013)).

1.4 Estimation

In this section, I discuss my approach to estimating the relevant structural parameters of the model. I do so in two steps. First, I develop and implement a new strategy to identify non-homothetic CES production functions. I then calibrate the remaining parameters to match empirical moments in German manufacturing in the period 1993 to 2002.

1.4.1 Production Function Estimation

Challenges to Identification

The identification of the non-homothetic CES production function is subject to two challenges. A common approach to estimating a CES production function (e.g., Goldin and Katz (1996), Oberfield and Raval (2014)) is to estimate relative factor demand directly. Changes in relative labor demand between two skill types s and s' can be written as:

$$d\log\left(l_{s,f}/l_{s',f}\right) = -\sigma d\log\left(W_{s,f}/W_{s',f}\right) + \left(\varepsilon_s - \varepsilon_{s'}\right) d\log Q_f + \gamma_{s,s'f}, \tag{1.20}$$

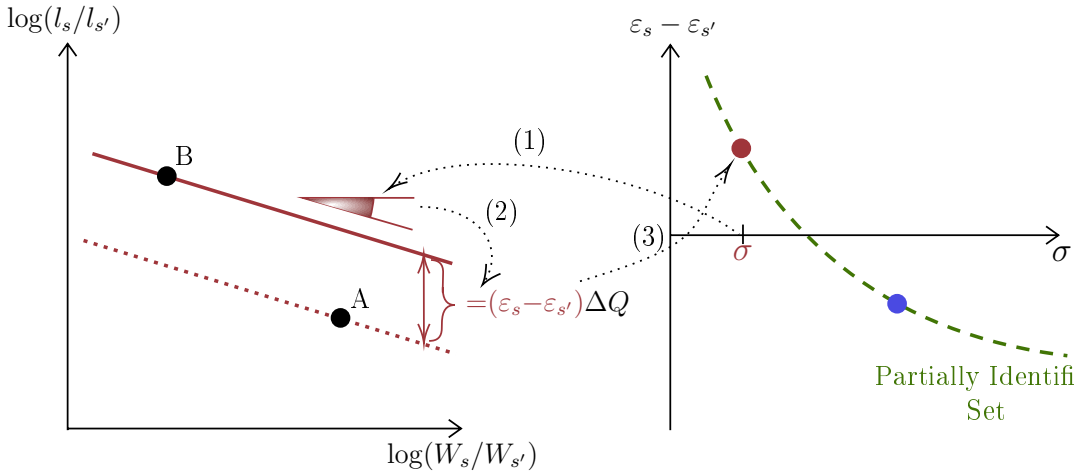
where $\gamma_{s,s',f} \equiv d\log\left(\Omega_{s,f}/\Omega_{s',f} \cdot \beta_{s,f}/\left(\beta_{s,f}+1\right) \cdot \left(\beta_{s',f}/\beta_{s',f}+1\right)\right)$ is an unobserved error. To illustrate potential sources of bias, I allow the elasticities of labor supply β_s and skill-specific technology shifters Ω_s to be firm-specific.[21]

The identification of the parameters ε_s and σ is subject to two independent challenges. First, output Q_f is endogenous to changes in unobserved changes in labor demand $\gamma_{s,s'f}$, irrespective of the assumptions placed on labor markets.[22] Second,

[21] In addition, this illustrates that the approach to estimating the production function does not depend on the particular microfoundation adopted to generate upward-sloping labor supply functions, so long as the elasticity of labor supply faced by an individual firm is exogenous.

[22] This threat arises for any production function that is not separable in all inputs.

Figure 1.5: Identification Through Exogenous Changes in Wages, Employment and Output



*Notes:*This figure illustrates the logic of the identification argument. The left figure considers a change in observed labor demand and wages from point A to point B. The right figure illustrates the space spanned by the elasticity of substitution σ and relative output scale elasticities $\varepsilon_s - \varepsilon_{s'}$.

upward-sloping labor supply curves introduce simultaneity bias, and shifts in relative labor demand need to be separately identified from shifts in relative labor supply. Thus, both simultaneity, as well as potentially unobserved changes in labor demand, pose a threat to identification.

To deal with these challenges, I propose an estimation strategy that combines one instrumental variable for partial identification with variation across labor markets for full identification of the structural parameters of interest. I proceed by illustrating the idea of partial identification by way of a graphical argument, followed by a formal derivation.

Identification Strategy

Informal Graphical Argument The central insight of the argument is that changes in wages, employment, and output in response to a shock that is exogenous to unobserved changes in labor demand can provide partial identification of the elasticities of labor demand. Figure 1.5 illustrates the underlying logic of the argument.

The left graph in Figure 1.5 shows changes in wages and employment from point A to point B. Assuming a value for the elasticity of substitution σ, two lines with slope $-\sigma$ through points A and B recover the old and new labor demand. This, in turn, allows computing by how much labor demand has shifted vertically. Given that the initial shift from A to B is assumed to be independent of unobservable shocks to labor demand, equation (1.20) implies that the vertical shift equals the non-homothetic effects of output on labor demand, $(\varepsilon_s - \varepsilon_{s'})\Delta Q$. Since one observes changes in output, and given an assumed elasticity of substitution σ, one can compute a unique $(\varepsilon_s - \varepsilon_{s'})$ that rationalizes the observed changes.

Repeating this procedure over alternative guesses for the elasticity of substitution, one can compute a set of parameters that are consistent with the observed changes. If one can observe another change similar to the one from A to B depicted in Figure 1.5 (for example, in another regional labor market or another period in time), one can construct another set of partially identified parameters. If these hyperbolae, in turn, do neither lie on top of each other nor intersect - and production technologies are invariant across regions/time - their intersection recovers both σ and $(\varepsilon_s - \varepsilon_{s'})$.

Formal Argument The formal argument follows the same logic as the graphical one. First, I use changes in wages, employment, and output in response to an identifying shock for partial identification of the structural parameters. I then formalize the conditions, under which cross-regional variation provides full identification of the labor demand elasticities.

Denote $l_{s,s',f,t} \equiv \log l_{s,f,t}/l_{s',f,t}$ and $w_{s,s',f,t} = \log\left(W_{s,f,t}/W_{s',f,t}\right)$ and $q_{f,t} = \log Q_{f,t}$. Letting $dx_t = x_{t+1} - x_t$, changes in labor demand between skill types s and s' between periods t and $t+1$ are given by:

$$dl_{s,s',f,t} = -\sigma d\left(w_{s,s',f,t}\right) + \left(\varepsilon_s - \varepsilon_{s'}\right) dq_{f,t} + \gamma_{s,s',f,t}, \tag{1.21}$$

where $\gamma_{s,s',f,t}$ is the unobserved structural shock to labor demand. The covariance between observed changes in relative labor demand and an empirical shock $\xi_{f,t}$ - that is assumed to be orthogonal to changes in the error $\omega_{s,s',f,t}$ - across firms f equals:

$$\text{Cov}\left(dl_{s,s',f,t}, d\xi_{f,t}\right) = -\sigma \text{Cov}\left(dw_{s,s',f,t}, d\xi_{f,t}\right) + \left(\varepsilon_s - \varepsilon_{s'}\right) \text{Cov}\left(dq_{f,t}, d\xi_{f,t}\right) + \text{Cov}\left(d\gamma_{s,s',f,t}, d\xi_{f,t}\right). \tag{1.22}$$

Provided that $\xi_{f,t}$ is correlated with changes in relative employment levels, one can derive the following restriction on the technological parameters:

$$1 = \phi \frac{\text{Cov}\left(dw_{s,s',f,t}, d\xi_{f,t}\right)}{\text{Cov}\left(dl_{s,s',f,t}, d\xi_{f,t}\right)} + \theta_s \frac{\text{Cov}\left(dq_{f,t}, d\log\xi_{f,t}\right)}{\text{Cov}\left(dl_{s,s',f,t}, d\log\xi_{f,t}\right)} + \nu_{s,s',t}, \tag{1.23}$$

where $\phi \equiv -\sigma$, $\theta_s \equiv \varepsilon_s - \varepsilon_{s'}$ and $\nu_{s,s',t}$ is an error given by:

$$\nu_{s,s',t} \equiv \frac{\text{Cov}\left(d\gamma_{s,s',f,t}, d\xi_{f,t}\right)}{\text{Cov}\left(dl_{s,s',f,t}, d\xi_{f,t}\right)}.$$

Stacked for all skill groups, equation (1.23) defines a set of moment conditions that provide partial identification of the structural parameters:

$$\mathcal{G}\left(\Theta\right) = \mathbf{0}, \tag{1.24}$$

where $\mathcal{G}\left(\Theta\right) \equiv \left(\phi \frac{\text{Cov}\left(dw_{s,s',f,t}, d\xi_{f,t}\right)}{\text{Cov}\left(dl_{s,s',f,t}, d\xi_{f,t}\right)} + \theta_s \frac{\text{Cov}\left(dq_{f,t}, d\xi_{f,t}\right)}{\text{Cov}\left(dl_{s,s',f,t}, d\xi_{f,t}\right)} + \nu_{s,s',t} - 1\right)_{s \in \mathcal{S} \setminus s'}$.

To see why this provides partial identification, first, note that the covariance ratios are computable by way of two-stage regressions. $\text{Cov}\left(dq_{f,t}, d\xi_{f,t}\right) / \text{Cov}\left(dl_{s,s',f,t}, d\xi_{f,t}\right)$, for example, is the coefficient estimate of a two-stage regression that first regresses changes in employment on changes in $\xi_{f,t}$, and then regresses the fitted values for employment on changes in output. Given an empirical shock $\xi_{f,t}$, these quantities can, therefore, be computed using observed changes in wages, employment, and output of firms. As changes in $\xi_{f,t}$ are assumed to be uncorrelated with the unobserved error, the

term $\nu_{s,s',t}$ is equal to zero.[23] Therefore, equation (1.23) provides partial identification of the parameters.[24]

Given observed changes in separate regional labor markets r, one can compute sets of analogous moment conditions $\mathcal{G}_r(\Theta)$ for each labor market r. The estimator of the technological parameters is given by:

$$\Theta^* = \arg\min_{\Theta} \boldsymbol{\mathcal{G}}(\Theta)' W \boldsymbol{\mathcal{G}}(\Theta), \tag{1.25}$$

where $\boldsymbol{G}(\Theta) \equiv [\mathcal{G}_r(\Theta)]_r$ collects moment conditions across regions, and W is a weighting matrix.

Θ^* identifies Θ under three conditions. First, changes in $\xi_{f,t}$ need to be correlated with firm-level wages, employment, and output (relevance). Second, changes in $\xi_{f,t}$ need to be uncorrelated with changes in unobserved sources of heterogeneity in labor demand across firms (orthogonality). These conditions ensure that for each region, $\mathcal{G}_r(\Theta)$ provides partial identification of Θ.[25] Further, full identification requires that the hyperbolae computed across different regions do not lie on top of each other. A sufficient requirement for full identification is that for worker groups s and s' and regions r and r' :

$$\frac{\mathrm{Cov}_r(dl_{s,s',f,t}, d\xi_{f,t})}{\mathrm{Cov}_r(dq_{f,t}, d\xi_{f,t})} \neq \frac{\mathrm{Cov}_{r'}(dl_{s,s',f,t}, d\xi_{f,t})}{\mathrm{Cov}_{r'}(dq_{f,t}, d\xi_{f,t})}. \tag{1.26}$$

The condition stated in equation (1.26) is reminiscent of heteroskedasticity based conditions for partial identification in Leamer (1981) and Feenstra (1994). Appendix 1.D.1 provides a more detailed discussion of this identifying assumption and argues

[23] Formally, the probability limit taken with respect to firms f equals zero: $p\lim_{f\to\infty} \nu_{s,s',t} = 0$.

[24] Note that these steps are conceptually equivalent to the logic underlying Figure 1.5.

[25] For example, idiosyncratic shocks to firms' product demands satisfy these conditions. However, these shocks would not satisfy this condition if the elasticity of the labor supply faced by individual firms were endogenous to, say, the size of the firm. Appendix 1.D.1 gives more details on how to augment the approach to partial identification in this case.

that it holds in the empirical application if for example the share of exporting firms differs across regions.

The estimator defined in equation (1.25) fits in the class of Classical Minimum Distance estimators. Appendix 1.D derives its asymptotic distribution that is later used to construct standard errors.

Implementation To obtain identifying shocks that affect firm-level wages, output and employment, and are not systematically correlated with unobserved shocks to labor demand, I construct Bartik-type (Bartik (1991)) firm-level shocks to output demand that are a variant of firm-level export shocks constructed in earlier papers (Hummels et al. (2014), Berman et al. (2015), Caliendo et al. (2017), Garin and Silvero (2018)).

The Bartik instrument generates exogenous variation in product demand between otherwise similar firms that is based on *where* rather than *which* products a firm is selling. To define the instrument, let $EXP_{s,t}^{GER \to c}$ denote the aggregate exports of the German manufacturing sector s to country c. For each firm observed in the data, let t_0 denote the year where the firm was first observed exporting, if at all. Denoting the sales share of firm f in region r at time t_0 by ω_{f,r,t_0}, the firm-level demand shock for time $t > t_0$ is defined as:

$$D_{f,t} = \sum_r \omega_{f,r,t_0} EXP_{s,t}^{GER \to c}. \tag{1.27}$$

As pointed out in Garin and Silvero (2018), even though the shock $D_{f,t}$ is firm-level in construction, it may nonetheless contain demand variation that also affects other firms that sell similar products to firm f. However, in this case, so long as $D_{f,t}$ does vary across firms and is exogenous to unobserved changes in labor demand, it identifies the parameters of interest.

Identification requires that $D_{f,t}$ is not systematically correlated with unobserved firm-level changes that affect labor demand between worker types - such as factor-biased technological change. Recent literature points out that exogeneity in Bartik instruments can stem from two sources. Borusyak et al. (2018) or Adao et al. (2018) argue that variation in changes in export demand across sufficiently many regions alone can be sufficient to generate asymptotically consistent estimates. Goldsmith-Pinkham et al. (2018), on the other hand, point out that exogeneity in the "shift shares" alone can also sufficient to yield consistent parameter estimates.

I observe firm-level export shares of firms across most three regions.[26] Therefore, I augment the standard Bartik instrument with an estimated exogenous probability of exporting. I fit a probit model that projects a firm's current exporter status on its lagged exporter status, its past position in the domestic sales distribution as well as a dummy for whether it is located in a formerly East German state. Denoting $p^X_{f,t}$ the resulting estimated probability that firm f exports in year t, the empirical demand shifter $\xi_{f,t}$ is defined as:

$$\xi_{f,t} = p^X_{f,t} D_{f,t}. \tag{1.28}$$

I implement the estimation strategy for three skill groups. I refer to these groups as high skill, medium skill, and low skill, respectively, for the remainder of the chapter. High skill workers are those in jobs that pay on average more than the 70th percentile of jobs in their sector, while the jobs of low skill workers fall into the bottom three percentiles. Firm size Q is measured by value-added. To estimate a medium-term production function, I use changes across all available lags.

Results Individual moments used in the minimum distance estimator are shown in Table 1.13. The coefficient estimates and standard errors are displayed in Table 1.1.

[26] The firm survey, in most years, provides only export shares to the rest of the world. For selected years, export shares to Eastern Europe and the Euro area are also featured in the data.

Table 1.1: Estimates of Technology Parameters

Description	Parameter	Estimate	Standard Error
Elasticity of Substitution	σ	1.92	0.45
Scale Complementarity	$\varepsilon_{\mathrm{H}} - \varepsilon_{\mathrm{M}}$	0.31	0.21
	$\varepsilon_{L} - \varepsilon_{\mathrm{M}}$	-0.40	0.09
Observations	122,842		

Notes: This table presents the parameter estimates of the non-homothetic CES production function. H, M, L denote high, medium, and low skill workers, respectively. Estimates are obtained by implementing the estimation strategy outlined in Section 1.4.1. The construction of the standard errors is detailed in Appendix 1.D. The sample includes all manufacturing firms in the Linked-Employer-Employee Data longitudinal model 1993 - 2014 from the Institute for Employment Research (IAB), and differences are estimated across all available lags.

I estimate that worker groups are gross substitutes with an elasticity of substitution equal to $\sigma = 1.92$. High skill types H have the highest scale elasticity, while low skill workers are least complementary with firm scale.

These estimates qualitatively rationalize the sorting patterns displayed in Section 1.2 as being driven in part by non-homotheticities in production. Thus, the estimates imply that trade liberalization will tend to shift labor demand towards more high skill worker types.

1.4.2 Calibration of the Remaining Structural Parameters

Parameters & Simulation

Table 1.2 summarizes the parameters that require estimation. I normalize the total labor force of the Home economy and choose the total stock for each skill group s to reflect the distribution of types in the data. The elasticity of substitution across goods - η - is set to 5 from Broda and Weinstein (2006). I parameterize the underlying distribution of firm heterogeneity in demand shifters and amenities by a multivariate log-normal distribution.

Table 1.2: List of Parameters

Description	Parameterization	Parameter
Firm Heterogeneity	$(\varphi, A) \sim MV\log - \text{normal}$	$\boldsymbol{\mu}, \boldsymbol{\Sigma}$
Labor Supply Elasticity		β_s
Shifters in Productions		Ω_s
Size of the Foreign Market		Y^*
Domestic Price of Foreign Varities		P^*
Fixed Cost		F_X, F_E

Note: Parameters not estimated: $\eta = 5$, L_s for all worker groups s, $\varepsilon_2 = 0.6$, $\tau = 1.3$.

To solve the model for a given set of parameters, I discretize the joint distribution of demand shifters φ and amenities A. Here, I sketch the solution algorithm, and Appendix 1.D provides further details.

The initial step is to guess the equilibrium number of firms that choose to enter. Upon entering, firms learn about φ and A and maximize profits taking aggregate equilibrium outcomes - the price index, aggregate labor demand, and expenditure - as given. Hiring and wage decisions depend on a firm's output, which, in turn, affects marginal cost and, therefore, prices and demand. Taken aggregates as given, firms' profit-maximizing choices of scale, wages, and hiring can be solved for as a fixed point.

The optimal pricing decisions of firms yield marginal costs, which aggregate to the domestic price index P. The individual employment decisions of firms on the other labor demand aggregate to labor demand Λ_s for each worker type. Therefore, both the price index and aggregate labor demand solve fixed points.

Optimal firm choices that are consistent with aggregate prices and labor market clearing provide firm-level wages and profits. Wages and profits across firms aggregate to domestic expenditure Y. The algorithm iterates over updated guesses for expenditure Y until convergence.

The final step is to derive expected profits, which updates the mass of entering firms. For a new guess for the number of entering firms, I return to the initial step

Table 1.3: Targeted Moments and Associated Parameters

Description	Parameters	Moments
Firm Heterogeneity	$\boldsymbol{\mu}, \boldsymbol{\Sigma}$	Sales distribution
		CoV $(\log W_f, \log l_f)$
		Residual Inequality (levels)
Labor Supply Elasticitiy	β_s	Residual Inequality (relative)
		Firm Wage Premia
Shifters in Productions	Ω_s	Mean Skill Wage Premium
Foreign Demand Shifter	Y^*	Export share
Price of Foreign Varities	P^*	Import Share in GDP
Fixed Cost	F_E	Mass of firms,
	F_X	Share of exporters

Notes: This table provides an overview of the empirical moments used for the calibration of the model.

and re-calculate optimal firm choices that are consistent with product market clearing and labor market clearing. This procedure is repeated until convergence.

Targeted Moments

Table 1.3 presents the list of moments targeted in the estimation.[27] For guidance, the second column of Table 1.3 lists parameters and their associated target moments. I briefly elaborate on the underlying logic for key parameters.

β_s affects the firm-level elasticity of wages with respect to sales, as shown in Proposition 1.2. For a given distribution of firm sales, the level of β_s affects the aggregate dispersion of wages within worker group s. Therefore differences in wage dispersion between worker groups as well as the relation between firm sales and wages are directly informative about β_s.

The parameters of the variance-covariance matrix $\boldsymbol{\Sigma}$ are associated with the distribution of sales, the level of wage dispersion, and the covariance between wages and employment at the firm level. A higher (lower) covariance between demand shifters

[27] Appendix 1.A.2 details the construction of the empirical moments.

and amenities weakens (strengthens) the correlation between wages and employment along the firm sales distribution in the model. I include the correlation between wages and employment across all firms, as well as those in the top quintile of the sales distribution, as targets in the estimation.

The productivity shifters Ω_s affect the relative technological advantage and therefore mean differences in log-wages between worker types. For the estimation, I normalize $\Omega_2 = 1$.

The identification of the parameters related to international trade is standard. An increase in the fixed cost of exporting F_X weakly decreases the share of firms that find it profitable to export. Exporting fixed cost F_X thus govern the share of exporting firms. The (relative) size of the foreign market Y^* governs the export share of exporting plants. Export shares in the structural model are constant and given by $\frac{P_F Q_F}{P_H Q_H} = \tau^{1-\eta} Y^* / \left(P^{\eta-1} Y\right)$. The export share in sales across exporting firms informs Y^*. The structural expression for domestic spending on foreign relative to home goods is given by $\left(\frac{P^*}{P}\right)^{1-\eta}$. P^* directly affects domestic consumption shares. Reductions in P^* increase domestic competition from abroad and tend to increase consumer spending on foreign varieties.

Parameter Estimates and Model Fit Table 1.4 presents the calibrated parameters. Labor supply elasticities β_s are estimated to vary across skill groups, and the model assigns lower labor supply elasticities to skill types that display higher levels of within-group wage inequality in the data. The estimates imply that low skill workers receive a mark-down of 13 percent on their marginal revenue product. High skill workers, in turn, receive a mark-down of 20 percent. Equivalently, the estimates imply that workers in group 1 would be willing to sacrifice 13 percent of their earnings to remain employed at their current firm. Conversely, high wage worker types would be willing to sacrifice 20 percent of their earnings to keep their current job. The

Table 1.4: Calibrated Parameters

Parameter	Estimate	Parameter	Estimate
β_{L}	6.9	Ω_{L}	0.14
β_{M}	5.5	Ω_{M}	1
β_{H}	3.9	Ω_{H}	1.75
μ_{φ}	0.03	F_E	0.002
μ_A	0	F_X	0.004
σ^2_{φ}	2.3	P^*	0.005
σ^2_A	0.10	Y^* $(\times 10^{-6})$	1.3
$\sigma_{A\varphi}$	0.08		

Notes: This table presents the calibrated parameters. β_s is the elasticity of labor supply for skill group s. H, M, L denotes high, medium, and low skill, respectively. μ_{φ} and μ_A are means of the multivariate log Normal that parameterizes the underlying distribution of demand shifters φ and amenities A. σ^2_{φ} is the variance of demand shifters, σ^2_a is the variance of amenities and $\sigma_{a\varphi}$ is the covariance between amenities and demand shifters. Parameters Ω are technological productivity shifters. F_X and F_E denote the fixed cost of exporting and entry, respectively.

estimated labor supply elasticities are similar in magnitude to estimates from studies that rely on similar models of the labor market (Lamadon et al. (2019), Haanwinckel (2018)).

The estimated parameters of the distribution of firm heterogeneity implies that amenities are moderately positively correlated with demand shifters. The parameters related to international trade - fixed cost of exporting, foreign prices, and foreign demand shifters - compare closely to similar models.[28]

To assess the model fit, Table 1.5 displays empirical targets and the associated simulated moments. Overall, the model manages to fit the targeted moments well. The model adequately captures relative wages at different percentiles of worker-group specific distributions and relative mean wages between groups, as well as the targeted moments related to international trade.

[28]Note that Y^* corresponds to the foreign demand shifter and is not equal to foreign relative income, but also includes information on the foreign price index.

Table 1.5: Model Fit

Moment	Model	Data	Moment	Model	Data
Wage Inequallity Within Skill Types			Sales Distr.		
$sd(\log W)$			p25-p10 (logs)	0.76	0.63
Low	0.27	0.27	p50-p10	1.51	1.39
Medium	0.28	0.29	p75-p10	2.51	2.47
High	0.34	0.34	p90-p10	3.52	3.7
$50-10$ ratio (log)			Trade		
Low	0.34	0.37	Exporter Share	0.18	0.18
Medium	0.37	0.41	Export Share Sales	0.22	0.22
High	0.48	0.50	Import Share	0.26	0.26
$90-10$ ratio (logs)			$\log W = \alpha + \gamma_s \log Rev$		
Low	0.70	0.69	γ_L	0.02	0.02
Medium	0.72	0.73	γ_M	0.04	0.03
High	0.88	0.87	γ_H	0.08	0.05
Mean Wage Differences			Corr($\log W$, $\log L$)		
Low to Medium	-0.14	-0.13	Sample	0.16	0.19
High to Medium	0.26	0.27	p80 Sales	0.04	0.07

Notes: This table presents simulated targeted moments and their empirical counterparts. H, M, and L denotes high, medium, and low skill, respectively. Empirical moments capture manufacturing firms and are calculated for the period 1993-2002.

The largest mismatch between empirical and simulated moments occurs in the domestic sales distribution. This, in part, may reflect that a log-normal distribution is only partially suited to fit the entire distribution of firm sales (see, for example, Nigai (2017)).

To check for over-identification, I now assess the model's implications for moments that were not directly targeted by the calibration procedure.

Model Fit for Non-Targeted Moments

Employment Distribution The parameters of the production function are directly estimated from firm-level responses in employment and wages to demand shocks. Therefore, the overall distribution of workers along the firm size distribution was not directly targeted. Figure 1.7 plots the simulated and empirical distribution of workers along the quintiles of the firm sales distribution. The model adequately captures that the employment share of high skilled workers is increasing, while that of low skill workers is decreasing along the firm size distribution.

Within-Firm Inequality The estimation procedure did not explicitly target the relationship between firm sales and within-firm inequality. I test the model's ability to account for this fact by comparing the relationship between within-firm wage dispersion to firm revenues in the simulated model to the empirical relationship in the data. Further, high skill worker types are paid relatively more than their coworkers in larger firms. I also test this prediction using the data simulated by the model.

Table 1.14 compares the model generated regression coefficients to their empirical counterparts. The model adequately accounts for the empirical relationship between within-firm wage dispersion and revenues. While it qualitatively fits the relationship between wage differentials within the firm and firm sales, the effect of firm sales on the relative wages of high skilled workers is larger than in the data, albeit it is only off by a small margin.

Wage distributions for exporting and non-exporting firms Demand shifters φ are the primary predictor of exporting decisions. However, firms of different sizes pay different wages due to heterogeneity in amenities. As opposed to models with a single dimension of firm heterogeneity, some domestic firms, therefore, pay

higher wages than exporting firms. This is an important feature of empirical wage distributions.

Figure 1.8 displays simulated kernel density plots of log wages across domestic and exporting firms. Consistent with the data, wages paid by domestic firms generally more dispersed. While exporting firms on average pay a wage premium, high skill workers receive higher firm-exporter wage premia, mirroring the fact that firm scale has unequal effects on wages by skill group.

1.5 Trade and Policy Counterfactual

I now come to the primary concern of my analysis: How does trade affect the distribution of wages, within and between firms, and within and between skill groups? Wage inequality in German manufacturing, as measured by the variance of log earnings, has increased by 19% from 1993-2002 to 2002-2014. Simultaneously, the transformation of former socialist countries in Eastern Europe, and the integration of China into the world economy led to new trade opportunities.[29] In this section, I use the estimated model to study how trade shocks have contributed to the observed increase in wage inequality. I then evaluate the effect of a tax intervention that was theoretically derived in Proposition 1.5, and that aims to improve equilibrium allocations in trade and product markets.

1.5.1 The Distributional Consequences of Trade

Changes in German Trade Participation

Between the 1990s and the first decade of the 2000s, Germany increased its trade participation significantly, which reflects both the expansion into new Eastern markets

[29]For an analyis of the reduced-form effects of these events on German labor markets, see Dauth et al. (2018, 2014, 2017).

Table 1.6: Empirical Changes in Trade Related Moments

	1993-2002	2003-2014	Change
Share of Exporting Firms	0.18	0.25	+7 p.p.
Firm Export Share in Sales	0.24	0.29	+5 p.p.
Import Share in GDP	0.25	0.36	+11 p.p.

Notes: This table displays empirical changes in trade-related moments. p.p. denotes percentage points. The share of exporting firms and the export share in sales in manufacturing firms are calculated from the IAB firm panel. Average import shares are taken from the World Bank's World Development Indicators.

in Europe as well as the entry of China into the World Trade Organization. Table 1.6 shows that the share of exporters has increased by 40 percent during the two periods. The average foreign sales share among exporters in turn increased by 25 percent, while the aggregate import share has increased by 35 percent.

For the counterfactual analysis, I consider changes in variable exporting trade cost τ (-11 percent), fixed cost of exporting F_X (-9 percent), and the foreign price index P^* (-15 percent), which match the empirical changes displayed in Table 1.6.

Counterfactual Effect of Trade on the Distribution of Earnings

The counterfactual exercises indicate that trade had a sizeable effect on overall wage inequality. Table 1.6 shows that overall wage inequality increases by 4.2 percent, which accounts for 22 percent of the overall 19 percent increase in wage inequality in the data.

The majority of studies focusing on the effect of international trade on residual inequality abstract from within-firm inequality (e.g., Helpman et al. (2017), Egger et al. (2013) and Amiti and Davis (2012)). Table 1.6 shows that within-firm inequality accounts for one third of the total counterfactual distributional changes.[30] The last column of Table 1.6 shows that 16 percent of the overall counterfactual change in

[30]Here, I use the fact that the aggregate variation in wages can be decomposed as: $\text{Var}\left(\log W_{s,f}\right) = \text{Var}\left(\log W_{s,f} - \log \overline{W}_f\right) + \text{Var}\left(\log \overline{W}_f\right)$,where $\overline{W}_f$ denotes the mean wage paid by employer f.

Table 1.7: Counterfactual Effect of Trade on Aggregate Earnings Inequality

Overall Change		%
Aggregate Inequality	$\text{VAR}(\log W_{f,s})$	+4.2
Decomposition		% of total
Within Firm Inequality	$\text{VAR}\left(\log W_{f,s} - \log \overline{W}_f\right)$	34
Between Firm Inequality	$\text{VAR}\left(\log \overline{W}_f\right)$	66
Heterogeneous Skill Wage Premia	$\text{VAR}\left(\log \overline{W}_{f,s} - \log \overline{W}_f - \log \overline{W}_s\right)$	16

Notes: This table displays the simulated counterfactual effect of trade on wage inequality. $\log \overline{W}_f$ denotes mean log wages of firm f. $\log \overline{W}_s$ denotes mean log wages across all workers belonging to skill group s.

inequality is due to heterogeneous changes in firm wage premia between worker groups, indicating that both a worker's employer, as well as his type, are important determinants of his wage exposure to international trade.

Table 1.15 provides a more detailed overview of the counterfactual effects on wage inequality. Counterfactual changes imply that trade explains about a third of the observed increase in average wages between groups. This reflects that aggregate labor demand shifts toward workers in high wage worker groups as firms increase their scale in response to the export demand shock.

Table 1.15 further shows that trade has the largest effect on wage inequality within high skill workers. The standard deviation of wages within high skill workers increases by 2.8 percent, while the data shows an increase of 14 percent for the same period. This, in turn, is partly driven by the fact that between-firm inequality within high skill workers is rising, as indicated by the increase in the 90-10 pay ratio. In comparison, counterfactual wage inequality within low skill workers in group 1 increases by 1.4 percent, compared with an empirical increase of 7 percent in the data.

1.5.2 Policy Counterfactual

The parameter estimates imply that labor market sorting is inefficient in equilibrium. As a consequence, the gains from trade might be affected by inefficiencies in the

Table 1.8: Optimal Tax Reform

Skill Group	Payroll subsidy/Income Tax	
	Theory	Implementation
Low		13%
Medium	$\frac{1}{1+\beta_s}$	15%
High		20%

*Notes:*This table displays the set of income taxes that, according to 1.5, restores the Walrasian equilibrium allocation in labor and product markets. In the Walrasian equilibrium, workers earn their marginal revenue product of labor, rather than a monopsonistic mark-down on their marginal revenue product.

labor market and product market outcomes. Proposition 1.5 implies that the size of these losses can be quantified by implementing an optimal tax reform to reevaluate the same trade counterfactual. Table 1.8 displays the set of correcting proportional taxes. The correcting taxes are progressive in skill: Since the labor supply of skilled workers is less elastic, incentivizing the best firms to hire more such workers requires larger wage-bill subsidies. As discussed previously, the net welfare effects of the tax reform depends on allocative gains in labor and product markets and direct losses in labor income stemming from taxation.

The model-implied changes in welfare, relative to the initial counterfactual trade equilibrium, are displayed in Table 1.9. The results suggest that imperfect competition in labor markets creates significant distortions that undermine the gains from trade for workers. Relative to the trade counterfactual, the tax reform increases worker welfare on average by 6 percent. The gains associated with improved market allocations, therefore, outweigh potential wage losses stemming from taxation.

The remaining columns in Table 1.9 give further insights into the channels through which these gains materialize. Relative to the initial counterfactual allocation, the tax reform reduces the profit share in income by 17 percent. The tax reform redistributes national income from firms to workers, which reflects that firms produce at more

Table 1.9: Effect of a Tax Reform on Counterfactual Changes from Trade

Outcome		Change to Trade Counterfactual (%)
Worker Welfare	$\mathbb{E}\log U$	
Low Skill		+7
Medium Skill		+6
High Skill		+5
Profit Share of Income	Π/Y	-17
Share of Exporting Firms		+3
Overall Wage Inequality	$\text{Var}(\log W_s)$	-0.3
Within Group Inequality	$sd(\log W_s)$	
Low Skill		-0.5
Medium Skill		-0.3
High Skill		-0.3
Between Group Inequality	$\log \overline{W}_s/\overline{W}_2$	
Low to Medium Skill		+0.4
High to Low Skill		+0.1

Notes: This table shows THE percentage change in the estimated effect of a tax reform relative to the trade counterfactual. $\log \overline{W}_s$ denotes mean log wages across all workers belonging to group s.

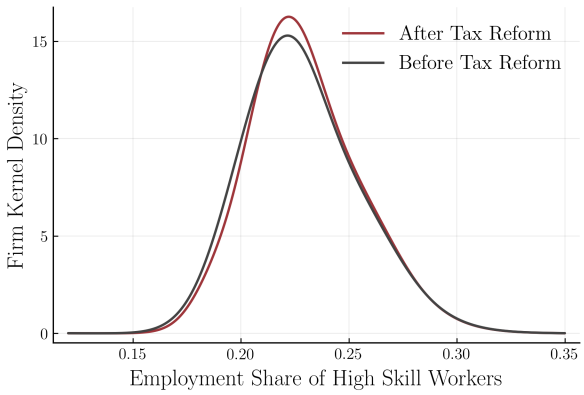
efficient scale. The ratio of variable profits to total wage cost of a (domestic) firm before the tax reform is given by:

$$\frac{P_f Q_f - C_f}{C_f} = \left(1 - \frac{\eta - 1}{\eta} \cdot \frac{1}{\mathcal{W}_f}\right), \tag{1.29}$$

where $\mathcal{W}_f = \sum_s \omega_{s,f} \left(\frac{\beta_s + 1}{\beta_s} \cdot \frac{\varepsilon_s - \sigma}{1 - \sigma}\right)$ is the previously defined wedge between average and marginal cost. After the tax reform, this wedge reduces to $\widetilde{\mathcal{W}}_f = \sum_s \omega_{s,f} \left(\frac{\varepsilon_s - \sigma}{1 - \sigma}\right)$. The tax reform, therefore, increases the gains from trade for workers by reallocating profits from workers to firms.

The tax reform also increases the share of exporting firms. The exercise thus illustrates that imperfect competition in labor markets reduces the gains from trade

Figure 1.6: Tax Induced Reallocation of High Skill Workers



Notes: This figure displays simulated kernel density plots of firm-level employment shares of high skilled workers after trade liberalization. Blue indicates the employment shares before the tax reform, while red indicates employment shares after the tax reform.

through an extensive margin by reducing the number of firms that reach sufficient scale to find it profitable to export.

The effects of the tax reform on labor market allocations reduce wage dispersion within groups. Within-group inequality decreases for all groups under the tax reform. Relative to the initial increase in inequality induced by trade, the tax reform decreases within-group inequality on average by 20 percent across worker groups.

Between groups, wage inequality increases. This reflects that the sorting of high skilled workers to large firms strengthens, which is illustrated in Figure 1.6 After the tax, mass in the distribution of the employment share of skilled workers across firms shifts from the left-tail into newly exporting firms.

In sum, wage inequality decreases after the tax reform, implying that the increase in aggregate skill premia is offset by a more than proportional decrease in within-group inequality.

To summarize, the results imply that imperfect competition in labor markets affects the gains from trade for workers through at least three channels: The allocation

of national income to profits and wages, the share of firms that export, and the sorting of workers to firms.

1.6 Conclusion

The distributional consequences of trade liberalization is one of the most hotly-debated issues of our time. In this chapter, I outline a hitherto neglected mechanism through which international trade affects wage inequality. The key to this theoretical mechanism is that larger firms pay higher wages and have higher employment for more skilled workers, which induces wage inequality between firms for a given worker type, and wage inequality within firms between worker types. As international trade costs fall, more productive firms expand as they enter export markets, while less productive firms contract in the domestic market, which increases the dispersion in employment across firms. As contracting firms reduce their relative wage and employment for more skilled workers, and expanding firms increase their relative wages and employment for more skilled workers, this increases overall wage inequality through both higher between and within-firm wage inequality.

To provide microfoundations for the observed differences in relative wages and employment across firms of different sizes, I develop a theoretical model in which firms operate a non-homothetic production technology and face an upward-sloping labor supply function for each type of worker. The non-homotheticity in production implies that firms of different sizes have different relative productivities and relative demands for workers with different skills. Combining these differences in relative demand for more and less-skilled workers with an upward-sloping supply function for each type of worker induces the positive comovement between relative wages and relative employment across firms of different sizes.

To quantify the importance of this mechanism for the distributional consequences of trade liberalization, I structurally estimate the model using matched employer-employee data and a new method that separately identifies the elasticities of labor demand and labor supply. I show that the estimated model can account for the reduced-form patterns in the data not only qualitatively, but also quantitatively. I show that the model is successful in matching both targeted and non-targeted moments, including the observed patterns of wage inequality both between and within firms.

In counterfactuals, I show that this new mechanism is quantitatively relevant for understanding the impact of trade on wage inequality. The changes in trade costs implied by the observed data raise overall wage inequality by 4.2 percent, which corresponds to 22 percent of the overall increase in wage inequality in Germany during my sample period. I find that the imperfect competition introduced into the labor market by upward-sloping labor supply curves leads to quantitatively relevant distortions in the allocations of skilled and unskilled workers across firms of different sizes. Implementing the optimal tax scheme to eliminate these distortions, decreases wage inequality within skill groups by 20 percent, raises worker welfare by 6 percent on average, and therefore increases the magnitude of the welfare gains of trade.

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Appendix

1.A Data Appendix

1.A.1 Data Overview

All data in this chapter is taken from the LIAB, a linked employer-employee data set provided by the German Institute for Employment Research (IAB). The firm-level variables used in this chapter include:

- Sales, as measured by overall revenues. Values before 2001 are reported in Deutsche Mark and converted to EUR using an exchange rate of 1.95.
- Intermediate input share in sales.
- Value-added: Calculated using information on intermediate input shares and sales.
- Exports: Export share in sales. Across all years, the overall export share in sales is available. For selected years, this is broken down into sales in countries added in the course of the EU 2004 expansion and sales in countries belonging to the EURO monetary currency union.
- Industry affiliation.
- Land (Federal state), or Kreis (municipality)

To calculate aggregates, I use the provided sampling weights.

The data on workers are drawn from a sample of administrative, social security records in Germany It contains information on daily earnings, unemployment spells, education (no high school, high school, technical university, university), training (completed vocational training, university degree), gender, age, tenure at the firm and occupation at the three-digit level. Throughout, I focus on full-time workers and exclude trainees or voluntary workers from the sample.

An important limitation of the dataset is the top coding of wages. In particular, about 9% of wages of the overall sample in each year are censored at the reporting maximum. Therefore, I impute wages of top earners following the approach in Card et al. (2013) and Dustmann et al. (2009). I estimate censored regressions for each year and a total of 25 age-training cells, allowing the variance to differ within each cell. For each year, censored wages are imputed as the sum of the predicted wage and a random component, drawn from a normal distribution with mean zero and a separate variance for each year-age-training group, obtained from the standard error of the forecast for uncensored wages. This imputation procedure increases the mean of log wages by about 0.03 and the standard deviation of log wages by about 0.05 in each year.[31]

1.A.2 Construction of Empirical Moments for Model Estimation

To estimate the model, I construct the following empirical moments for manufacturing firms

- Normalized distribution of log sales: Sales of establishments are normalized by average sales of their sector of production. Both averages and the resulting firm

[31] For affected wages, wages on average increase by 0.5 with a standard deviation of 0.4. This corresponds to an average increase of 10% over the reporting maximum.

sales distribution are weighted using the sampling weights provided by the IAB establishment panel.

- Wage distribution by worker types: Moments related to workers' wages are constructed by constructing wages $W_{s,f}$ at the worker group, and establishment level. The provided establishment sampling weights are used to construct aggregate wage distributions. To control for heterogeneity among that is not captured by the model, $W_{s,f}$ is defined as establishment-worker-group-year fixed effect of a Mincer wage regression of individual log wages on worker observables fixed effects for age groups, occupations, sectors of employment, federal state that the employer is located in and years. Wages $W_{s,f}$ are then used to construct aggregate wage distributions, using the establishment panel weights provided by the survey.

1.B Theoretical Appendix

1.B.1 Properties of the Non-Homothetic CES Functional Form

Following the exposition in Comin et al. (2017), consider the following generalization of the production function in the main text:

$$\sum_s \Omega_s^{1/\sigma} \left(\frac{L_i}{g_s(Q)} \right)^{(\sigma-1)/\sigma} = 1. \tag{1.30}$$

The production function in the main text is a special case for $g_s(Q) = Q^{-\frac{\varepsilon_i - \sigma}{\sigma - 1}}$. Thus, $g_s'(Q) < 0$ corresponds to the case where $-\frac{\varepsilon_s - \sigma}{\sigma - 1} < 0$, that is $\frac{\varepsilon_s - \sigma}{\sigma - 1} > 0$.

Lemma 1.1. *If $\sigma > (<)1$ and $g_s'(Q) > (<)0$, then $Q(\mathbf{L})$ as implicitly defined by (1.30) is strictly increasing and concave.*

Proof. Establishing monotonicity is straightforward. To show concavity, suppose for the sake of a contradiction that there exist Q' and Q'' such that $\mathcal{Q} \equiv \mathcal{Q}\left(\alpha Q' + (1-\alpha)Q''\right)$ is strictly smaller than both Q' and Q''. For the case $\sigma \geq 1$ and thus $g_s'(Q) > 0$,

$$\begin{aligned} 1 &= \textstyle\sum_s \theta_s^{1/\sigma} \left(\alpha \frac{L_i}{g_s(\mathcal{Q})} + (1-\alpha)\frac{L_i}{g_s(\mathcal{Q})}\right)^{\frac{\sigma-1}{\sigma}} \\ &> \textstyle\sum_s \theta_s^{1/\sigma} \left(\alpha \frac{L_i}{g_s(Q')} + (1-\alpha)\frac{L_i}{g_s(Q'')}\right)^{\frac{\sigma-1}{\sigma}} \\ &\geq \textstyle\alpha \sum_s \theta_s^{1/\sigma} \left(\frac{L_i}{g_s(Q')}\right)^{(\sigma-1)/\sigma} + (1-\alpha)\sum_s \theta_s^{1/\sigma} \left(\frac{L_i}{g_s(Q'')}\right)^{(\sigma-1)/\sigma}, \end{aligned}$$

where in the first inequality we have used monotonicity of $g_s(.)$ and in the second we have used the assumption that $\sigma > 1$. The last line implies a contradiction to the initial assertion. For the case that $\sigma < 1$,the inequalities are reversed, also implying a contradiction. □

This implies that $\frac{\varepsilon_s - \sigma}{1-\sigma} > 0$ for all s are a sufficient condition to ensure that the implicitly defined production function is strictly increasing and concave in all its arguments.

1.B.2 Microfoundations for non-homothetic Production Functions

Multinomial Choice with Scale Effects

Random utility models may microfound CES utility if an appropriate unobserved underlying shock to preferences taking the form of a Frechet or logit distribution is assumed (McFadden (1973)). Here, I demonstrate how this argument extends to production in the context of a task-based theory of input choice.

A firm has to complete a unit interval of tasks $j \in [0,1]$ to produce a unit of output. For each task s, the firm can hire a unit of time of a worker of type $s \in S$ at wage w_s to complete the specified task. The overall cost of having a task j completed

by occupation s is assumed to be log-linear and is specified as follows:

$$\log c\left(j,s,Q\right)=\sigma\log w_s-\log\theta_s^{1/\sigma}-\frac{\varepsilon_s-1}{1-\sigma}\log Q+\nu_{j,s}, \tag{1.31}$$

where $\nu_{j,s}$ is an idiosyncratic cost-shock that is assumed to be Frechet distributed according to

$$G(\nu)=e^{-z^{-(\sigma-1)}}. \tag{1.32}$$

Minimizing cost for a given target level of output, the firm then chooses for each task j a worker type s that can complete this task most effectively:

$$s^*(j)=\arg\min_s \log c\left(s,j,Q\right)$$

The probability that a given worker type is chosen to complete task j therefore depends directly on firm scale Q if $\varepsilon_s\neq\varepsilon_{s'}$. An alternative interpretation is that the nature of the tasks themselves change as firms grow larger, given that organizational needs and production arrangements need to vary accordingly. The following result confirms that the resulting cost function will be equivalent to the cost function implied by the non-homothetic CES.

Proposition 1.6. *The mixed random cost task assignment model defined by the cost functions (1.31) and Type-II Extreme Value distributed idiosyncratic cost shocks is isomorphic to a non-homothetic CES model in which firms produce according to a non-homothetic production technology with respect to output and elasticity of substitution σ between worker groups.*

Proof. The proof is a straightforward application of the well-known Frechet algebra. □

Technology Choice

Here, I show that a non-homothetic CES production function can be derived from a model of technology choice. Firms optimally choose technologies from a menu. Firms trade off the fixed cost of adopting the technology against potential savings in variable costs of production. Technologies might thereby vary in factor intensities and use, for example, different proportions of high skilled workers.

For simplicity, I assume that firms only hire two types of workers of either high or low skill. Firms choose a technology t from a menu of technologies $\mathcal{T}$. Individual technologies are characterized by their cost function:

$$\mathcal{T} = \left\{ t \in \mathbb{R}_+ : TC(t,Q) = \left(fh(t) + Qg(t)\right)\left(\alpha(t) w_l^{1-\sigma} + (1-\alpha(t)) w_h^{1-\sigma}\right)^{\frac{1}{1-\sigma}} \right\},$$

where f denotes a fixed cost of production. Firms thus trade off fixed cost, as governed by $h(.)$ agains variable cost governed by $g(.)$. Further, $\alpha\left(t\right)$ governs the relative technological advantage that high and low skill workers have across different technologies. Conditional on a desired level of output Q, firms choose $t^*(Q)$ so as to minimize total cost:

$$t^*(Q) = \min_t \left\{ TC(t,Q) : TC \in \mathcal{T} \right\}. \tag{1.33}$$

Note that for $\sigma = 1$ and $h(t) = 1 + (\eta - 1)\, 1_{t=1}$, and $g(t) = 1_{t=0} + \frac{1}{\gamma} 1_{t=1}$ this reduces to the production function in Bustos (2011a).

Under the condition that this problem has a unique solution, the optimal choice reduces to a total cost function that is equivalent to the one uniquely associated with the non-homothetic production structure. Given an optimal choice t^*, the cost

function can be written as:

$$TC(q,\mathbf{w}) = \underbrace{(fh(t^*(Q)) + Qg(t^*(Q)))}_{\equiv A(q)} \underbrace{\left(\alpha(t^*(Q))w_l^{1-\sigma} + (1-\alpha(t^*(Q)))w_h^{1-\sigma}\right)^{\frac{1}{1-\sigma}}}_{\equiv\left(\alpha(Q)w_l^{1-\sigma}+(1-\alpha(Q))w_h^{1-\sigma}\right)^{\frac{1}{1-\sigma}}}$$

Lemma 1.2. *Assume that $h(.)$,$g(.)$, $\alpha(.) \in C^2$. If (i) $h(t)$ and $g(t)$ are log-concave and (ii) $\alpha(t)$ is log-convex if $\sigma > 1$ and log-concave if $\sigma < 1$, then $\forall Q$, there exists a unique technlogy $t^*(Q)$ that solves the cost-minimization problem in equation (1.33).*

Proof. The first-order condition with respect to t implies that the optimal technology choice t is characterized by:

$$0 = \frac{a'(t)}{a(t)} + \frac{1}{1-\sigma}\frac{b'(t)}{b(t)},$$

where $a(t) \equiv fh(t)+Qg(t)$ and $b(t) = \alpha(t)\left(w_l^{1-\sigma} - w_h^{1-\sigma}\right)+w_h^{1-\sigma}$. By the assumptions stated in the lemma, the RHS is monotonously decreasing. By the Intermediate Value Theorem, a unique solution to the firm's optimal technology choice exists. □

This implies that that cost can be written as:

$$C(w_l, w_h, Q) = A(Q)\left(\alpha(Q)\, w_l^{1-\sigma} + (1-\alpha(Q))\, w_h^{1-\sigma}\right)^{\frac{1}{1-\sigma}}, \tag{1.34}$$

where $A(Q) \equiv fh(t^*(Q)) + gq(t^*(Q))$.

To derive the resulting production function, I use the fact that the cost function is homogeneous of degree 1 in prices. Shephard's lemma implies that the input demand for type $i \in \{H, L\}$ is given by $L_i = \frac{\partial C(w_l,w_h,Q)}{\partial w_i}$. These two facts allow us to write labor demands:

$$L_l = A(Q)\left\{1 - \alpha(Q) + \alpha(Q)\left(\frac{w_h}{w_l}\right)^{1-\sigma}\right\}^{\frac{\sigma}{1-\sigma}}, \tag{1.35}$$

and

$$L_h = A(q)\left\{(1-\alpha(Q))\left(\frac{w_h}{w_l}\right)^{\sigma-1} + \alpha(Q)\right\}^{\frac{\sigma}{1-\sigma}}. \tag{1.36}$$

Combining both equalities gives:

$$1 = A(Q)\left[\alpha(Q)L_l^{\frac{\sigma-1}{\sigma}} + (1-\alpha(Q))L^{\frac{\sigma-1}{\sigma}}\right] \tag{1.37}$$

(1.37) corresponds to the general functional form of the non-homothetic CES derived in Sato (1975) which in turn generalizes the technology used in the main text.

1.B.3 Derivations & Proofs

Consumption Problem

All workers i of a given skill type have Cobb-Douglas preferences over consumption and jobs that take the following form:

$$U(i,f) = \log C_i + \log A_f + \frac{1}{\beta}\epsilon_{i,f}, \tag{1.38}$$

where $C_i = \left(\sum_{f\in\mathcal{F}} \varphi_f^{\frac{\eta-1}{\eta}} c_{f,i}^{\frac{\eta-1}{\eta}} + (c_i^*)^{\frac{\eta-1}{\eta}}\right)^{\frac{\eta}{\eta-1}}$ is a CES consumption aggregator over domestic and foreign varieties.

Workers supply one unit of labor inelastically to the firm that maximizes their utility. This utility maximization problem can be solved in two steps. First, workers maximize utility from consumption, subject to the following budget constraint:

$$\sum_{f\in\mathcal{F}} p_f c_f = W_{s,f}.$$

This yields the following demand schedule for domestic varieties:

$$c_{f,i} = \varphi^{\eta-1} p_f^{-\eta} P^{\eta-1} W_{s,f}.$$

Aggregated over all domestic individuals, this yields the demand schedules for workers in the main text:

$$D_f(p,\varphi) = \varphi^{\eta-1} p^{-\eta} P^{\eta-1} \left(\sum_s \int_{f \in \mathcal{F}} W_{s,f} l_{s,f} df \right).$$

The indirect utility of an individual worker working form firm f, in turn, can be written as:

$$U(i,f) = \log\left(W_{s,f}/P\right) + \log A_f + \frac{1}{\beta_s} \log \epsilon_{i,f}.$$

In the second step, workers choose the job that maximizes their indirect utility. This is described in the next section.

Logit Choice Probabilities

I derive the probability $\lambda_{s,f}$ that workers of skill type s chooses to work for firm f. The idiosyncratic preferences $\epsilon_{i,f}$ over jobs are independently, identically distributed extreme value with cumulative distribution function:

$$F(x) = e^{-e^{-x}}.$$

Following McFadden (1973), the probability that a worker chooses job f is given by:

$$\begin{aligned} P_{s,f,i} &= \mathbb{P}\left(\beta_s \log W_{s,f} A_f + \epsilon_{i,f} > \beta_s \log W_{s,f'} A_{f'} + \epsilon_{i,f'}, \forall f' \neq f\right) \\ &= \mathbb{P}\left(\epsilon_{i,f'} < \epsilon_{i,f} + \beta_s \left(\log W_{s,f} A_f - \log W_{s,f'} A_{f'}\right), \forall f' \neq f\right) \end{aligned}.$$

Taking $\epsilon_{i,f}$ as given, this expression equals the cumulative distribution function for each $\epsilon_{i,f'}$ evaluated at $\epsilon_{i,f} + \beta_s \left(\log W_{s,f} A_f - \log W_{s,f'} A_{f'}\right)$. Since the preference shocks

are independent, this cdf can be calculated for each $\epsilon_{i,f}$:

$$P_{s,f,i}|\epsilon_{i,f} = \prod_{f' \neq f} e^{-e^{-\left(\epsilon_{i,f} + \beta_s \left(\log W_{s,f} A_f - \log W_{s,f'} A_{f'}\right)\right)}}.$$

The choice probability integrates this expression over all possible realizations of $\epsilon_{i,f}$:

$$P_{s,f,i} = \int \left(\prod_{f' \neq f} e^{-e^{-\left(\epsilon_{i,f} + \beta_s \left(\log W_{s,f} A_f - \log W_{s,f'} A_{f'}\right)\right)}} \right) d\epsilon_{i,f}.$$

Calculating this integral gives the choice probability for an individual worker:

$$P_{s,f,i} = \frac{e^{\beta_s \log W_{s,f} A_f}}{\sum_{f'} e^{\beta_s \log W_{s,f'} A_{f'}}} = \frac{\left(W_{s,f} A_f\right)^{\beta_s}}{\sum_{f'} \left(W_{s,f'} A_{f'}\right)^{\beta_s}}.$$

This choice probability is the same for all workers i belonging to type s.

Derivation of the cost function

Throughout the derivation, I suppress amenities A.

The Lagrangean solving the firm's cost minimization problem defined in equation (1.11) is given by:

$$\mathcal{L} = \sum_s W_s\left(l_s\right) l_s + \lambda \left(1 - \sum_s \Omega_s^{\frac{1}{\sigma}} l_s^{\frac{\sigma-1}{\sigma}} Q^{\frac{\varepsilon_s - \sigma}{\sigma}}\right),$$

where it is understood that $W_s\left(l_s\right)$ is given by the inverse of labor supply given by equation (1.9). The uniqueness of the solution follows from the fact that we are minimizing a strictly convex objective over a convex set, given that the production function is globally quasi-concave in labor inputs.

Taking first-order conditions with respect to l_s and solving for the multipliers on the labor supply equations, we obtain:

$$\frac{\beta_s + 1}{\beta_s} W_s = \lambda \frac{\sigma - 1}{\sigma} \Omega_s^{\frac{1}{\sigma}} l_s^{-\frac{1}{\sigma}} Q^{\frac{\varepsilon_s - \sigma}{\sigma}}.$$

where $\beta_s = \frac{d \log \mathcal{L}_s}{d \log W_s}$ is the elasticity of labor supply. The wage bill share of skill group s is given by:

$$\omega_s \equiv \frac{W_s l_s}{\sum_{s'} W_{s'} l_{s'}} = \frac{\frac{\beta_s}{\beta_s + 1} \Omega_s^{\frac{1}{\sigma}} l_s^{\frac{\sigma - 1}{\sigma}} Q^{\frac{\varepsilon_s - \sigma}{\sigma}}}{\sum_{s'} \frac{\beta_s'}{\beta_{s'} + 1} \Omega_{s'}^{\frac{1}{\sigma}} l_{s'}^{\frac{\sigma - 1}{\sigma}} Q^{\frac{\varepsilon_{s'} - \sigma}{\sigma}}}.$$

By the envelope theorem, marginal cost are given by:

$$MC(Q) = -\lambda \frac{1}{Q} \sum_s \Omega_s^{\frac{1}{\sigma}} l_s^{\frac{\sigma - 1}{\sigma}} Q^{\frac{\varepsilon_s - \sigma}{\sigma}} \frac{\varepsilon_s - \sigma}{\sigma}.$$

Solve for the multiplier λ and substitute this term into the first-order condition to obtain the expression for wages given in the main text:

$$W_s = \frac{\beta_s}{\beta_s + 1} MC(Q) \frac{\Omega_s^{\frac{1}{\sigma}} l_s^{-\frac{1}{\sigma}} Q^{\frac{\varepsilon_s - \sigma}{\sigma}}}{\frac{1}{Q} \sum_{s'} \Omega_{s'}^{\frac{1}{\sigma}} l_{s'}^{\frac{\sigma - 1}{\sigma}} Q^{\frac{\varepsilon_{s'} - \sigma}{\sigma}} \frac{\varepsilon_{s'} - \sigma}{1 - \sigma}}.$$

To derive marginal cost, multiply both sides of this expression by l_s and sum over all s to obtain total labor cost $C(Q)$:

$$C(Q) \equiv \sum_s W_s l_s = Q MC(Q) \frac{\sum_s \frac{\beta_s}{\beta_s + 1} \Omega_s^{\frac{1}{\sigma}} l_s^{\frac{\sigma - 1}{\sigma}} Q^{\frac{\varepsilon_s - \sigma}{\sigma}}}{\sum_{s'} \Omega_{s'}^{\frac{1}{\sigma}} l_{s'}^{\frac{\sigma - 1}{\sigma}} Q^{\frac{\varepsilon_{s'} - \sigma}{\sigma}} \frac{\varepsilon_{s'} - \sigma}{1 - \sigma}}.$$

$$\sum_{s'} \Omega_{s'}^{\frac{1}{\sigma}} l_{s'}^{\frac{\sigma - 1}{\sigma}} Q^{\frac{\varepsilon_{s'} - \sigma}{\sigma}} \frac{\varepsilon_{s'} - \sigma}{1 - \sigma} = \frac{Q}{C(Q)} MC(Q) \left(\sum_s \frac{\beta_s}{\beta_s + 1} \Omega_s^{\frac{1}{\sigma}} l_s^{\frac{\sigma - 1}{\sigma}} Q^{\frac{\varepsilon_s - \sigma}{\sigma}} \right)$$

Rearrange to solve for marginal cost:

$$MC\left(Q\right)=\frac{C(Q)}{Q}\sum_{s'}\frac{\Omega_{s'}^{\frac{1}{\sigma}}l_{s'}^{\frac{\sigma-1}{\sigma}}Q^{\frac{\varepsilon_{s'}-\sigma}{\sigma}}}{\sum_{s}\frac{\beta_s}{\beta_s+1}\Omega_{s}^{\frac{1}{\sigma}}l_{s}^{\frac{\sigma-1}{\sigma}}Q^{\frac{\varepsilon_{s}-\sigma}{\sigma}}}\frac{\varepsilon_{s'}-\sigma}{1-\sigma}.$$

Using the expression for wage bill shares, note that $\frac{\Omega_{s'}^{\frac{1}{\sigma}}l_{s'}^{\frac{\sigma-1}{\sigma}}Q^{\frac{\varepsilon_{s'}-\sigma}{\sigma}}}{\sum_{s}\frac{\beta_s}{\beta_s+1}\Omega_{s}^{\frac{1}{\sigma}}l_{s}^{\frac{\sigma-1}{\sigma}}Q^{\frac{\varepsilon_{s}-\sigma}{\sigma}}}=\omega_s\frac{\beta_s+1}{\beta_s}$. Plug this back into the above expression to derive the expression for marginal cost given in the main text:

$$MC\left(Q\right)=\frac{C\left(Q\right)}{Q}\sum_{s}\omega_s\frac{\beta_s+1}{\beta_s}\frac{\varepsilon_s-\sigma}{1-\sigma}.$$

It is immediately evident that total cost are increasing if $\frac{\varepsilon_s-\sigma}{1-\sigma}>0$. Lastly, note that using the first-order condition for wages and the constraint posed by the production technology, the multiplier λ equals:

$$\sum_{s}\left(W_s l_s\frac{\beta_s+1}{\beta_s}\right)=\lambda\frac{\sigma-1}{\sigma}.$$

Therefore, an alternative expression for wages that will be handy in the next proof is given by:

$$W_s=\frac{\beta_s}{\beta_s+1}\left\{\sum_{s}W_s l_s\frac{\beta_s+1}{\beta_s}\right\}\Omega_s^{\frac{1}{\sigma}}l_s^{-\frac{1}{\sigma}}Q^{\frac{\varepsilon_s-\sigma}{\sigma}}. \tag{1.39}$$

Convexity of Marginal Cost

Proposition 1.7. *Suppose* $\frac{\varepsilon_s-\sigma}{1-\sigma}\frac{\beta_s+1}{\beta_s}\geq 1$. *If* $\sigma<1$, *then (variable) cost are convex. If* $\sigma>1$,*then cost are convex if there exists a worker type* $s\in\mathcal{S}$ *such that for all* $s'\neq s$, $\varepsilon_s>\varepsilon_{s'}$ *and* $\frac{\varepsilon_s-\sigma}{1-\sigma}\frac{\beta_s+1}{\beta_s}\geq\frac{\varepsilon_{s'}-\sigma}{1-\sigma}\frac{\beta_{s'}+1}{\beta_{s'}}$.[32]

Proof. Define $\tilde{\omega}_s\equiv\frac{\omega_s\frac{\beta_s+1}{\beta_s}\frac{\varepsilon_s-\sigma}{\sigma-1}}{\sum_s\omega_s\frac{\beta_s+1}{\beta_s}\frac{\varepsilon_s-\sigma}{\sigma-1}}$. Define the wage bill share of worker group s by ω_s. The the elasticity of cost with respect to output equals: $\frac{\partial\log C(Q)}{\partial\log Q}=\sum_s\omega_s\left(1+\beta_s\right)\frac{\partial\log W_s}{\partial\log Q}=$

[32]If $\sigma>1$, a sufficient condition for locally convex marginal cost is given by: $\forall s$, $\frac{\beta_s+\sigma}{\sigma(1+\beta_s)}>\omega_s$, where ω_s denotes the wage-bill share of worker type s.

$\sum_s \omega_s \frac{\beta_s+1}{\beta_s}\frac{\varepsilon_s-\sigma}{\sigma-1}$. The first equality follows from 1.39. The superelasticity of total cost with respect to output is given by

$$\frac{\partial^2 \log C(Q)}{\partial \log Q^2} = \sum \tilde{\omega}_s \left(\frac{\partial \log W_s l_s}{\partial \log Q} - \frac{\partial \log C(Q)}{\partial \log Q} \right)$$

Assumption 1.3.2 implies that $\sum_s \omega_s \frac{\beta_s+1}{\beta_s}\frac{\varepsilon_s-\sigma}{1-\sigma} > 0$ and thus a sufficient condition for increasing superelasticity of marginal cost is given by:

$$\sum_s \omega_s (1+\beta_s) \frac{\partial \log W_s}{\partial \log Q} \frac{\beta_s+1}{\beta_s}\frac{\varepsilon_s-\sigma}{1-\sigma} - \left(\sum \omega_s (1+\beta_s) \frac{\partial \log W_s}{\partial \log Q} \right)^2 > 0$$

This condition can be restated as:

$$\sum_s \omega_s (1+\beta_s) \frac{\partial \log W_s}{\partial \log Q} \frac{\beta_s+1}{\beta_s}\frac{\varepsilon_s-\sigma}{1-\sigma} - \left(\sum_s \omega_s (1+\beta_s) \frac{\partial \log W_s}{\partial \log Q} \right) \left(\sum_s \omega_s \frac{\beta_s+1}{\beta_s}\frac{\varepsilon_s-\sigma}{1-\sigma} \right) > 0 \tag{1.40}$$

This condition can be understood as a restriction on the covariance between labor supply elasticity adjusted wage growth and increases in cost:

$$\mathrm{Cov}_{\omega_s} \left\{ (1+\beta_s) \frac{\partial \log W_s}{\partial \log Q}, \frac{1+\beta_s}{\beta_s}\frac{\varepsilon_s-\sigma}{1-\sigma} \right\} \geq 0. \tag{1.41}$$

This condition will be satisfied if ε_s and β_s are sufficiently negatively correlated - that is, if workers that are more productive are on average harder to hire.

Finally, I show marginal costs are increasing under the conditions stated in the proposition. Consider the elasticity of marginal cost with respect to output:

$$\frac{\partial \log MC\,(Q)}{\partial \log Q} = \frac{\partial \log C(Q)}{\partial \log Q} - 1 + \frac{\partial^2 \log C}{\partial \log Q^2}.$$

Using the above derivations, this can be rewritten as follows:

$$\frac{\partial \log MC(Q)}{\partial \log Q} = -1 + \frac{\sum \omega_s \frac{1+\beta_s}{\beta_s} \frac{\varepsilon_s - \sigma}{1-\sigma} \left\{ (1+\beta_s) \frac{\partial \log W_s}{\partial \log Q} \right\}}{\sum \omega_s \left\{ \frac{\beta_s+1}{\beta_s} \frac{\varepsilon_s - \sigma}{1-\sigma} \right\}},$$

A sufficient condition for increasing marginal cost is given by:

$$\sum \omega_s \left\{ \frac{1+\beta_s}{\beta_s} \frac{\varepsilon_s - \sigma}{1-\sigma} (1+\beta_s) \frac{\partial \log W_s}{\partial \log Q} \right\} > \sum \omega_s \left\{ \frac{\beta_s+1}{\beta_s} \frac{\varepsilon_s - \sigma}{1-\sigma} \right\}. \tag{1.42}$$

The elasticity of wages equals:

$$\frac{\partial \log W_s}{\partial \log Q} = \frac{\sigma}{\beta_s + \sigma} \left\{ \underbrace{\sum_k \left(\frac{W_k l_k \frac{1}{\beta_k}}{\sum_l W_l l_l \frac{1}{\beta_l}} \right)}_{\hat{\omega}_s} (\beta_k + 1) \frac{\partial \log W_k}{\partial \log Q} - 1 + \sum_s \omega_s \frac{\beta_s + 1}{\beta_s} \frac{\varepsilon_s - \sigma}{1-\sigma} + \frac{\varepsilon_s}{\sigma} \right\}.$$

Let $a_s \equiv \frac{\partial \log W_s}{\partial \log Q}$. The wage elasticities then can be written as the following system of equations:

$$Aa = \varepsilon,$$

where the matrix A is given by:

$$A = \begin{bmatrix} \frac{\beta_1+\sigma}{\sigma} - \hat{\omega}_1 (1+\beta_1) & -(\beta_2+1)\tilde{\omega}_2 & \dots & -(\beta_S+1)\tilde{\omega}_S \\ & \frac{\beta_2+\sigma}{\sigma} - \hat{\omega}_2 (1+\beta_2) & & \\ & & \dots & \\ & & & \\ -(\beta_1+1)\tilde{\omega}_1 & & & \frac{\beta_S+\sigma}{\sigma} - \hat{\omega}_S (1+\beta_S) \end{bmatrix}.$$

If $\frac{\beta_s+\sigma}{\sigma} - \hat{\omega}_s (1+\beta_s) > 0$ for all s, then Gershgorin's circle theorem implies that A is a M-matrix, and thus that $a >> 0$. If $\frac{\partial \log W_s}{\partial \log Q} \geq 0$ for all worker types, then condition (1.42) holds under the parametric restrictions stated in the proposition.

For $\sigma < 1$, $\frac{\beta_s+\sigma}{\sigma} - \hat{\omega}_s(1+\beta_s) > 0$ since $\hat{\omega}_s < 1$,and thus, marginal cost are increasing globally under the conditions stated in the proposition.

For $\sigma > 1$, note that since $MC(Q) = \sum \omega_s(1+\beta_s)\frac{\partial \log W_s}{\partial \log Q} > 0$, there exists at least one s such that $\frac{\partial \log W_s}{\partial \log Q} > 0$. Without loss of generality, let $s = 1$ be that worker group. Since marginal cost are positive, we know that: $\omega_1(1+\beta_1)\frac{\partial \log W_1}{\partial \log Q} > -\sum_{k\neq 1}\omega_k(1+\beta_k)\frac{\partial \log W_k}{\partial \log Q}$. This is equivalent to:

$$\omega_s(1+\beta_s)\frac{\partial \log W_1}{\partial \log Q} > -\sum_{k\neq s}\omega_k(1+\beta_k)\left(\frac{\beta_1+\sigma}{\beta_k+\sigma}\frac{\partial \log W_1}{\partial \log Q} + \frac{\varepsilon_s - \varepsilon_1}{\beta_k+\sigma}\right).$$

The increase in the wage by worker group 1 can be bound as:

$$\frac{\partial \log W_1}{\partial \log Q}\left\{\omega_1(1+\beta_1) + \sum_{k\neq s}\omega_k\frac{1+\beta_k}{\beta_k+\sigma}(\beta_1+\sigma)\right\} > \sum_{k\neq s}\omega_k\frac{1+\beta_k}{\beta_k+\sigma}(\varepsilon_1-\varepsilon_k)$$

Next, turning again to equation (1.42), we can apply similar steps to isolate $\frac{\partial \log W_1}{\partial \log Q}$ and write the condition for increasing marginal cost as the following inequality:

$$\begin{aligned}\frac{\partial \log W_1}{\partial \log Q}\left\{\omega_1(1+\beta_1) + \sum_{k\neq s}\omega_k\frac{(1+\beta_k)}{\beta_k+\sigma}(\beta_1+\sigma)\frac{\left(\frac{1+\beta_k}{\beta_k}\frac{\varepsilon_k-\sigma}{1-\sigma}-1\right)}{\left\{\frac{1+\beta_1}{\beta_1}\frac{\varepsilon_1-\sigma}{1-\sigma}-1\right\}}\right\} \\ > \sum_{k\neq s}\omega_k\frac{(1+\beta_k)}{\beta_k+\sigma}(\varepsilon_1-\varepsilon_s)\frac{\left(\frac{1+\beta_k}{\beta_k}\frac{\varepsilon_k-\sigma}{1-\sigma}-1\right)}{\left\{\frac{1+\beta_1}{\beta_1}\frac{\varepsilon_1-\sigma}{1-\sigma}-1\right\}}\end{aligned} \tag{1.43}$$

There exist two possibilities. Either, the term on the right-hand side is negative, in which case the inequality holds as $\frac{1+\beta_k}{\beta_k}\frac{\varepsilon_k-\sigma}{1-\sigma} > 1$. If the terms on the RHS are negative, in other words, if wages were decreasing for all other worker groups, then given that the proposition implies that $\frac{\left(\frac{1+\beta_k}{\beta_k}\frac{\varepsilon_k-\sigma}{1-\sigma}-1\right)}{\left(\frac{1+\beta_1}{\beta_1}\frac{\varepsilon_1-\sigma}{1-\sigma}-1\right)} < 1$. Given that we can bound the wage growth by worker group 1, we have that the inequality must hold and therefore have shown a sufficient condition for increasing marginal cost if $\sigma > 1$. □

Proof of Proposition1.3

Proof. To show concavity of the profit function, consider the second derivative of operating profits with respect to output Q :

$$\frac{\partial^2 \pi(\varphi, A)}{\partial Q} = -\left(\frac{\eta-1}{\eta^2}\right) Q^{-1/\eta-1}\left((\varphi Y)^{\frac{1}{\eta}} P^{(\eta-1)/\eta} + (\varphi Y^*)^{\frac{1}{\eta}}\right) - \frac{\partial MC(Q, A)}{\partial Q} < 0,$$

since $\eta > 1$ and marginal cost are convex.

The profit function is given by:

$$\pi(\varphi, A) = \varphi\left(\frac{\eta}{\eta-1} MC(Q, A)\right)^{1-\eta}\left(YP^{\eta-1} + 1_X \tau^{1-\eta} Y^*\right) - C(Q, A) - 1_X F_X.$$

Cost and marginal cost are not directly affected by φ, and thus $\pi(\varphi, A)$ is increasing in φ. Marginal cost and cost are decreasing in amenities A, implying that $\pi(\varphi, A)$ is increasing in A.

If there is no international trade, that is if $P^* = Y^* = 0$, the fixed point theorems in Kennan (2001b) apply and imply a fixed point exists. Consider now the case where $P^* > 0, \quad Y^* > 0$. Using the CES demand structure, the fixed point can be written as a system of equations in quantities, prices, and the aggregate price index.

$$f_1(\mathbf{p}; \mathbf{Q}, P) = P - \left(\int_{f \in \mathcal{F}} \varphi p_f^{1-\eta} df + (P^*)^{1-\eta}\right)^{\frac{1}{1-\eta}}$$

$$f_k(\mathbf{p}; \mathbf{Q}, P) = p_k - \left(Q_{H,k}^{-1/\eta} + (\tau Q_{F,k})^{-1/\eta}\right) \varphi^{1/\eta}\left(YP^{\eta-1} + Y^*\right)^{1/\eta}.$$

$f = \left(f_1, \{f_k\}_{k \in 2,\ldots,|\mathcal{F}|+1}\right)$ is strictly monotone in all its arguments. Given that $P^*, Y^* > 0$, $f(\mathbf{0}) < 0$ and $\lim_{\lambda \to \infty} f(\lambda \mathbf{x}) > 0$. The intermediate value theorem thus implies the existence of a fixed point. To prove uniqueness, I show that gross substitution holds. $\frac{\partial f_1^2}{\partial x \partial y} = 0$, for all $x \neq y$. Also, $\frac{\partial^2 f_k}{\partial p_k \partial Q} = \frac{\partial^2 f_k}{\partial p_k \partial P} = 0$. Lastly,

$\frac{\partial^2 f_k}{\partial Q \partial P} = \frac{\eta-1}{\eta} P^{\eta-2} \frac{1}{\eta} Q_{i,k}^{-1/\eta-1} > 0$ for $i \in \{H, F\}$. Therefore, gross substitution holds, and standard arguments imply that a unique fixed point exists. □

Proof of Proposition 1.4

Proof. The relative change in wages in response to a change in trade cost can be expressed as:

$$\frac{d \log W_s(\varphi)}{d \log \tau} - \frac{d \log W_{s'}(\varphi)}{d \log \tau} = -\frac{1}{\sigma} \left(\frac{d \log l_s(\varphi)}{d \log \tau} - \frac{d \log l_{s'}(\varphi)}{d \log \tau} \right) + \left(\frac{\varepsilon_s - \varepsilon_{s'}}{\sigma} \right) \frac{d \log Q(\varphi)}{d \log \tau} \tag{1.44}$$

To show the first statement, assume that $\beta_s = \beta$ and $\varepsilon_s = \varepsilon$. In this case, the relative change in wages for two skill groups s and s' depend only on aggregate outcomes common to all firms:

$$\frac{d \log W_s(\varphi)}{d \log \tau} - \frac{d \log W_{s'}(\varphi)}{d \log \tau} = -\frac{1}{\sigma + \beta} \left(\frac{d \log \Lambda_s}{d \log \tau} - \frac{d \log \Lambda_{s'}}{d \log \tau} \right).$$

Therefore within-firm wage inequality changes proportionally across all firms.

To show the second statement, assume that labor markets are equally competitive, that is $\beta_s = \beta$. Using the expression for labor supply, we can then express the relative pass-through of a trade shock as:

$$\frac{d \log W_s(\varphi)}{d \log \tau} - \frac{d \log W_{s'}(\varphi)}{d \log \tau} = \frac{1}{\sigma + \beta} \left(- \left(\frac{d \log \Lambda_s}{d \log \tau} - \frac{d \log \Lambda_{s'}}{d \log \tau} \right) + (\varepsilon_s - \varepsilon_{s'}) \frac{d \log Q(\varphi)}{d \log \tau} \right) \tag{1.45}$$

For firms that see an increase in market size, $\frac{d \log Q}{d \log \tau} > 0$, employees with larger technological scale complementary will, therefore, see larger relative wage gains.

To show the third statement, consider now the case where $\varepsilon_s = \varepsilon_{s'}$. Heterogeneous changes in firm-level wage premia across firms now reflect differences in labor supply

elasticities:

$$\begin{aligned}\frac{d\log W_s(\varphi)}{d\log\tau} - \frac{d\log W_{s'}(\varphi)}{d\log\tau} = \quad & -\frac{1}{\sigma}\left(\beta_s\frac{d\log W_s}{d\log Q} - \beta_{s'}\frac{d\log W_{s'}}{d\log Q}\right)\frac{d\log Q(\varphi)}{d\log\tau} \\ & -\frac{1}{\sigma}\left(\frac{d\log\Lambda_s}{d\log\tau} - \frac{d\log\Lambda_{s'}}{d\log\tau}\right)\end{aligned} \tag{1.46}$$

A lower labor supply elasticity β_s in the labor market will put larger upward pressure on wages at firms that grow in scale in response to a change in trade cost. □

Proof of Proposition 1.5

Proof. In a competitive labor market, firms act as wage takers and wages equal the marginal revenue product of labor, that is:

$$W_{s,f} = MRPL_{s,f}. \tag{1.47}$$

In the following, I drop the dependency of cost and wages on amenities from the algebraic expressions. Following the steps from the previous derivation of the cost function, marginal costs are given by:

$$MC\left(Q\right) = \frac{C}{Q}\sum_s \omega_s\left(\frac{\varepsilon_s - \sigma}{1-\sigma}\right), \tag{1.48}$$

where ω_s denotes the labor cost share of worker group s in the competitive allocation. Showing that the proposed tax policy achieves the same worker allocation with competitive labor markets is equivalent to showing that labor demand and cost correspond to (1.47) and (1.48) respectively.

Under the proposed tax reform, firms pay a fraction $1-\tau_s$ of the wage bill while the government subsidizes the remainder. The first-order condition for a firm's optimal employment of worker type s then becomes:

$$(1-\tau_s)\,W_{s,f} = \frac{\beta_s}{\beta_s+1} MRPL_{s,f}.$$

If $\tau_s = \frac{1}{1+\beta_s}$, labor demand is equal to equation (1.47).

I now show that marginal costs are equivalent to those of a firm that sets wages equal to the marginal revenue product of labor. The gross wage-bill share is given by $\omega_s = \frac{\Omega_s^{\frac{1}{\sigma}} l_s^{\frac{\sigma-1}{\sigma}} Q^{\frac{\varepsilon_s-\sigma}{\sigma}}}{\sum_{s'} \Omega_{s'}^{\frac{1}{\sigma}} l_{s'}^{\frac{\sigma-1}{\sigma}} Q^{\frac{\varepsilon_{s'}-\sigma}{\sigma}}}$. Marginal costs are, by the envelope theorem, given by:

$$MC(Q) = -\lambda \frac{1}{Q} \sum_s \Omega_s^{\frac{1}{\sigma}} l_s^{\frac{\sigma-1}{\sigma}} Q^{\frac{\varepsilon_s-\sigma}{\sigma}} \frac{\varepsilon_s - \sigma}{\sigma}. \tag{1.49}$$

Wages can be expressed as: $W_s = MC(Q) \frac{\Omega_s^{\frac{1}{\sigma}} l_s^{-\frac{1}{\sigma}} Q^{\frac{\varepsilon_s-\sigma}{\sigma}}}{\frac{1}{Q}\sum_{s'} \Omega_{s'}^{\frac{1}{\sigma}} l_{s'}^{\frac{\sigma-1}{\sigma}} Q^{\frac{\varepsilon_{s'}-\sigma}{\sigma}} \frac{\varepsilon_{s'}-\sigma}{1-\sigma}}$ and total cost are given by $C(Q) \equiv \sum_s (1-\tau_s) W_s l_s = QMC(Q) \frac{\sum_s (1-\tau_s) \Omega_s^{\frac{1}{\sigma}} l_s^{\frac{\sigma-1}{\sigma}} Q^{\frac{\varepsilon_s-\sigma}{\sigma}}}{\sum_{s'} \Omega_{s'}^{\frac{1}{\sigma}} l_{s'}^{\frac{\sigma-1}{\sigma}} Q^{\frac{\varepsilon_{s'}-\sigma}{\sigma}} \frac{\varepsilon_{s'}-\sigma}{1-\sigma}}$. This can be rearranged as follows:

$$\frac{\sum_s (1-\tau_s) W_s l_s}{Q} \sum \omega_s \frac{\varepsilon_{s'} - \sigma}{1-\sigma} = MC(Q) \left(1 - \sum_s \omega_s \tau_s\right). \tag{1.50}$$

Noting that $(1 - \sum_s \omega_s \tau_s) = \sum_s \omega_s (1-\tau_s) = \frac{\sum_s W_s l_s (1-\tau_s)}{\sum_s W_s l_s}$, marginal cost are therefore given by $MC(Q) = \frac{\sum_s W_s l_s}{Q} \sum_s \omega_s \left(\frac{\varepsilon_s - \sigma}{1-\sigma}\right)$.

Consequently, marginal costs are equivalent to the competitive case that is characterized by equation (1.48). Finally, the labor allocation is not distorted, given that non-progressive income taxes enter log-additively into workers' optimal choice of employment. As a result, the allocation of workers to firms and output in the equilibrium with labor market frictions equals that of the equilibrium with competitive labor markets, where wage differences reflect compensating differentials only. □

1.B.4 Theoretical Extensions

Upward Sloping Labor Supply Curves in a Model of Directed Search

While the model presented in the main text microfounds upward-sloping labor supply curves by means of idiosyncratic employment preference shocks to individual workers, another microfoundation is given by standard search models, as in Burdett and Mortensen (1998).

Labor markets are segregated by worker type s and the mass of workers of type s is given by L_s. Workers have linear indirect utility in income. Unemployed workers search for employment, receiving wage offers at Poisson rate λ_s. Workers can choose to accept a wage offer, in which case they work for their chosen employer until the match is terminated, which happens at exogenous Poisson rate χ_s.

This setting gives rise to upward-sloping labor supply curves. The following proposition shows that the labor supply elasticity, albeit not constant, is closely related to the elasticity in the main text if the underlying source of heterogeneity across firms is drawn from a Pareto distribution.

Proposition 1.8. *Assume that the underlying firm productivity distribution is Pareto with shape parameter p. Denoting labor supply by $\mathcal{L}_s(W_{s,f})$, we have that the elasticity of labor supply to an individual firm f with respect to wages is given by*

$$\frac{d\log \mathcal{L}_s(W_{s,f})}{d\log W_{s,f}} = 2p\frac{\lambda_s/\chi_s(1-F_s(W_{s,f}))}{1+\lambda_s/\chi_s(1-F_s(W_{s,f}))},$$

where $F(.)$ is the equilibrium distribution of wages.

Proof. In this set-up, the steady state mass of workers $\mathcal{L}_s$ that accept jobs at a firm posting wages $W_{s,f}$ can be shown to equal:

$$\mathcal{L}_s(W_{s,f}) = \frac{\lambda_s/\chi_s}{L_s\left[1+\lambda_s/\chi_s(1-F_s(W_{s,f}))\right]^2}, \tag{1.51}$$

where $F_s(W_{s,\varphi})$ is the share of firms that offers wages less than $W_{s,f}$ in equilibrium. The labor supply function in equation (1.51) thus displays similar behavior to the expression for labor supply presented in the main text. In particular, firms that offer higher wages attract more workers, and upward shifts in the wages offered by all other firms decrease the labor supply to firm f. Further, the distribution of wages is a sufficient statistic for the labor supply to the firm.

Ignoring issues of differentiability, the elasticity of a firm's labor supply takes the following form:

$$\frac{d\log \mathcal{L}_s}{d\log W_{s,f}} = \frac{2W_{s,f}\left(\lambda_s/\chi_s \frac{\partial F_s\left(W_{s,f}\right)}{\partial W}\right)}{\left(1+\lambda_s/\chi_s\left(1-F_s\left(W_{s,f}\right)\right)\right)}.$$

If firms are only heterogeneous in productivity, then the wage offer distribution inherits the shape of the underlying productivity distribution, as wages are monotonous in productivity. If productivity is drawn from the Pareto distribution, that is $F_s(W_{s,f}) = 1-\left(\frac{a}{\varphi}\right)^p$, then in equilibrium, the above expression simplifies to:

$$\frac{d\log \mathcal{L}_s}{d\log W_{s,\varphi}} = 2\frac{\lambda_s/\chi_s p\left(\frac{a}{\varphi}\right)^p}{1+\lambda_s/\chi_s\left(\frac{a}{\varphi}\right)^p} = 2p\frac{\lambda_s/\chi_s p\left(1-F_s\left(W_{s,f}\right)\right)}{1+\lambda_s/\chi_s\left(1-F_s\left(W_{s,f}\right)\right)}.$$

□

Extension: Heterogeneous Ability within Worker Types

The baseline model assumes that workers of a given type s are homogeneous inputs in production. As a consequence, wages in the baseline model are pinned down at the level of worker types and firms. In this section, I show that the framework readily extends to allow for variation in wages at the level of individual workers and firms, while still preserving the key implications displayed in the main text.

To this end, I allow for exogenous differences in labor efficiency units - or ability - across workers i, denoted e_i.

Firms production technologies are as described in Section 1.3, however labor inputs are now aggregates of efficiency units. Denoting by $\mathcal{I}_{s,f}$ the set of workers of type s employed at firm f, labor inputs are now given by:

$$l_{s,f} = \int_{i \in \mathcal{I}_{s,f}} e_i di. \tag{1.52}$$

Firms' wages reflect efficiency wages $w_{i,s,f} = e_i W_{s,f}$ that closely resemble the wages in the main text, adjusted for efficiency units.

The total number of workers of worker type s is given by L_s, while the (type-specific) distribution of efficiency units is denoted by $F_s(e)$. Workers still receive idiosyncratic preference shocks and choose their optimal employer, subject to being eligible to their rejection cutoffs. As a result, the total number of efficiency units supplied to a firm posting a wage $W_{s,f}$ and non-wage amenities $a_{s,\varphi}$ is now given by:

$$l_{s,f} = L_s a_{s,f} W_{s,f}^{\beta_s} \int_{\underline{e}_s}^{\infty} e^{\beta_s} \Delta(e)_s^{-1} dF_s(e). \tag{1.53}$$

and $\Delta_s(e) = \int_{\varphi'} a_{s,\varphi} \left(eW_{s,f}\right)^{\beta_s}$ is a measure of aggregate demand for worker type s that is similar to the one given in the main text.

To pin down wages, we can solve for the cost minimization problem of the firm, as in the main text. In particular, the problem can now be written:

$$TC(Q) = \min_{w_{s,f}, \underline{e}_{s,f}} \sum_s W_{s,f}^{1+\beta_s} L_s A_{s,f} \tilde{\Delta}^{-1}.$$

subject to $1 = \sum_s \Omega_s^{1/\sigma} l_s^{\frac{\sigma-1}{\sigma}} Q^{\varepsilon_s/\sigma-1}$ and $\tilde{\Delta}_s = \int_{\underline{e}_s}^{\infty} e^{\beta_s} {\Delta_s}^{-1}(e) dF_s(e)$.

Following similar steps as in Appendix 1.B, it is simple proof the following proposition, which generalizes the results in Proposition 1.2 to the current setting:

Proposition 1.9. *The following structural expression gives wages:*

$$\log \tilde{w}_{i,s,\varphi} \equiv \log e_i w_{s,f} = \chi_s + \eta_{\beta_s}\psi_i + \eta_{\varepsilon_s}\lambda_{f,1} + \eta_{\beta_s}\lambda_{f,1} + \nu_{f,s}. \tag{1.54}$$

If $\beta_s = \beta$ and $\varepsilon_s = \varepsilon$, wages are log-additive in a worker fixed effect, worker type fixed effect and firm fixed effect:

$$\log \tilde{w}_{i,s,f} = \chi_s + \psi_i + \lambda_f + \nu_{f,s}. \tag{1.55}$$

Proof. The first order condition pinning down wages $w_{s,\varphi}$ is given by:

$$W_{s,f} = \frac{\beta_s}{\beta_s + 1}\frac{\sigma - 1}{\sigma}\Omega_s^{\frac{1}{\sigma}} l_s^{-\frac{1}{\sigma}} Q^{\frac{\varepsilon_s - \sigma}{\sigma}}\lambda.$$

The earnings of employee i with efficiency unit e_i are then given by

$$\tilde{w}_{i,s,f} = \frac{\beta_s}{\beta_s + 1} e_i \frac{\sigma - 1}{\sigma} l_s^{-\frac{1}{\sigma}} Q_f^{\frac{\varepsilon_s - \sigma}{\sigma}}\lambda_f.$$

Solving for l_s and rearranging yields the following expression for efficiency wages:

$$\log \tilde{w}_{i,s,f} = \frac{\sigma}{\sigma + \beta_s}\log\left(\frac{\Omega_s\beta_s}{\beta_s + 1}\left(\frac{L_s A_{s,f}}{\tilde{\Delta}}\right)^{-\frac{1}{\sigma}}\right) + \frac{\sigma}{\sigma + \beta_s}\log e_i + \frac{\varepsilon_s - \sigma}{\sigma + \beta_s}\log Q_f + \frac{\sigma}{\sigma + \beta_s}\log\lambda_f.$$

□

The proposition shows that the model, under the same conditions as stated in Proposition 1.2, rationalizes a reduced form model for wages that is log-additive in individual worker and firm type fixed effects.

Multilateral Wage Bargaining and Convex Vacancy Posting Cost

The model in the main text employs a simple model of monopsonistic competition in labor markets to generate wage differences for similar workers across firms. Here, I show that the key implications of the model for wage outcomes are robust to alternative assumptions on the structure of labor markets and are not dependent on the type of competition that is assumed in product markets.

Labor markets are segregated by worker type $s \in \mathcal{S}$. Workers match randomly with firms. Upon matching, firms multilaterally bargain with all worker types over wages. Let β_s denote the bargaining weight of worker group s,while the outside option of a worker of type s is equal to $\overline{W}_s$. The cost of posting V vacancies equals V^{γ_s} per unit of time, the (equilibrium) probability of being matched with workers - taken as given by firms - is q_s and the job desctruction rate is χ_s.

As shown in Stole and Zwiebel (1996), wages are described by a set of differential equations. Suppressing firm subscripts, wages $\{W_s\}_{s\in\mathcal{S}}$ solve:

$$W_s(\mathbf{L}) \;\; = (1-\beta_s)\,\overline{W}_s + \beta_s\left(MRPL_s - \textstyle\sum_{s'} l_s \frac{\partial W_s}{\partial l_s}\right) \quad , \quad \forall s \in \mathcal{S}. \tag{1.56}$$

where $\mathbf{L} \equiv [L_s]_{s\in\mathcal{S}}$ and $MRPL_s$ is the marginal revenue product of workers of type s. The solution to this set of differential equations can be derived from minimally adjusting the results in Cahuc et al. (2008).

The following proposition shows that this alternative model gives rise to near equivalent structural expressions for wages. It also highlights that labor supply elasticities are closely related to inverse measures of the convexity of iso-elastic vacancy cost, as shown for simple cases in Manning (2011).

Proposition 1.10. *Assume that outside options are equal to zero for all worker types, that is* $\forall s$, $\overline{W}_s = 0$. *A model with multilateral bargaining, random search and convex*

vacancy posting cost then implies the following structural expression for wages:

$$\begin{aligned}\log W_{s,f} &= \alpha_s + \tfrac{\varepsilon_s}{\sigma}\left(\tfrac{\tilde{\gamma}_s}{\tilde{\gamma}_s+\sigma}\right)\log Q_f + \left(\tfrac{\tilde{\gamma}_s}{\tilde{\gamma}_s+\sigma}\right)\log\left(P_f \int_0^1 \tfrac{1}{\beta_s} z^{\frac{1-\beta_s}{\beta_s}-\frac{1}{\sigma}} G_s\left(\mathbf{L}A_i\left(z\right)\right)dz\right) \\ &= \alpha_s + \eta_{\varepsilon_s}\psi_{1,f} + \eta_{\gamma_s}\psi_{2,f}\end{aligned}, \tag{1.57}$$

where $\tilde{\gamma}_s \equiv \frac{1}{\gamma_s} - 1$, $\alpha_s = \frac{\sigma}{\tilde{\gamma}_s+\sigma}\log\frac{1-\beta_s}{\iota_s}$ *and* $\iota_s \equiv \frac{\chi_s}{\gamma_s q_s}$. $A_i(z)$ *is a* $S \times S$ *diagonal matrix with entries* $a_{j,i} = z^{\frac{\beta_j}{1-\beta_j}\frac{1-\beta_i}{\beta_i}}$ *and* P_φ *is the equilibrium price that firm* φ *charges in equilibrium.* G_s *denotes the function* $G_s \equiv \frac{\frac{\sigma-1}{\sigma}\Omega_s^{\frac{1}{\sigma}}}{\sum \Omega_s^{\frac{1}{\sigma}} l_s^{\frac{\sigma-1}{\sigma}} Q^{\frac{\varepsilon_s-\sigma}{\sigma}\frac{\varepsilon_s-\sigma}{1-\sigma}}}$.

Proof. The result will follow from the following lemma. □

Lemma 1.3. *Under non-homothetic technologies given in equation (1.4), wages in the multilateral bargaining model are given by:*

$$W_s = (1-\beta_s)\bar{W}_g + PQ^{\frac{\varepsilon_s}{\sigma}} l_s^{-\frac{1}{\sigma}} \int_0^1 z^{\frac{1-\beta_s}{\beta_s}-\frac{1}{\sigma}} G_s\left(\mathbf{L}A_i\left(z\right)\right)dz, \tag{1.58}$$

,

where $A_i(z)$ *is a* $S \times S$ *diagonal matrix with entries* $a_{j,i} = z^{\frac{\beta_j}{1-\beta_j}\frac{1-\beta_i}{\beta_i}}$ *and* P *is the price that firm* f *charges.*

Proof. The result is a direct consequence of the result stated in appendix B.4. in Cahuc et al. (2008), generalized to allow for non-competitive input markets. Denote by F the implicit production function defined by the non-homothetic CES. Imposing that the $p'th$ derivative of $l_s^{(p)} \times MRPl_s^{(p)} = P \times l_s^{(p)}\frac{\partial F}{\partial l_s}$ in continuous at zero and that $\lim_{N\to 0} Nw(N) = 0$, replacing $\frac{\partial F}{\partial L_s}$ in Cahuc et al. (2008) by $MRPL_s$ and following the steps of the proof implies that wages in equilibrium to satisfy

$$W_s = (1-\beta_s)\bar{W}_s + P\int z^{\frac{1-\beta_s}{\beta_s}} \frac{\partial \log F}{\partial \log L_s}\left(\mathbf{L}A_i(z)\right)dz \tag{1.59}$$

Taking derivatives and pulling out the term involving output Q, and redefining the remainding term to be equal to G_s gives the result stated in the lemma. □

In steady-state, firm-level employment of each type s is equal to the ratio of match and separation probabilities multiplied by the number of vacancies that a firm posts: $l_s = V_s \frac{q_s}{\chi_s}$. Under convex vacancy posting cost, the optimal number of vacancies solves the following first-order condition:

$$MRPL_s = W_s + \sum_{s'} l_s \frac{\partial W_s}{\partial l_s} + \iota_s l_s^{\frac{1}{\gamma_s}-1},$$

where $\iota_s \equiv \frac{\chi_s}{\gamma_s q_s}$. Following the same steps as in in Cahuc et al. (2008), labor demand can be shown to solve:

$$PQ^{\frac{\varepsilon_s}{\sigma}} l_s^{-\frac{1}{\sigma}} \int_0^1 \frac{1}{\beta_s} z^{\frac{1-\beta_s}{\beta_s}-\frac{1}{\sigma}} G_s\left(\mathbf{L}A_i\left(z\right)\right) dz = W_s + \iota_s l_s^{\frac{1}{\gamma_s}-1}. \tag{1.60}$$

Assuming that outside options are normalized to zero, that is $\overline{W}_s \equiv 0$, combining equation (1.58) and equation (1.60), implies that labor demand equals:

$$l_s = \left(\frac{(1-\beta_s)}{\iota_s} PQ^{\frac{\varepsilon_s}{\sigma}} \int_0^1 \frac{1}{\beta_s} z^{\frac{1-\beta_s}{\beta_s}-\frac{1}{\sigma}} G_s\left(\mathbf{L}A_i\left(z\right)\right) dz \right)^{\frac{\sigma}{\tilde{\gamma}_s+\sigma}},$$

where $\tilde{\gamma}_s \equiv \frac{1}{\gamma_s} - 1$. Plugging this expression into the expression for wages, we obtain the result.

1.C Table and Figure Appendix

Table 1.10: The Effect of Firm Sales on Worker Wages by Skill Group

	(1)	(2)	(3)	(4)	(5)	(6)
Skill Group	Sales	Rev/L	VA	Sales	Rev/L	VA
1	0.016***	0.007	0.012	0.002	−0.008**	−0.009*
	(3.57)	(0.88)	(1.37)	(0.27)	(-2.45)	(-1.79)
2	0.021***	0.014*	0.017*	0.005	−0.004	−0.007
	(4.73)	(1.72)	(1.94)	(0.78)	(−1.07)	(−1.25)
3	0.024***	0.019**	0.020***	0.008	0.002	−0.003
	(5.37)	(2.24)	(2.27)	(1.32)	(0.46)	(-0.63)
4	0.026***	0.022***	0.023***	0.012*	0.006*	0.001
	(5.97)	(2.66)	(2.55)	(1.76)	(1.73)	(-0.1)
5	0.028***	0.025***	0.025***	0.015**	0.011***	0.002
	(6.48)	(3.06)	(2.81)	(2.24)	(3.11)	(0.5)
6	0.030***	0.029***	0.027***	0.018***	0.017***	0.006
	(6.91)	(3.48)	(3.06)	(2.72)	(4.61)	(1.18)
7	0.033***	0.032***	0.029***	0.022***	0.022***	0.009*
	(7.31)	(3.92)	(3.32)	(3.21)	(6.12)	(1.88)
8	0.036***	0.037***	0.033***	0.026***	0.029***	0.014***
	(8.24)	(4.71)	(3.77)	(3.71)	(7.68)	(2.75)
9	0.041***	0.045***	0.038***	0.032***	0.038***	0.020***
	(9.87)	(5.51)	(4.24)	(4.51)	(9.92)	(4.13)
10	0.051***	0.060***	0.049***	0.042***	0.053***	0.03***
	(10.45)	(7.58)	(5.26)	(5.5)	(12.02)	(8.19)
Within R^2	0.32	0.33	0.33	0.31	0.31	0.31
Firm Controls	✓	✓	✓			
Worker Controls	✓	✓	✓	✓	✓	✓
Industry FE	✓	✓	✓			
Occupation FE	✓	✓	✓			
Year FE	✓	✓	✓			
Education FE	✓	✓	✓			
Worker FE				✓	✓	✓
Firm FE				✓	✓	✓
Observations	5061226	5061226	5061226	6483778	6483778	4902074

Notes: This table presents the estimated relation between firm sales on individual worker wages across skill groups, as in equation (1.1). Skill groups are defined in section 1.2. Firm controls: revenue share of intermediate inputs, average skill intensity. Worker controls: age, gender, and nationality. Standard errors are clustered at the establishment level. t-statistics are in parentheses. *** indicates significance at the 1%, ** at the 5% and * at the 10% level.

Table 1.11: The Effect of Firm Size on Worker Wages Relative to the Mean Wage of Their Employer by Skill Group

	(1)	(2)	(3)	(4)	(5)	(6)
Skill Group	Sales	Rev/L	VA	Sales	Rev/L	VA
1	−0.014***	−0.020***	−0.015***	−0.007*	−0.012***	−0.006
	(-13.36)	(-11.25)	(-12.92)	(-1.79)	(-14.8)	(-1.43)
2	−0.011***	−0.014***	−0.011***	−0.007*	−0.012***	−0.005
	(-10.45)	(-8.48)	(-10.28)	(-1.79)	(-12.2)	(-1.41)
3	−0.008***	−0.009***	−0.005***	−0.007*	−0.012***	−0.005
	(–7.69)	(–6.04)	(–7.54)	(-1.80)	(-12.2)	(-1.40)
4	−0.005**	−0.006***	−0.006**	−0.006*	−0.011***	−0.005
	(-5.44)	(-3.88)	(-5.31)	(-1.78)	(-11.4)	(-1.39)
5	−0.003***	−0.003*	−0.003***	−0.006*	−0.011***	−0.005
	(-3.09)	(-1.79)	(-2.99)	(-1.71)	(-10.7)	(-1.35)
6	−0.001	0.001	−0.001	−0.006	−0.010***	−0.005
	(-0.83)	(0.24)	(0.69)	(-1.59)	(-9.77)	(-1.28)
7	0.002	0.004**	0.002	−0.005	−0.009***	−0.004
	(1.38)	(2.30)	(1.58)	(-1.39)	(-8.29)	(-1.11)
8	0.005**	0.009***	0.005**	−0.004	−0.07***	−0.003
	(4.51)	(5.48)	(4.92)	(-1.08)	(-6.68)	(-0.72)
9	0.009***	0.002***	0.009***	−0.002	−0.003***	−0.00
	(8.12)	(9.18)	(8.77)	(-0.44)	(-2.75)	(-0.01)
10	0.018***	0.029***	0.018***	0.004	0.01***	0.01*
	(13.70)	(15.72)	(14.77)	(1.13)	(2.7)	(1.7)
Within R^2	0.22	0.23	0.22	0.06	0.06	0.05
Firm Controls	✓	✓	✓			
Worker Controls	✓	✓	✓	✓	✓	✓
Industry FE	✓	✓	✓			
Occupation FE	✓	✓	✓			
Year FE	✓	✓	✓			
Education FE	✓	✓	✓			
Worker FE				✓	✓	✓
Firm FE				✓	✓	✓
Observations	5061226	5061226	5061226	6483788	6483788	4902074

Notes: Coefficient estimates of estimating equation (1.2). Firm control: Revenue share of intermediate inputs. Worker controls include age, gender and nationality. Regressions (1) to (3) include fixed effects for a worker's occupation, sector of occupation, the federal state of residence, and years. Standard errors are clustered at the establishment level, and t-statistics are in parentheses. *** indicates significance at the 1%, ** at the 5% and * at the 10% level.

Table 1.12: Workforce Composition and Firm Performance

	Skill Intensity
Log Revenue	0.33***
	(24.01)
Firm Controls	✓
Fixed Effects	✓
Within R^2	0.11
Observations	69004

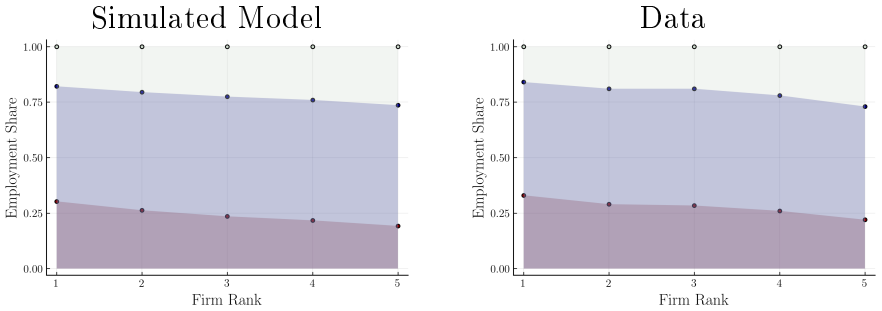
Notes: This table presents the regression results of projecting a firm's skill-intensity, measured by the average wage rank of its employees, on log revenues, firm controls, and fixed effects. Standard errors are displayed in parentheses and clustered at the level of employers f. Fixed effects are included for sectors, federal states, and years. Firm controls include the share of intermediate inputs in total revenues, the total number of workers, average employee age, the share of female employees, and the share of german employees.

Table 1.13: Moments for Production Function Estimation

Moment	Skill Group s	Region	
		East	West
$\frac{\text{Cov}\left[d\log\left(l_{s,f,t}/l_{L,f,t}\right), d\log\xi_{f,t}\right]}{\text{Cov}\left[d\log\left(W_{s,f,t}l_{s,f,t}/W_{M,f,t}l_{M.f.t}\right), d\log\xi_{f,t}\right]}$	Low	1.22	0.88***
		(0.85)	(5.96)
	High	0.59**	0.95***
		(1.98)	(5.97)
$\frac{\text{Cov}\left[d\log Q_{f,t}, d\log\xi_{f,t}\right]}{\text{Cov}\left[d\log\left(W_{s,f,t}l_{s,f,t}/W_{M,f,t}l_{M.f.t}\right), d\log\xi_{f,t}\right]}$	Low	3.76	−5.07***
		(0.53)	(-6.6)
	High	1.33	5.65***
		(0.98)	(6.80)
First Stage F		24.3	
Group×Year×Lag Fixed Effect		✓	
Observations		123,082	

Notes: Estimated moments used for the estimation of the production function parameters. t-statistics are displayed in paentheses. *** indicates significance at the 1%, ** at the 5% and * at the 10% level.

Figure 1.7: Sorting: Employment Shares of Medium Skilled Workers in Blue, of Low Skilled Workers in Red



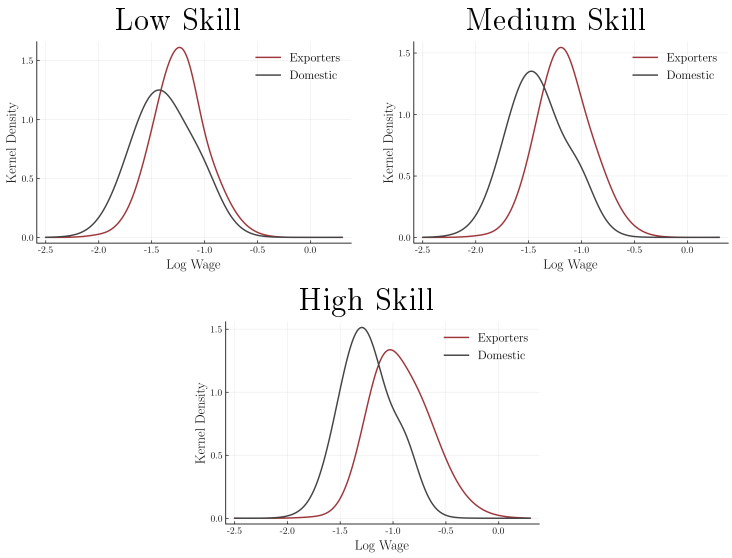
Notes: This figure plots model simulated employment distributions along the firm sales distribution on the left and the empirical distribution on the right. Firm ranks correspond to quintiles of the firm sales distribution.

Table 1.14: Over-Identification Check: Returns to Skill and Firm Size

		Wage Relative to Mean Firm Wage	
		Model	Data
Log Sales × Skill group	L	-0.04	-0.02
	M	-0.003	-0.001
	H	0.05	0.02
		$sd(\log W_f)$	
		Model	Data
Log Sales		0.01	0.01

Notes: The first panel displays the coefficient estimate β_s of estimating: $\log W_{f,s} - \log \overline{W}_f = \alpha + \beta_s \log \text{Sales}_{f,t} + \epsilon_{f,t}$. H, M, and L denote high, medium, and low skill worker groups. The estimation results reported from the data point are based on individual worker observations and control for worker heterogeneity not captured by the model: Age, gender, tenure, sector, occupation, education. The second panel displays the coefficient estimate β of estimating: $sd\left(\log W_{f,s}|f\right) = \alpha + \beta \log \text{Sales}_f + \gamma \log L_{f,t} + \epsilon_f$. The estimation results reported from the data control for firm heterogeneity that is not captured by the model: Sector and intermediate input share.

Figure 1.8: Simulated Wage Distributions Across Exporting and Domestic Firms



Notes: This figure displays simulated wage distributions by skill type and exporter status of a worker's employers.

Table 1.15: Detailed Counterfactual Effects of Trade on Wages

	Change		
	Model	Data	% Explained
Low Skill			
sd($\log W$)	0.003	0.017	17
90-10 ratio	0.019	0.03	62
Medium Skill			
sd($\log W$)	0.004	0.02	21
90-10 ratio	0.011	0.13	9
50-10 ratio	0.03	0.05	61
High Skill			
sd($\log W$)	0.008	0.05	16
90-10 ratio	0.03	0.12	26
50-10 ratio	0.03	0.05	61
Mean Wage Differences			
Between High and Medium Skill	0.01	0.029	32
Between Medium and Low Skill	-0.008	-0.031	24

*Notes:*This table displays a detailed breakdown of the counterfactual effects of trade liberalization on earnings inequality in Germany between 1993-2002 and 2003-2014.

1.D Estimation Appendix

1.D.1 Production function estimation

Estimator Properties

The estimation approach leverages a classical minimum distance estimator. This is natural, given that the estimation procedure first estimates regional pass-throughs of firm-level demand shocks into relative employment and wages and then uses these moments to a system of moment equations.

Denote by $\hat{\beta}^X_{Y,\hat{\xi}}$ the coefficient estimate of a two-stage IV regression of an outcome X on a dependent variable Y,instrumented by changes in $\hat{\xi}$ as a first stage. The set

of moment condition in equation (1.24) can then be written as:

$$\mathcal{G}\left(\Theta, \hat{\beta}\right) = 0. \tag{1.61}$$

For a weighting matrix W and set of estimates $\hat{\beta}$, the minimum distance estimator for the parameters of interest $\hat{\Theta}$ then solves the following problem:

$$\hat{\Theta} = \arg\min_{\Theta} \mathcal{G}\left(\Theta, \hat{\beta}\right)' W \mathcal{G}\left(\Theta, \hat{\beta}\right). \tag{1.62}$$

The estimate will thus solve the following first-order condition:

$$\left(\frac{\partial \mathcal{G}\left(\hat{\Theta}, \hat{\beta}\right)}{\partial \Theta}\right)' W \mathcal{G}\left(\hat{\Theta}, \hat{\beta}\right) = 0. \tag{1.63}$$

$\hat{\beta}$ is a consistent estimator of β. Then the continuous mapping theorem implies that $\hat{\Theta}$ is a consistent estimator of the true underlying set of parameters, that is $\hat{\Theta} \xrightarrow{p} \Theta$. To construct standard errors, note that the estimates inherit any imprecision stemming from the set of two-stage IV estimates $\hat{\beta}$. To derive the variance-covariance matrix, define a mapping H that maps the estimates of reduced form moments into the structural parameters of interest by way of the first-order condition (1.63):

$$H\left[\hat{\beta}, \Theta\left(\hat{\beta}\right); W\right] \equiv \left(\frac{\partial \mathcal{G}\left(\hat{\Theta}, \hat{\beta}\right)}{\partial \Theta}\right)' W \mathcal{G}\left(\hat{\Theta}, \hat{\beta}\right) = 0. \tag{1.64}$$

Denoting by P the total number of observations used to compute the moments β, the asymptotic distribution of $\hat{\Theta}$ can be derived by applying first the implicit function theorem and then the Delta method. The asymptotic distribution of $\hat{\Theta}$ is then given by:

$$\sqrt{P}\left(\hat{\Sigma} - \Sigma\right) \xrightarrow{d} \mathcal{N}\left(0, \tilde{H}' V_{\hat{\beta}} \tilde{H}\right), \tag{1.65}$$

where $\tilde{H} \equiv \left(H_2\left[\hat{\beta}, \hat{\Theta}; W\right]\right)^{-1} H_1\left[\hat{\beta}, \hat{\Theta}; \Omega\right]$. H_2 and H_1 denote multivariate derivatives of $\frac{\partial \mathcal{G}(\Theta,\beta)}{\partial \Theta}' W\mathcal{G}(\Theta, \beta)$ with respect to Θ and β respectively. $V_{\hat{\beta}}$ denotes the variance-covariance matrix of the estimates of β. The standard errors of the parameters depend directly on the variance-covariance structure obtained from the estimation of β.

Identification

Endogenous elasticity of labor supply to the firm The identification argument laid out in Section 1.4.1 allows the elasticity of the elasticity of labor supply to be firm-specific. However, it assumes that the elasticity to labor supply is exogenous to the actions of the firm. However, in many models of monopsony, the elasticity of the labor supply to the firm depends on the wage that it offers (e.g. Burdett and Mortensen (1998), Manning (2011), Manning and Petrongolo (2017), Berger et al. (2019)). Here I lay out sufficient conditions under which the estimation approach outlined in the main text can be augmented to accommodate endogenous heterogeneity in labor supply to the firm.

Consider an (equilibrium) labor supply function $\mathcal{L}(W, \Omega)$ to an individual firm (omitting subscripts for skill types) and assume that $\mathcal{L}$ is continuously differentiably. W denotes the wage, and Ω denotes general equilibrium objects, such as wages paid by all other firms and the stock of total workers. Denote $\beta(W, \Omega) \equiv \frac{\partial \log \mathcal{L}}{\partial \log W}$ the elasticity of labor supply to individual firms. Wages are be given by equation (1.12) with labor supply elasticities being given by $\beta(W, \Omega)$.

The estimation approach outlined in the main text requires partial identification of the parameters of the production function from a shock that is exogenous to unobserved sources of heterogeneity in labor demand. If changes in the mark-down on wages $M(\beta) \equiv \frac{\beta(W)}{\beta(W)+1}$ in response to the shock are estimable, partial identification can be attained. Intuitively, changes in the mark-down term are estimable, if $\beta(W)$

admits "sufficient statistics" in the sense of Chetty (2009). $\beta(W,\Omega)$ is said to admit sufficient s tatistics, if there exist statistics $\mathbf{t}=(t_1,...,t_N)$ such that

$$d\log\beta=\alpha_w d\log W+\sum_{n=1}^{N}\alpha_N d\log t_n.$$

Changes in the mark-down on wages can be written:

$$dm\equiv d\log M(\beta)=\underbrace{\left(\alpha_w d\log W+\sum_{n=1}^{N}\alpha_N d\log t_n\right)}_{\equiv dz}\underbrace{\left(-\frac{\beta}{\beta+1}\right)}_{\equiv\tilde{M}}.$$

The covariance between changes in the mark-down and an exogenous shock ξ can be written:

$$Cov(dm,d\xi)=E(dz)\,Cov\left(\tilde{M},d\xi\right)+E\left(\tilde{M}\right)Cov(dz,d\xi)+\nu,$$

where $\nu=E\left[\left(\tilde{M}-E\left(\tilde{M}\right)\right)(dz-E(dz))(\xi-E(\xi))\right]$.

If *changes* in ξ are independent from initial *levels* in mark-downs M, then $Cov\left(\tilde{M},d\xi\right)=0$ and $\nu=0$. Then the above expression simplifies to:

$$Cov(dm,d\xi)=E(M)\,Cov(dz,d\xi).$$

Identification requires that the following term is estimable, up to structural constants:

$$E(\tilde{M}_s)Cov(dz_s,d\xi)-E(\tilde{M}_{s'})Cov(dz_{s'},d\xi)+(\varepsilon_s-\varepsilon_{s'})\,dq.$$

If the statistics $\mathbf{t}=(t_1,...,t_N)$ can be observed, then $Cov(dz,d\xi)$ is computable, up to the constants $\alpha_w,(\alpha_n)$. If $\beta>1$, the last term in turn can be expanded:

$$E\left(\tilde{M}\right)=\frac{b}{1+b}+\frac{b}{(1+b)^2}E(dz)+\mathcal{O}\left(\frac{b^2}{(1+b)^3}\right),$$

for some constant b. Thus partial identification to first-order is ensured.

Sufficient statistics are admitted in many models. An extension of the present framework where firms internalize their effect on aggregate labor demand admits the sufficient statistic $t_{s,f} = \frac{W_{s,f} l_{s,f}}{\sum_{f'} W_{s,f'} l_{s,f'}}$, as in Berger et al. (2019).

Variation across regions A condition for full identification is that the system of moment conditions is not collinear:

$$\frac{\text{Cov}_r\left(d\log\left(\frac{l_{s,f,t}}{l_{s',f,t}}\right), d\log\hat{\xi}_{f,t}\right)}{\text{Cov}_r\left(d\log\left(Q_{f,t}\right), d\log\hat{\xi}_{f,t}\right)} \neq \frac{\text{Cov}_{r'}\left(d\log\left(\frac{l_{s'',f,t}}{l_{f,s',t}}\right), d\log\hat{\xi}_{f,t}\right)}{\text{Cov}_{r'}\left(d\log\left(Q_{f,t}\right), d\log\hat{\xi}_{f,t}\right)}.$$

Using the structural expression for labor supplies, the equilibrium change in relative labor supplies is given by:

$$\begin{aligned}
\text{Cov}_r\left(d\log\left(\frac{l_{s,f,t}}{l_{s',f,t}}\right), d\log\hat{\xi}_{f,t}\right) &= \beta_s \text{Cov}_r\left(d\log\left(W_{s,f,t}\right), d\log\hat{\xi}_{f,t}\right) \\
&- \beta_{s'} \text{Cov}_r\left(d\log\left(W_{s',f,t}\right), d\log\hat{\xi}_{f,t}\right) \\
&+ \text{Cov}_r\left(d\log\left(\Lambda_s/\Lambda_{s'}\right), d\log\hat{\xi}_{f,t}\right) \\
&+ \text{Cov}_r\left(d\log\left(A_{s,f}/\Lambda_{s',f}\right), d\log\hat{\xi}_{f,t}\right)
\end{aligned}$$

The effect operating through aggregate labor demand can be written as:

$$\text{Cov}_r\left(d\log\left(\Lambda_s\right), d\log\hat{\xi}_{f,t}\right) = \sum_{f\in\mathcal{F}} \frac{W_{s,f} l_{s,f}}{\sum_{s,f'} W_{s,f'} l_{s,f'}} \beta_s \text{Cov}_r\left(d\log\left(\frac{W_{s,f}}{A_{s,f}}\right), d\log\hat{\xi}_{f,t}\right).$$

These terms will differ across regions so long as employment shares and shock exposure, as measured by the covariance term on the RHS, are not perfectly correlated across regions. As the empirical implementation uses a foreign demand shock, this condition will be satisfied if, for example, the market wage bill shares of exporting and domestic firms differ across both regions. Given the sizable structural differences between former East and West German federal states, this is likely to be the case in the data.

The covariance between changes in a firm's output and some structural shock is given by, suppressing region subscripts:

$$\begin{aligned}\text{Cov}\left(d\log Q_{f,t}, d\log\hat{\xi}_{f,t}\right) = \quad & \text{Cov}\left(\frac{\tau Q^X_{f,t}}{Q_{f,t}}\left(-\eta\frac{d\log MC_{f,t}}{d\log\hat{\xi}_{f,t}} - \eta d\log\tau + d\log Y^*\right), d\log\hat{\xi}_{f,t}\right) \\ & + \text{Cov}\left(\frac{Q^H_{f,t}}{Q_{f,t}}\left(-\eta\frac{d\log MC_{f,t}}{d\log\hat{\xi}_{f,t}} + d\log P^{\eta-1}Y\right), d\log\hat{\xi}_{f,t}\right).\end{aligned}$$

If the equilibrium distribution of export-shares in output $\frac{\tau Q^X_{f,t}}{Q_{f,t}}$ (over firms) differs across regions, then $\text{Cov}_r\left(d\log\left(Q_{f,t}\right), d\log\hat{\xi}_{f,t}\right)$ will differ across regions.

To summarize, the set of partially identified parameters across regions will inform the technological parameters if the regions differ in the characteristics of exporting firms, export shares of firms, and/or the distribution of workers across firms.

1.D.2 Model Solution Algorithm

I first discretize the joint distribution of demand shifters φ and amenities A by calculating nodes and their associated weights through a quadrature routine (qnwlogn) that is supplies as part of both the "QuantEcon.jl" and "CompEcon.jl" packages in Julia.

The solution algorithm of the model is detailed below.

1. Guess the aggregate number of firms.
2. Guess aggregate income D = Labor Income + Profits - Fixed Cost
3. Loop: Solve for equilibrium in product and labor markets, given the guess for D.
   (a) Guess labor market tightness for all worker groups s : $\Delta_s = \left(\int W^{\beta_s}_{s,f} df\right)^{-1}$
      i. Loop: Solve for price index P
         A. Guess P.

B. Given guesses for Δ_s, D and P, solve for profit-maximizing wages, labor demands and market entry decisions of firms.

C. Use the marginal costs obtained in step B. to calculate an updated guess for the aggregate price index. Update guess for P until convergence.

ii. Use wages from step ii. to update the guess on aggregate labor demand. Update guess until convergence.

4. Use wages, profits, and market entry decisions obtained in step 2. to update guess of income D. Update guess with step-size halfway between the old and new guess and return to step 1. Repeat until convergence.

5. Given the implied expected profits, calculate the mass of entering firms. Update the initial guess by taking a convex combination of initial and implied mass of firms and return to step 1 until convergence.

1.D.3 Calibration Algorithm

To calibrate the model, define the loss function:

$$L(\Theta) = (\mathcal{M}(\Theta) - \overline{m})' W (\mathcal{M}(\Theta) - \overline{m}),$$

where $\mathcal{M}(\Theta)$ is a vector that contains the simulated moments for parameter values Θ, $\overline{m}$ denotes the vector of empirical target moments, and W is a weighting matrix. I weight moments by the square of their inverse target value.

To find the set of parameters that best fits the target moments $\mathcal{M}(\Theta)$, I implement the following algorithm.

1. Initialize guess for the parameter space. $a_0 = \left[\underline{\Theta}_0, \overline{\Theta}_0\right]$

2. Evaluate the objective function at points given by a Sobol sequence with 500 elements through the parameter space.

3. Keep the guesses falling into the 30th percentile of Loss function evaluations and update the guess of the parameter space through keeping the respective highest and lowest values.

4. Return to step 2 and increase the number of elements in the Sobol sequence.

5. Repeat this procedure until convergence.

A Sobol sequence (Sobol (1967)) generates quasi-random numbers through $A \subset \mathbb{R}^n$ that fill the space of possibilities more evenly than pseudo-random numbers and therefore allows for faster convergence of the algorithm. To implement the algorithm, I use the "Sobol.jl" package in Julia.

Chapter 2

Trade and Structural Transformation: Assessing the Decline of U.S. Manufacturing Employment

2.1 Introduction

In this chapter, we quantitatively investigate how trade affects a country's structural transformation. Structural change has been a robust feature of economic development, significantly affecting the allocation of productive factors across sectors and places. This structural transformation of economic activity affects a vast array of outcomes, including relative factor returns such as the skill wage premium, and patterns of international specialization. Further, this structural change affects how people live and organize their lives as productive capacities shift from manufacturing-focused production patterns towards the needs of a service-oriented economy. In this chapter, we study quantitatively how international trade interacts with a country's structural transformation.

The previous literature focusing on economic growth and structural change has gone a long way in identifying and structurally assessing key drivers of secular trends but has mainly focused on closed economy frameworks.[1] While the assumption of a closed economy may have been appropriate for the larger part of the relevant time series, seeing that trade volumes in both intermediate and final goods have nearly tripled over the past 20 years suggests that a quantitative re-assessment is in order. Indeed, a country's ability to decouple its production patterns from its domestic consumption needs may have become increasingly consequential for the recent decades amid rising trade.

To motivate the potential role for international trade in understanding domestic sectoral shifts in economic activity, we provide reduced-form evidence suggesting that international trade accounts for about a third of the overall decline in the manufacturing employment share from 1995 to 2011 in the United States. This chapter seeks to understand quantitatively to what degree changes in trade frictions have contributed to these trends. Further, recent decades have seen an increase in the tradability of services. Services are traditionally assumed to be non-tradable, mainly due to issues related to the precise classification of service activities or the reliability/availability of the data. We make use of the fact that recent international input-output tables allow tracking bilateral trade flows in goods as well as services, and ask to which degree decreasing trade frictions in services interact with a country's pattern of structural change.

To give quantitative answers to these questions, we develop a new framework to study the impact of international trade on structural change. To disentangle the role of international trade from classical forces considered in the structural change literature, we incorporate demand effects into our model, modeling intra-temporal preferences across sectors following the Generalized CES formulation first put forward

[1] See for example Herrendorf et al. (2013) for a comprehensive review.

by Hanoch (1975) and Sato (1975). As recently shown by Matsuyama (2015) and Comin et al. (2017), this class of preferences will give rise to non-homothetic demand curves. In contrast to the class of preferences used in Swiecki (2017), these preferences allow us to separate the impact of income and price effects on a country's structural transformation. In contrast to the Stone-Geary formulation used, for example, in Uy et al. (2013), our chosen class of preferences do not become homothetic in the limit, allowing us to account for a wide variety of observed expenditure shares.

On the production side, we incorporate multi-sectoral production with input-output linkages as in Caliendo and Parro (2015) into a quantitative framework of international trade a la Eaton and Kortum (2002), allowing for multiple factors of production, sector-varying factor intensities as well as sector-varying productivity dispersion parameters. Accounting for both sector-biased technological growth as well as varying factor intensities, thereby accounts for both Ricardian and Heckscher-Ohlin forces of international trade. We fully estimate all relevant parameters in the model, including the technological dispersion parameters, and provide first estimates for the services sector.

Endogenizing the evolution of investment, we allow capital to be optimally chosen within the model. Unlike Kortum et al. (2016), however, we are able to formulate the competitive equilibrium of the model rather than the social planner's problem, owing to the fact that our modeling assumptions imply that whilst capital is chosen optimally by forward-looking agents, investment is fully pinned down by the current-period equilibrium. In contrast to Anderson et al. (2015), our setup also implies a closed-form solution to the investment problem of the household, while still being able to account for a rich multi-sectoral setup with intermediate input trade. However, unlike Reyes-Heroles (2016), we do not endogenize external imbalances, which, as shown in Reyes-Heroles (2018), is a quantitatively important channel for the effects of international trade on structural transformation.

Our modeling choices preserve many desirable features of recent quantitative models of international trade. In particular, we can fully solve our model in relative changes, greatly reducing the data requirements for counterfactual exercises (Dekle et al. (2007)). We provide restrictions on trade cost under which the existence and uniqueness of the equilibrium is ensured. Specifically, our uniqueness proof establishes a condition under which Gross Substitution for the implied excess factor demand system holds. We provide a way to check this condition using only observables numerically.

Further, we show that given preference and production function parameters, using only data on expenditure shares, trade shares as well as factor compensation and investment, the model can be uniquely inverted to yield the changes in technologies and trade costs that rationalize observed allocations as an equilibrium of the model.[2] We use the invertibility property of the model to calibrate trade costs and patterns of comparative technological advantage for ten countries and five sectors from 1995 to 2011.

We use our fully estimated model to understand the role of changing trade frictions for the recent decline in US manufacturing. Using our reduced-form benchmark of trade accounting for a third of the loss in US manufacturing jobs, we use the model to infer changes in trade costs for manufacturing goods that would counterfactually save that many jobs, taking the estimated paths of technologies and trade costs as given. We find that a yearly uniform increase over the observed change in trade costs in manufacturing goods of 2.3% would have saved about 1.5 million jobs in the manufacturing sector, while reducing aggregate welfare. Over the period from 1995 to 2011, this corresponds roughly to the global reduction in tariffs since 1995 brought about by multilateral WTO agreements and lends further support to the hypothesis that increased competition from, for example, China contributed significantly to the

[2]To do so, we require the assumption that the CES weights in demand are fixed.

drop in US manufacturing.[3] We undertake the same exercise but asking instead whether a change in trade frictions in services could have saved the equivalent of 1.5 million jobs over these 17 years. We find that a 5.5 percent *decrease* in trade costs in services would have saved the same number of jobs in manufacturing as the corresponding increase in manufacturing trade costs. Two forces are key to this result. First, decreasing services trade costs reduce prices for services relative to manufacturing, which increases manucturing employment since services and manufacturing are estimated to be complements.[4] Second, decreasing trade costs raise real income, which increases employment in manufacturing sectors with high income elasticity. A key finding of this chapter, therefore, is that trade in services has the potential to interact with structural transformation in a perhaps surprising way.

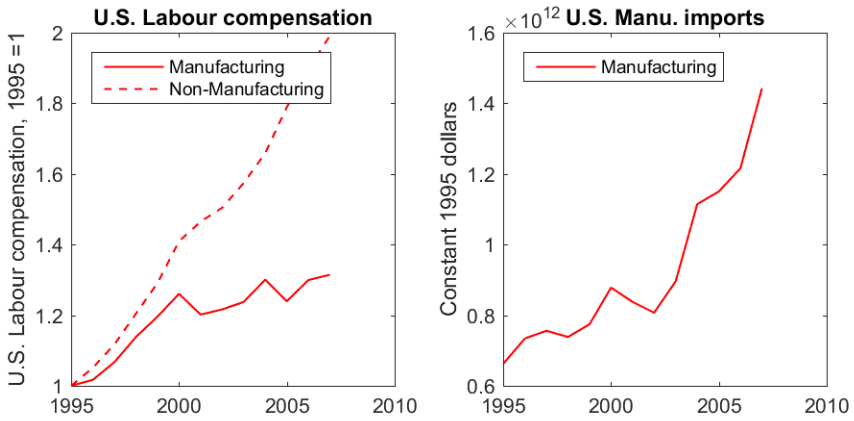
We conclude by undertaking predictive exercises beyond our sample period, implying that in our baseline scenario, US manufacturing employment will decline another 0.7% in its share by 2023, or the equivalent of about 800.000 jobs. Decreasing trade costs beyond the fitted trends similar to the changes that would have saved 1.5 million US jobs between 1995 and 2011, we predict that this loss would be mitigated by about fifty percent through the increased tradability of services. This finding leads us to the perhaps surprising conclusion that one tool to revive manufacturing employment in the future can be the reduction of trade costs in services. Increases in tariffs in the manufacturing sector can have a similar effect, but likely at the expense of domestic price levels and welfare.

The structure of this paper is as follows. Section 2.2 presents facts that motivate our modeling choices and will guide our counterfactuals. Section 2.3 describes the model in full detail. Section 2.4 discusses the estimation of all parameters relevant for counterfactuals as well as the inversion that we undertake to recover trade costs

[3] Caliendo et al. (2019) focus specifically on the role of falling import trade costs from China.

[4] Similarly, Cravino and Sotelo (2019) find that manufacturing trade reduces the price of manufacturing relative to services, which reduces manufacturing employment if services and manufacturing are complements.

Figure 2.1: Growth in Labor Compensation and Increased Trade in the US



Notes: The left panel displays growth rates in labor cost in manufacturing and non-manufacturing sectors. The right panel plots the value of US manufacturing imports. Data sources: World Input Output Database.

and technological paths from the model. Section 2.5 presents the counterfactual and prediction exercises and section 2.6 concludes.

2.2 Motivating Facts

The U.S. manufacturing employment compensation share fell by 31.5% between 1995 and 2007, corresponding to about 5 million jobs. Figure 2.1 depicts the relative growth in labor cost for the manufacturing and non-manufacturing sector and illustrates the decline in the labor compensation share of US manufacturing industries. The right panel displays the growth in manufacturing imports over the same period.

Economists and politicians alike have proposed a host of explanations, including increased import competition in output markets (Autor et al. (2013)), or changes in the labor-cost share (Neiman and Karabarbounis (2014)). To motivate our work, we start by conducting novel reduced-form decompositions of the relative decline in US manufacturing employment. Simple accounting allows us to write total labor

compensation in the manufacturing sector across its industries S_M in country i, $w_M^i L_M^i$ as:

$$w_M^i L_M^i = \sum_{s_M \in S_M} \underbrace{\alpha_{S_M}^L}_{\text{Labor share}} \underbrace{y_s^i}_{\text{Gross Output}}, \tag{2.1}$$

where $\alpha_{s,M}^L$ denotes the labor cost-share in manufacturing sector s_M and y_S^i denotes gross output of industry s in country i. The following remark shows that the growth of labor compensation in US manufacturing industries can be decomposed into a level, a compositional, as well as a labor-cost-share effect.

Remark 2.1. The growth rate in labor compensation, g_{wL}, denoting next period values of variable x by x' and $g_x \equiv \frac{x'}{x} - 1$, can to a first-order be decomposed as follows:

$$g_{wL} = \underbrace{\sum y_s g_{y_s}}_{\text{Level}} + \underbrace{\sum_s \frac{\alpha_s y_s'}{\sum_k \alpha_k y_k'} g_{\alpha_s}}_{\text{Labor-Cost Share}} + \underbrace{\frac{\sum_s \alpha_s \frac{y_s'}{\sum_k y_k'}}{\sum_s \alpha_s \frac{y_s}{\sum_k y_k}} - 1}_{\text{Sector Composition}} \tag{2.2}$$

The first term captures a pure level effect: Part of changes in labor compensation will be driven by the output growth in the sub-industries of the US manufacturing sector. The second and third term capture the contribution of changes in the labor cost-share as well as compositional effects within the manufacturing industry.

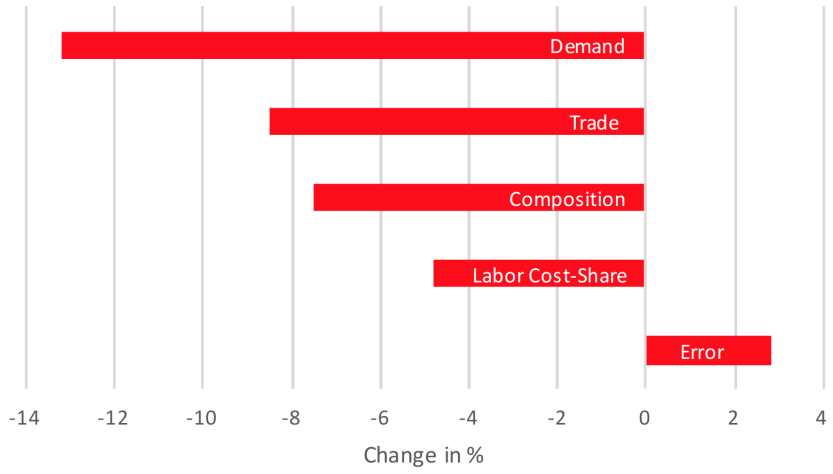
Further, the gross output of industry s in country i is given by:

$$y_s^i = \sum_n \lambda_s^{in} D_s^n,$$

where λ_s^{in} denotes the share of counry n's total expenditure on sector s goods that is sourced from country i, and D_s^n denotes the gross value of country n's demand for sector s goods. Using this, we can exactly decompose the growth rate of sectoral output as follows:

$$g_{y_s^i} = \sum_n g_{\lambda_s^{in}} + g_{D_s^n}. \tag{2.3}$$

Figure 2.2: Decomposed Growth of the US Labor Compensation Share of Manufacturing



Notes: This figure decomposes the change in the US manufacturing labor cost share between 1995 and 2011 according to equations (2.2) and (2.3). Data Sources: World Input Output Database, KLEMS.

Armed with equations (2.2) and (2.3), we undertake an accounting exercise that decomposes changes in the manufacturing labor compensation share into (1) changes in the labor cost-share, (2) compositional effects, (3) changes in demand and (4) changes in world market shares.[5]

Figure 2.2 displays the results of this decomposition: Losses in market shares (trade) account for 9 percent of the total decrease of 31.6 percent in the manufacturing employment share. In comparison, shifts in relative demand for manufacturing goods decreased the labor compensation share of manufacturing by 13.2 percent. This simple exercise suggests that accounting for changes in trade shares - absent in most closed-economy models of structural change - is essential for understanding the recent U.S. experience of structural change.

[5]We use the World Input Output Database and KLEMS to implement these decompositions. Please see section 2.4. for a detailed description of our data sources.

2.3 A Quantitative Model of Trade and Structural Transformation

This section describes our structural framework and presents key results regarding the existence and uniqueness of the dynamic equilibrium. We construct a multi-sectoral model of trade suited for quantitatively studying the impact of trade on structural change. Major drivers of models of structural change in closed economies – price effects, income effects, dynamic capital paths – are explicitly modeled, as are both technological and factor-driven motives for trade. Our framework thereby nests many previous models in the literature as special cases while preserving the tractability of recent quantitative trade models.

Time is discrete and indexed by t, an index we often omit for clarity of exposition. There are N countries, indexed by indices $n, l, k \in \mathcal{N}$. In each country, the output of S sectors, indexed by $s, s' \in \mathcal{S}$, can be either used as an intermediate input in the production of other goods and services or for final consumption. Investment goods are produced using goods from all other sectors. All sectors use both capital and labor as primitive factors of production.[6]

2.3.1 Production

Sectors combine primary factors of production as well as intermediate inputs purchased from other sectors to produce their final output, which can be used as an intermediate input, consumption, or for the production of investment. We impose no restrictions on the tradability of sectoral output. That is, all output can potentially be traded internationally, in both goods and service sectors. Also, departing from Caliendo and Parro (2015), we allow the model to account for differing trade shares

[6] Our model easily generalizes to F factors of productions, plus capital.

in intermediates and final goods by allowing trade costs to vary depending on what kind of good is shipped.

Technology

A continuum of final good producers in each sector indexed by ω employ factors and intermediate goods to produce final goods according to a Cobb-Douglas technology:

$$y_s^n(\omega) = z_s^n(\omega) \left(l_s^n(\omega)^{\beta_s^n} k_s^n(\omega)^{1-\beta_s^n} \right)^{\vartheta_s^n} \left(\prod_{s'} M_{s's}^n(\omega)^{\alpha_{s',s}^n} \right)^{1-\vartheta_s^n},$$

where β_s^n denotes the labor share in value added, ϑ_s^n denotes the value added share in production and $\alpha_{s's}^n$ denote the cost shares of sector s' intermediate goods in the production of sector s goods in country n. $M_{s's}^n$ in turn denotes an aggregate of sector s' intermediates used in the production in sector s in country n over the unit interval of available intermediates in that sector and is given by:

$$M_{s's}^n(\omega) \equiv \left(\int_0^1 m_{s's}^n(\omega, \varpi)^{\frac{\nu-1}{\nu}} d\varpi \right)^{\frac{\nu}{\nu-1}}.$$

We follow Eaton-Kortum (2002) and model $z_s^n(\omega)$ as a variety-specific productivity draw from to a Frechet distribution:

$$F_s^n(z) = e^{-T_s^n z^{-\theta_s}}.$$

We assume that efficiency draws are independent across goods and countries. Assuming that markets are perfectly competitive, the price $q_s^n(\omega)$ of sector s variety ω supplied to the domestic market is simply equal to the marginal cost of production.

$$q_s^n(\varpi) = \frac{q_s^n}{z_s^n(\varpi)},$$

where q_s^n is is the cost of an input bundle in country n in sector s. This in turn can be characterized as:

$$q_s^n = \Psi_s^n \left((w^n)^{\beta_s^n} (r^n)^{1-\beta_s^n} \right)^{\vartheta_s^n} \left(\prod_{s'} (Q_{s's}^n)^{\alpha_{s',s}^n} \right)^{1-\vartheta_s^n}. \tag{2.4}$$

Here, Ψ_s^n is a constant of technology parameters,[7], w^n and r^n respectively denote the wage and rental rate in country n, and $Q_{s's}^n$ is the price index of the composite of intermediate goods shipped from sector s' to s.[8]

Producers serve final-good consumers, other producers of final goods and services as well as investment goods producers around the world. Trade across national borders is assumed to be frictional. We assume that the trading costs that a good incurs when crossing a border are different depending on whether it is shipped as an intermediate, final, or investment good.[9] In particular, we denote by τ_s^{kn} the trade costs of shipping a final good in sector s from country k to n, and by $\bar{\tau}_{s's}^{kn}$ the trade costs of shipping a sector s' intermediate good from country k to sector s in country n. Finally, $\tau_{I,s}^{kn}$ denotes the cost of shipping a sector s good intended for the production of investment goods from country k to country n. All trade costs are assumed to satisfy the triangle inequality.

Suppliers compete on world markets and thus the price of a consumer located in country n, shopping for a variety ω in sector s is the price set by the most-cost effective producer and thus given by:

$$p_s^n(\omega) = \min_k \left\{ \tau_s^{kn} q_s^k(\omega) \right\}.$$

[7]Specifically, $\Psi_s^n = (\vartheta_s^n \beta_s^n)^{-\vartheta_s^n \beta_s^n} \left(\vartheta_s^n (1-\beta_s^n)\right)^{-\vartheta_s^n (1-\beta_s^n)} \prod_{s'} \left((1-\vartheta_s^n)\alpha_{s's}^n\right)^{-(1-\vartheta_s^n)\alpha_{s's}^n}$

[8]We will characterize this price index, which will implicitly carry information about the entire input-output network, in the next subsection.

[9]This assumption will allow us to rationalize the rich bilateral trade pattern across countries and across final, intermediate and investment goods.

Equivalently, the price actually paid for final goods used as intermediates for either investment or production, denoted respectively $p_{I,s}^n(\omega)$ and $q_{s's}^n(\omega)$, are given by:

$$p_{I,s}^n(\omega) = \min_k \left\{ \tau_{I,s}^{kn} q_s^k(\omega) \right\}$$

and

$$q_{s's}^n(\omega) = \min_k \left\{ \bar{\tau}_{s's}^{kn} q_s^k(\omega) \right\}.$$

We now turn to describing the production of investment goods used for the accumulation of capital in each country.

Investment Goods

Investment goods in each country are produced by combining domestic final goods according to the following Cobbb-Douglas production technology:

$$y_I^n = T_I^n \prod_s \left(y_{I,s}^n \right)^{\alpha_{s,I}^n},$$

Where $y_{I,s}^n$ is a CES aggregate over final goods sourced from world markets, given by:

$$y_{I,s}^n \equiv \left(\int_s q_{I,s}^n(\omega)^{\frac{\nu-1}{\nu}} d\omega \right)^{\frac{\nu}{\nu-1}}.$$

Denoting by $P_{I,s}^n$ the ideal price index of the aggregate bundles of final goods from sector s used to produce in investment goods in country n, unit costs in the investment goods sector can then be written as:

$$q_I^n = \frac{1}{T_I^n} \Psi_I^n \prod_s \left(P_{I,s}^n \right)^{\alpha_{I,s}^n} .. \tag{2.5}$$

Having described the supply side setup of the model, we now turn to the description of the demand side, spelling out preferences as well as the optimization problem that consumers face.

2.3.2 The Demand Side - Workers and Investors

Each country is populated by an exogenously evolving mass L_t^n of inhabitants. We assume that a fraction χ of them are workers, and a fraction $1-\chi$ are investors.[10] Workers supply labor, while investors accumulate and rent capital to domestic firms. The initial stock of capital in country n is denoted by K_0^n. Investors can purchase investment goods for $P_{I,t}^n$ to increase their capital stock according to the following law of motion:

$$K_{t+1}^n = (1-\delta^n)K_t^n + I_t^n, \tag{2.6}$$

where δ^n is the depreciation rate of investors' capital in country n. Agents take the prices for the factors that they supply to the economy as given.

We model investors as a dynasty that jointly decides the optimal allocation of aggregate capital and distributes the proceeds to all its members in order to maximize per-capita consumption over the lifetime of the dynasty. Preferences over inter-temporal consumption bundles are assumed to take the following form:

$$\sum_{t=0}^{\infty} \mu^t \log\left(\frac{C_t^{n,K}}{(1-\chi_t^n)L_t^n}\right),$$

with $\mu \in (0,1)$ denoting the discount factor. Each worker, in turn, is endowed with a unit of labor that is supplied inelastically at a wage w_t^n.

[10] In line with some papers in the Public Finance literature – where investors are often called capitalists, e.g. Judd (1985) or Chamley (1986) – we don't allow workers to invest. As explained in Moll (2014), this combined with log-utility for investors implies simple saving rate rules, and hence renders a simple analytical solution to each country's dynamic problem.

Intra-temporal preferences are captured by the aggregate consumption index $C_t^{n,j}$ for $j \in \{L, K\}$. Specifically, we assume a nested demand system over the S sectors of consumption goods. Following Comin et al. (2017), preferences over $C_{s,t}^{n,j}$ take the following generalization of the CES utility function:

$$\sum_{s \in \mathcal{S}} \zeta_s^{\frac{1}{\eta}} \left(\frac{C_{s,t}^{n,j}}{C_t^{n,j \, \frac{\varepsilon_s - \eta}{1-\eta}}} \right)^{\frac{\eta-1}{\eta}} = 1, \tag{2.7}$$

where $C_t^{n,j}$ is the implicitly defined aggregate consumption and $C_{s,t}^{n,j}$ denotes sectoral aggregate consumption. Note that we allow the sector-specific elasticity of income ε_s to vary across sectors; this preserves the special case of a homothetic demand system when ε_s is constant for all s. Moreover, we allow the shifters ζ_s at the aggregate level to be sector- but not country-specific, implying that technological differences will drive differences in sectoral compositions across countries over time.[11] We impose the empirically relevant case $\varepsilon_s \geq \eta$ for all s and $\eta < 1$. Given this assumption, the aggregate consumption index C^n is increasing in income, as well as weakly increasing and quasi-concave in all its arguments. Note, as well, that we are free to normalize $\varepsilon_1 = 1$.

Each sector-specific consumption good $C_{s,t}^{n,j}$ is a CES aggregate over a continuum of sector-specific varieties, consumed in amount $c_{s,t}^{n,j}(\omega)$:

$$C_{s,t}^{n,j} = \left(\int_0^1 c_{s,t}^{n,j}(\omega)^{\frac{\sigma_s - 1}{\sigma_s}} d\omega \right)^{\frac{\sigma_s}{\sigma_s - 1}}$$

In each period t, consumers in country n then maximize aggregate consumption subject to the following budget constraint:

$$\sum_{s \in \mathcal{S}} \int_0^1 p_{s,t}^n(\omega) c_{s,t}^{n,j}(\omega) = E_t^{n,j},$$

[11] For most of our empirical exercises, this assumption is innocuous as these shifters will be absorbed in the empirical consumption expenditure shares.

where $p^n_{s,t}(\omega)$ is the price of variety ω of sector s in country n, and $E^{n,j}_t$ is the income dedicated to consumption by a worker or a capitalist. The latter's consumption spending equals their income from capital less their spending on investment goods. Workers disposable income equals the sum of their labor income and their share in the countries trade deficit D^n_t. The trade deficit is assumed to be exogenous, and is divided equally among all workers. Hence we can write:

$$E^{n,L}_t = w^n_t + \frac{D^n_t}{\chi^n_t L^t_n}$$

$$E^{n,K}_t = \frac{r^n_t K^n_t - P^{n,I}_t I^n_t}{(1-\chi^n_t)L^n_t},$$

where I^n_t denotes the investment decision of the dynasty of investors. Note that we define the relevant income to be in per-capita terms as income per capita is relevant under a non-homothetic demand system while it carries the same implications as using aggregate income in the homothetic case.

As is common with nested preference structures, the intra-temporal problem can be solved in two stages. In the first stage, the consumer chooses the expenditure $E^{n,j}_{s,t}$ that is to be allocated to sector s goods. Then, given sectoral expenditures, $E^{n,j}_{s,t}$, in the second stage final good expenditures within sector s are optimally chosen. Investors, in addition to that have to solve a dynamic problem, which can be solved in another stage: Investors first choose consumption and investment so as to allocate resources across periods optimally. Taken this as given, they then solve the intra-temporal allocation described above. In the second stage, given $E^{n,j}_{s,t}$, we obtain the usual demand schedule for available varieties in sector s:

$$c^n_{s,t}(\omega) = \frac{\left(p^n_{s,t}(\omega)\right)^{-\sigma_s}}{\left(P^n_{s,t}\right)^{1-\sigma_s}} E^{n,j}_{s,t}, \tag{2.8}$$

where the ideal consumption price index $P^n_{s,t}$ in sector s and country n is:

$$P^n_{s,t} = \left(\int_0^1 \left(p^n_{s,t}(\omega) \right)^{1-\sigma_s} d\omega \right)^{\frac{1}{1-\sigma_s}}. \tag{2.9}$$

We now turn to the problem of choosing sector expenditure shares $E^{n,j}_{s,t}$ given the price indices $P^n_{s,t}$ and consumption spending $E^{n,j}_t$. All derivations can be found in the appendix. The Marshallian demand for sectoral aggregates is given by:

$$C^{n,j}_{s,t} = \frac{\zeta_s \left(P^n_{s,t} \right)^{-\eta}}{\left(P^{n,j}_t \right)^{\varepsilon_s - \eta}} \left(E^{n,j}_t \right)^{\varepsilon_s} \tag{2.10}$$

$P^{n,j}_t$ is the consumer price index of consumer j, and is given by:

$$P^{n,j}_t = \left(\sum_{s \in \mathcal{S}} \zeta_s \left(C^{n,j}_t \right)^{\varepsilon_s - 1} \left(P^n_{s,t} \right)^{1-\eta} \right)^{\frac{1}{1-\eta}}, \tag{2.11}$$

where $C^{n,j}_t$ is the aggregate consumption index of consumer j. $C^{n,j}_t$ solves:

$$\left(E^{n,j}_t \right)^{1-\eta} = \sum_{s \in \mathcal{S}} \zeta_s \left(C^{n,j}_t \right)^{\varepsilon_s - \eta} \left(P^n_{s,t} \right)^{1-\eta} \tag{2.12}$$

Note how, owing to the assumed preference structure, aggregate income and income per capita no longer affect aggregate demand in the same manner. For instance, changing labor income per capita will shift expenditure shares from low- to high-income elasticity goods. For the case of standard CES preferences, such change will leave expenditure shares unchanged. We can express sectoral expenditure shares as follows:

$$e^{n,j}_{s,t} = \frac{\zeta_s \left(C^{n,j}_t \right)^{\varepsilon_s - \eta} \left(P^n_{s,t} \right)^{1-\eta}}{\sum_{s'} \zeta_{s'} \left(C^{n,j}_t \right)^{\varepsilon_{s'} - \eta} \left(P^n_{s',t} \right)^{1-\eta}}. \tag{2.13}$$

2.3.3 Equilibrium Characterization

We first derive the static equilibrium taking the endogenous current-period investment decision as given. Therefore, we drop time indices for ease of notation and re-introduce them for the dynamic part of the equilibrium.

Static part

To characterize the optimal behavior of both final and intermediate goods producers, we split the problem in two stages. In the first stage, we use the problem of intermediate goods providers to characterize the marginal cost function of final good producers. These cost functions will relate to final goods prices through the pricing expressions given above.

Prices Our distributional assumptions regarding the productivity parameters of producers across countries and sectors imply that we can follow steps similar to Eaton and Kortum (2002) to characterize price indices and trade shares. In particular, the production price index $Q^n_{s's}$ faced by producers in sector s, country n using intermediates from sector s' takes the following well-known form:

$$\begin{aligned} Q^n_{s's} &= \left(\int_\Psi q^n_{s's}(\varpi)^{1-\nu} d\varpi \right)^{\frac{1}{1-\nu}} \\ &= \gamma_{s'} \Phi^{n\ -1/\theta_{s'}}_{s',s}, \end{aligned}$$

where θ_s is the sector-specific dispersion parameter, $\gamma_{s'} \equiv \left(\Gamma \left(\frac{\theta_{s'}+1-\nu}{\theta_{s'}} \right) \right)^{1/(1-\nu)}$ is a constant, $\Phi^n_{s',s} = \sum_l T^l_{s'} (q^l_{s'} \bar{\tau}^{ln}_{s's})^{-\theta_{s'}}$ is a country- and sector-specific technological index, and q^n_s are unit costs given in expression (2.4).

Analogously, our setup implies that the consumer price index for the final aggregate consumption good in sector s in country n can be written as follows:

$$\begin{aligned} P_s^n &= \left(\int p_s^n(\omega)^{1-\sigma_s} d\omega \right)^{1/(1-\sigma_s)} \\ &= \gamma_s \Phi_{F,s}^{n^{-1/\theta_s}}, \end{aligned}$$

where θ_s is the sector-specific dispersion parameter, $\gamma_s \equiv \left(\Gamma \left(\frac{\theta_s + 1 - \sigma_s}{\theta_s} \right) \right)^{1/(1-\sigma_s)}$ is a constant, $\Phi_s^n = \sum_l T_s^l (q_s^l \tau_s^{ln})^{-\theta_s}$ is a country- and sector-specific technological index. Finally, the price of investment goods can be shown to be equal to:

$$P_I^n = \frac{1}{T_I^n} \Psi_I^n \prod_s \left(P_{I,s}^n \right)^{\alpha_{I,s}^n}$$

where

$$\begin{aligned} P_{I,s}^n &= \left(\int p_{I,s}^n(\omega)^{1-\sigma_s} d\omega \right)^{1/(1-\sigma_s)} \\ &= \gamma_{I,s} \Phi_{I,s}^{n^{-1/\theta_s}}, \end{aligned}$$

with $\gamma_{I,s'} \equiv \left(\Gamma \left(\frac{\theta_s + 1 - \nu}{\theta_s} \right) \right)^{1/(1-\nu)}$ and $\Phi_s^n = \sum_l T_s^l (q_s^l \tau_{I,s}^{ln})^{-\theta_s}$.

Trade shares Our framework yields the usual straightforward characterization of the relevant trade shares in intermediate, final goods as well as investment goods, which in turn will facilitate the formulation of the equilibrium's market clearing conditions.

In particular, the share of sector s' goods used in the production of sector s in country n originating from country l can be written as:

$$\begin{aligned}\pi_{s's}^{ln} &\equiv \frac{I_{s's}^{ln}}{I_{s's}^{n}} \\ &= \frac{T_{s'}^{l}(q_{s'}^{l}\bar{\tau}_{s',s}^{ln})^{-\theta_{s'}}}{\sum_k T_{s'}^{k}(q_{s'}^{k}\bar{\tau}_{s',s}^{kn})^{-\theta_{s'}}}.\end{aligned}$$

$I_{s',s}^{ln}$ is the intermediate good expenditure of sector s in country n in sector s' intermediates from country l, and $I_{s',s}^{n}$ are the total expenditures of that sector s from sector s'.

Similarly, for a given sector s and destination country n, the expenditure share on final consumption goods sourced from country l is given by:

$$\lambda_{s}^{ln} = \frac{T_{s}^{l}(q_{s}^{l}\tau_{s}^{ln})^{-\theta_s}}{\sum_k T_{s}^{k}(q_{s}^{k}\tau_{s}^{kn})^{-\theta_s}}.$$

Further, $\lambda_{I,s}^{ln}$ measures the fraction of sector s final goods shipped by country n for investment purposes in country n and can be written:

$$\lambda_{I,s}^{ln} = \frac{T_{s}^{l}(q_{s}^{l}\tau_{I,s}^{ln})^{-\theta_s}}{\sum_k T_{s}^{k}(q_{s}^{k}\tau_{s'}^{kn})^{-\theta_s}}.$$

Next, denote by F_s^n the total gross output of final goods in sector s - that is goods either used for investment or consumption - in country n. F_s^n can be expressed in terms of the world expenditure on these goods:

$$F_s^n = \sum_{l\in\mathcal{N}} \lambda_s^{nl}\left(e_s^{l,L}\left(w^l\chi^l L^l + D^l\right) + e_s^{l,K}\left(r^l K^l - P_I^l I^l\right)\right) + \sum_{l\in\mathcal{N}} \lambda_{I,s}^{nl}\alpha_{I,s}^{l} P_I^l I^l. \quad (2.14)$$

Next, denote by $\mathcal{I}_s^n$ the total gross output goods produced for the purpose of further usage as intermediate inputs in sector s in country n. This can be split into what sector s in country n sells to final as final goods, $\mathcal{I}_{F,s}^n$, and what it sells to produce

other intermediate goods around the world $\mathcal{I}_s^n$. The latter is given by:

$$\mathcal{I}_s^n = \sum_{l \in \mathcal{N}} \sum_{s' \in \mathcal{S}} (1 - \vartheta_{s'}^l) \alpha_{s,s'}^l \pi_{ss'}^{nl} \left(F_{s'}^l + \mathcal{I}_{s'}^l \right) \tag{2.15}$$

Using these components, we can define the market-clearing income conditions for labor and capital. For labor, we have:

$$w^n \chi^n L^n = \sum_{s \in \mathcal{S}} \beta_s^n \vartheta_s^n \left(\mathcal{I}_s^n + F_s^n \right) \tag{2.16}$$

For capital, we have:

$$r^n K^n = \sum_{s \in \mathcal{S}} (1 - \beta_s^n) \vartheta_s^n \left(\mathcal{I}_s^n + F_s^n \right) \tag{2.17}$$

This concludes the description of the static equilibrium. Taking this as given, we can characterize the optimal dynamic choices of investors in each country.

Dynamic part

Our assumptions regarding the inter-temporal preference structure, as well as the assumption that investors only care about one asset, implies, as is a known result pointed out in, for example, Lucas and Moll (2014), that the solution to the dynamic problem of the dynasty results in simple saving rules. As we show in the appendix, these policy rules imply that the aggregate capital stock in country n evolves according to the following law of motion:

$$K_{t+1}^n = \mu \left(\frac{r_t^n}{P_{I,t}^n} + (1 - \delta^n) \right) K_t^n. \tag{2.18}$$

The solution to the investor's problem implies that the growth rate of the capital stock depends solely on the rental rate of capital and the price of investment goods

in the current period. Thus, our setup implies that agents are optimally not forward-looking and base investment decisions solely on the current state of the world. This renders our model tractable, which has the additional advantage that establishing the existence and uniqueness of static equilibria implies the existence and uniqueness of a dynamic path.

Equilibrium definition

Putting all the pieces together, we are now in a position to define a competitive equilibrium.

Definition 2.1. Given factor endowments $\{L_t^n\}_{t\in\mathbb{N}}^{n\in\mathcal{N}}$ and K_0^n, a competitive equilibrium is a sequence of wages and rents $\{w_t^n, r_t^n\}_{t\mathbb{N}}^{n\in\mathcal{N}}$, aggregate consumption indices $\left\{C_t^{n,j}\right\}_{t\in\mathbb{N}}^{n\in\mathcal{N},j\in\{L,K\}}$ and capital stocks $\{K_t^n\}_{t\in\mathbb{N}}^{n\in\mathcal{N}}$ such that consumers and firms solve their optimization problems and markets for factors and goods clear.

2.3.4 Equilibrium properties

In this section, we discuss the properties of our equilibrium and derive conditions under which the existence and uniqueness of a competitive equilibrium are ensured.

Our first proposition is that the model can be re-written "in changes," despite having non- standard preferences over sectoral goods as well as a dynamic capital choice. To be more precise, a key feature of many recent quantitative models of international trade and economic geography is that they allow the researcher to solve for changes in endogenous variables after changing exogenous variables such as technologies or trade costs (Dekle et al. (2007)). This feature is desirable as it dramatically reduces the data requirements needed to undertake counterfactual exercises. Instead of having to know trade costs or technologies in levels, knowing changes in these variables is sufficient to study endogenous responses in reaction to this change.

Proposition 2.1. *Given trade shares π, λ, λ_I,investment I, expenditure shares* $\mathbf{e}$, *incomes wL, rK, the current period change in the capital stock, as well as data on deficits, counterfactuals can be undertaken without having to know the underlying elasticities $\boldsymbol{\sigma}, \nu$, the expenditure shifters $\boldsymbol{\zeta}$, the levels of technologies* $\mathbf{T}$, *the levels of trade cost τ, or the levels of factors* $\mathbf{L}, \mathbf{K}$.

All proofs are relegated to the appendix. Appendix 2.A displays the equations for the model in changes.

Next, we demonstrate that the existence of the general equilibrium can be established for any reasonable parametrization. Uniqueness for the dynamic equilibrium is ensured once we have established uniqueness of the static equilibrium. However, the uniqueness of the static equilibrium is harder to establish for two reasons: non-homothetictiy and the presence of production linkages. We present sufficient conditions to deal with the former, while Allen et al. (2015b) provide conditions sufficient to deal with the latter. These conditions might appear fairly restrictive, but we will explain in detail why there are reasons to believe uniqueness is to be expected nonetheless.

Assumption 2.1. *All parameters except trade costs are greater than zero and finite. Trade costs are larger than or equal to one.*

Proposition 2.2. *Under Assumption 2.1, a competitive equilibrium exists.*

Next, we provide sufficient conditions for uniqueness. As in Alvarez and Lucas (2007b), the proofs provide sufficient conditions under which the excess-demand functions for factors of production possess the Gross-Substitution (GS) property. GS holds if raising a factor price in one country raises excess demands of all other countries.

We first define simple cases of our economies for which uniqueness is easily obtained. We then explain how sufficient conditions can be found that relax these restrictions.

Proposition 2.3. *Suppose Assumption 2.1. holds, preferences are Cobb-Douglas, and $\mu = 1$. Then, there exists a finite $\overline{T}$ such that if $\bar{\tau}_{s's}^{n,l} \geq \overline{T}$, then the equilibrium is unique.*

This proposition provides the first proof for uniqueness for this class of models with intermediate inputs in a general setting.[12] The bound $\overline{T}$ can be computed numerically. Intuitively, sufficiently high trade costs in intermediates avoid the following scenario: An increase in factor prices in Germany might reduce excess demands in the US if, due to intermediate input linkages, the input price increase reduces the overall competitiveness of the US relative to Germany. Constant sectoral expenditure shares, as implied by the Cobb-Douglas demand system, ensure that shifts in demand do not counteract GS by undoing France's gain in competitiveness driven by increases in a factor price in Germany.

We now assume no intermediate input linkages and examine more general consumer preferences.

Proposition 2.4. *Suppose Assumption 2.1 holds, that there is no international trade, and $\mu = 1$. Then $\exists \bar{\theta}$, such that if $\theta_s \geq \bar{\theta}$ for all s, then the competitive equilibrium is unique. Further, $\exists \underline{\eta} \in (0,1)$, such that if $\eta \in \left[\underline{\eta}, 1\right]$,the competitive equilibrium is unique.*

The conditions in the proposition ensure that the gains in competitiveness in country m in response to an increase in factor prices in country n through international trade dominate any potential losses in competitiveness from shifting sectoral goods demands through changes in prices and income. Then, we can show that increase in factor prices in one country will raise excess factor demands in every other country.

[12] Allen et al. (2015b) provide other conditions for the same result by assuming enough symmetry between countries' trade costs and production functions, so that an increase in another country's costs of production changes the comparative advantage of every country in an uniform-enough way. However, the imposed restrictions are clearly violated in the data, while ours in principle allow for rich empirical patterns of trade costs and production technologies.

Finally, we can combine both types of assumptions to guarantee the uniqueness of an equilibrium in our general model. We also relax the assumption of constant nominal investment – this can be easily dealt with by a sufficiently high discount factor μ.[13]

Proposition 2.5. *Suppose Assumption 2.1. holds. Then, there exist a finite* $\overline{T}$*, a* $\underline{\eta} \in (0,1)$ *indpendent of* $\overline{T}$*, and a sufficiently high* $\underline{\mu}$ *independent of* $\overline{T}$,$\underline{\eta}$*, such that if* $\overline{\tau}^{nl}_{s's} \geq \overline{T}$,$\eta \in \left[\underline{\eta}, 1\right]$ *and* $\mu \in \left[\underline{\mu}, 1\right]$*, the competitive equilibrium is unique.*

Of course, this proposition is only interesting empirically to the extent that these bounds can be computed as a function of certain observables and parameters. The next proposition ensures that this is indeed the case.

Proposition 2.6. *Suppose that production parameters* $\alpha^n_{ss}, \vartheta^n_s, \beta^n_s$*,preference parameters* $\mu, \eta, \varepsilon_s, \chi$*, trade elasticity parameters* θ_s*, as well as the maximum possible decrease in factor returns are all known.*[14] *Then, the bounds* $\overline{T}$ *and* $\overline{\eta}$ *can be numerically computed as a function of observables. Moreover, one can directly verify a sufficient condition for GS to hold globally.*

The intuition is simple: Using the current equilibrium as well as knowledge about the maximum dispersion in factor returns, we can use the fact that computing changes in endogenous variables in our model generally does not require knowledge of levels in technology and trade costs to bound the response in unit costs and prices to any given shock. This, in turn, can be used to check a simple sufficient condition for gross substitution of the excess factor demand system. In principle, this provides an easily implementable way of checking a sufficient condition for uniqueness. It is useful

[13] In fact, we only need $(1-\delta)(1-\mu)$ to be sufficiently low. Intuitively, the reason we require that is that nominal investment can decrease after a positive shock to foreign factor prices, due to higher prices, and hence lower factor demand.

[14] That is, one needs to observe or estimate what could be the maximum wage or rent drop a country could experience while staying consistent with equilibrium. For certain simple cases of our models, these can be computed by hand. For the full model, where such computations are harder, one can assume that the observed data is the equilibrium with the largest dispersion in factor returns.

to remember that these conditions are only sufficient and potentially unnecessarily restrictive.

2.4 Estimation

In order to be able to fit our model to the data and conduct counterfactual exercises using our model, we estimate cost shares $\{\alpha^n_{ss'}, \vartheta^n_s, \beta^n_s\}$, preference parameters $\{\mu, \eta, \varepsilon_s, \chi\}$, as well as technology parameters $\{\theta_s, T^n_s, T^n_I, \tau^{kn}_s, \bar{\tau}^{kn}_{s's}, \tau^{kn}_{I,s}\}$. In this section, we lay out our strategy to recover these parameters from the data, using structural equations delivered by our model. We begin by giving a brief description of the data used throughout the empirical exercises, before turning to each subset of parameters.

2.4.1 Data & Aggregation of Sectors

Our main data source is the World Input Output Database, providing data on cross bilateral trade flows in intermediates and final goods for 35 sectors and 40 major countries as well as a Rest of the World, covering years 1995 to 2011. Where needed, we supplement this data from the EUKlems Sectoral Productivity Database, the World Klems Project as well as the Penn World Tables.

Trade in services captured by the data encompasses modes 1, 2, and 4, following the General Agreement on Trade in Services (GATS). Mode 1 corresponds to cross-border supply. Mode 2 captures service consumption abroad - a member of territory A provides a service to a member of territory B within the borders of territory B. Mode 4 also captures services that are delivered within the territory of the member, with the difference that the supplier is present as a natural person.

We calibrate the model to five sectors. Table 2.1 below summarizes our grouping of sectors in the ISIC Rev. 3 2-digit classification into a primary sector, basic and advanced manufacturing goods, as well as basic and advanced services.

Table 2.1: Sector Aggregation used in Empirical Exercises

Sector	Classification	ISIC Rev. 3 Sectors
1	Primary Sector	Agriculture and Mining
2	Basic Manufacturing	Food, Textiles, Wood Products, Printing, Rubber & Plastics Basic Metals
3	Advanced Manufacturing	Petroleum & Nuclear Fuel, Chemicals, Electrical, Optical & Transport Equipment
4	Basic Services	Construction, Wholesale & Retail Trade, Hotels, Restaurants, Inland & Water Transport, Travel Agencies
5	Advanced Services	Telecommunications, Financial Intermediation, Health, Real Estate, Renting of Machinery & Equipment, Business Activities, Education, Public Administration & Defence

The sector grouping is motivated by the empirical regularity that countries that are more advanced in their development path tend to concentrate consumption expenditure in those sectors that we associate with the label "Advanced." Meanwhile, countries further behind on their development path tend to spend larger shares of their income on the sectors labeled "Basic."

2.4.2 Estimation of Structural Parameters Required for Counterfactuals

Production cost shares $\{\alpha_{ss'}^n, \vartheta_s^n, \alpha_{s,I}^n, \beta_s^n\}$

Our assumptions regarding the functional forms of technologies allow us to read the intermediate input costs shares $\{\alpha_{ss'}^n, \alpha_{s,I}^n\}$ as well as value-added shares ϑ_s^n directly

from the available WIOD tables. To obtain the labor cost share within value-added, β_s^n, we combine data on sectoral labor compensation from the KLEMS database and the OECD STAN database. We compute averages over the years available in our data.

Trade Elasticity Parameters: θ

We now turn to estimating the trade elasticity – or technological dispersion in the Eaton and Kortum (2002) framework – parameters θ_s for all sectors. As we want to abstract from the general approach of treating only goods as tradable, we have to provide estimates for our service sectors. To our knowledge, this is the first paper to do so. The approach follows the following logic. We will exploit the fact that tariffs affect trade costs in goods one-to-one in order to estimate elasticities for the first three sectors. We will parametrize trade costs up to several fixed effects and then assume that the marginal effects of the factors explicitly accounted for – that is those who are not absorbed by fixed effects – on trade costs are symmetric across *all* sectors s. This parameterization, in turn, will allow us to recover the trade elasticity for the service sectors, for which equivalents of tariff data is not available.

Empirical Strategy We build on two prominent approaches in the literature: The Head-Mayer and the Head-Ries approach.[15] Both approaches bear the advantage that they are consistent with a wide class of models that give rise to a gravity equation and thus do not depend too crucially on the assumed microstructure of the model. The Head-Mayer approach uses variations in the trade shares with other countries relative to the own trade share to disentangle technologies and cost effects from trade costs. In particular, the Head-Mayer statistic for final goods - an equivalent formulation, of course, holds for intermediate goods - for an origin country k and a destination

[15] See Head and Mayer (2014) for a detailed review.

country n in sector s can be written as:

$$\log\left(\frac{\lambda_s^{kn}}{\lambda_s^{nn}}\right) = -\theta_s \log\left(\tau_s^{kn}\right) + \log\left(T_s^k \left(q_s^k\right)^{-\theta_s}\right) - \log\left(T_s^n \left(q_s^n\right)^{-\theta_s}\right) \tag{2.19}$$

The Head-Ries statistic reads:

$$\log\left(\frac{\lambda_s^{kn}\lambda_s^{nk}}{\lambda_s^{nn}\lambda_s^{kk}}\right) = -\theta_s \log\left(\tau_s^{kn}\tau_s^{nk}\right). \tag{2.20}$$

We adopt the following parametrization of trade costs in final goods in the primary sector as well as the manufacturing sectors. That is for $s \in \{1, 2, 3\}$:

$$\log\left(\tau_s^{ln}\right) = \text{tariff}_s^{ln} + \beta \mathbf{X}_{symm}^{ln} + \delta_{F,s}^{Import} + \delta_{F,s}^{Export}, \tag{2.21}$$

where $\mathbf{X}_{symm}^{ln}$ are symmetric observed characteristics between two countries, in particular a dummy indicating whether or not two countries share a common border, a common language, are both members of the GATT1995 trade agreement, share a common currency, share a common legal system as well as the distance between both countries. Note that the parameter vector β is not allowed to vary by sector, country, or type of good that is being shipped. This assumption will allow us to identify θ for the service sectors for which we have no tariff data. Importer and exporter fixed effects are allowed to vary by sector and country as well as depend on whether the good shipped is a final or intermediate good. We assume that tariffs apply equally to intermediate and final goods.

Equivalently, trade costs in intermediates are assumed to take the following form:

$$\log\left(\bar{\tau}_{ss'}^{ln}\right) = \text{tariff}_s^{ln} + \beta \mathbf{X}_{symm}^{ln} + \delta_{F,ss'}^{Import} + \delta_{F,ss'}^{Export}. \tag{2.22}$$

As both approaches are equally valid in theory, we will provide estimates using both the Head-Mayer as well as the Head-Ries approach. To do so, we stack the relevant

statistics for both final and intermediate goods for all available years and estimate $\theta_1, \theta_2, \theta_3$ as well as β. As we exploit both the cross-sectional as well as the time variation of our data, we add time fixed effects as is appropriate. In particular, we interact time fixed effects with the export and import fixed effects for the Head-Mayer approach to absorb the variation in technologies and unit costs in equation (2.19) over time.

We then estimate the corresponding specifications using our data on trade shares in the two service sectors. From the obtained estimates on the symmetric characteristics of trade costs, we can then recover θ_4 and θ_5, using our estimates for β from the previous step.

Data. We use the WIOD to construct the Head-Mayer statistics for major economies as well as an aggregate rest of the world for years 1995 to 2011. Bilateral tariff data for the primary and manufacturing sectors is taken from the WTO/WITS tariff database and the relevant gravity variables are extracted from the CEPII.

Results. Table 2.2 reports the results of our estimations across both approaches. As is evident from the results, the estimates have the correct sign and vary quite significantly across sectors in terms of magnitude. It is reassuring to observe that the magnitudes do not seem to depend very much on the particular approach that is chosen to obtain these estimates. Further, the estimates are in the range trade elasticities estimated in the previous literature for sectors traditionally considered in the trade literature and appear to be of a reasonable magnitude for the service sectors.

Preference Parameters: ε, η, χ

Empirical Strategy Comin et al. (2017) make use of the same class of preferences and estimate the relevant preference parameters of the utility function. However, we provide our own estimates. This is because our model requires us to know how the population in each country is split between workers and investors, as captured by the

Table 2.2: Trade elasticities estimates

θ	Head-Ries	Head-Mayer	Head-Ries	Head-Mayer
Primary Sector	6.3***	6.6***		
	(0.7)	(1.3)		
Basic Manufacturing	3.6***	3.7***		
	(0.4)	(0.4)		
Advanced Manufacturing	10.3***	11.8***		
	(0.7)	(0.9)		
Basic Services			7.8***	7.6***
			(0.1)	(0.1)
Advanced Services			8.1***	7.8***
			(0.1)	(0.1)
Fixed Effects	osi, dsi	otsi, dtsi	osi, dsi	otsi, dtsi
Observations	7335	25868	6418	12040
Adjusted R^2	0.884	0.524	0.810	0.679

Notes: Standard errors in parenthesis. p-values indicated by asterisks: $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$. Key to fixed effects: o=Origin, s=sector-(pair), i=intermediate or final good, t=year.

parameter χ.[16] As we will demonstrate below, we will use the solution of the intra-temporal problem of the household, observed aggregate consumption expenditure shares, sectoral price data, as well as the evolution of incomes of both investors and workers to identify the preference parameters as well as the appropriate share of workers that best rationalize the observed expenditure shares. As a robustness check, we will provide the estimates of the preference parameters that would have been obtained under the assumption of only a single class of households.

[16] We make χ non-country specific to ease the computational burden. However, identification is not threatened by letting this parameter vary by country.

Denote by $w_{K,t}$ the aggregate income share of investors. We can then write the total expenditure share in country n on sector s goods in year t as:

$$\begin{aligned}\log(e^n_{s,t}) &= \log(e^{n,K}_{s,t} w_{K,t} + e^{n,L}_{s,t} w_{L,t}) \\ &= (1-\eta)\log\left(P^n_{s,t}\right) + \log\left(\left(C^{n,K}_t\right)^{\varepsilon_s-\eta} + \left(C^{n,L}_t\right)^{\varepsilon_s-\eta}\right) + \text{cst}\end{aligned}$$

Relative expenditure shares can then be written:

$$\log\left(\frac{e^n_{s',t}}{e^n_{s,t}}\right) = \log\left(\frac{\zeta_{s'}}{\zeta_s}\right) + (1-\eta)\log\left(\frac{P^n_{s',t}}{P^n_{s,t}}\right) + \log\left(\frac{\left(C^{n,K}_t\right)^{\varepsilon_{s'}-\eta} + \left(C^{n,L}_t\right)^{\varepsilon_{s'}-\eta}}{\left(C^{n,K}_t\right)^{\varepsilon_s-\eta} + \left(C^{n,L}_t\right)^{\varepsilon_s-\eta}}\right). \tag{2.23}$$

It is easy to see that under the assumption of a single type of agent, this collapses to the estimation equation in Comin et al. (2017). Our set-up turns this log-linear specification into a non-linear one. In our model, consumption indices relate to observed prices, χ, and aggregate incomes of our two groups preference parameters through the following equations:

$$\left(E^{n,j}_t\right)^{1-\eta} = \sum_{s\in\mathcal{S}} \zeta_s \left(C^{n,j}_t\right)^{\varepsilon_s-\eta}\left(P^n_{s,t}\right)^{1-\eta}, \text{for } j \in \{K,L\}, \tag{2.24}$$

$$E^{n,L}_t = \frac{(\text{Labor Compensation})^n_t + D^n_t}{\chi L^t_n}, \tag{2.25}$$

$$E^{n,K}_t = \frac{r^n_t K^n_t - P^{n,I}_t I^n_t}{(1-\chi)L^n_t}. \tag{2.26}$$

Given data on capital and labor compensation, deficits as well as investment, we jointly estimate equations 2.23 and 2.24 via a non-linear least square regression. We include country-sector-pair fixed effects. As we use all available countries in our

estimation, the system is over-identified. We interpret the resulting error terms as measurement error (in prices, for example).

Data. Sectoral prices are taken from the EU-Klems Database, where we aggregate sectors into our five categories by taking value-added averages across the relevant sectors. The labor share in each sector is constructed from the EU Klems database, and total labor and capital compensation are constructed by splitting value-added implied by the WIOD accordingly. Consumption expenditure shares, as well as investment, are also constructed from the WIOD. In order to maximize power, we do not restrict our country sample and include all years and countries for which we can construct all required time series.

Results. We implement the estimation of the preference parameters running a constraint non-linear least-squares procedure. As a robustness check, we run the same procedure, but assuming only one type of household, making the worker share parameter χ redundant.

As evident in equation (2.23), preference parameters are identified up to a normalization. We choose the primary sector as our normalization, and when reporting the results, we order sectors by increasing income elasticity and report the estimated difference in income elasticities to the respective next lower ranked sector. Table 2.3 reports the results.

We find that the primary sector has the lowest income elasticity, followed by basic manufacturing and basic services goods. For this pair, we cannot reject the null that the difference in the income elasticity in these sectors is 0. Advanced manufacturing exhibits an income elasticity that is higher and significantly different from basic services - and basic manufacturing for that matter. The highest-ranked sector in terms of its income elasticity is advanced services.

Our estimates imply that we cannot reject a non-homothetic preference structure in our data. That is, the estimated demand system implies non-homothetic Engel

Table 2.3: Estimates of Preference Parameters

Parameters	Estimates
η	0.7^{***}
	(0.14)
χ	0.80^{***}
	(0.02)
$\varepsilon_{BM} - \varepsilon_P$	0.35^{***}
	(0.1)
$\varepsilon_{BS} - \varepsilon_{BM}$	0.16
	(0.1)
$\varepsilon_{AM} - \varepsilon_{BS}$	0.75^{***}
	(0.13)
$\varepsilon_{AS} - \varepsilon_{AM}$	0.27^{**}
	(0.12)
Observations	1420
Adjusted R^2	0.984

Notes: Standard errors in parenthesis. p-values indicated by asterisks: $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$. P=Primary Sector, BM= Basic Manufacturing, AM= Advanced Manufacturing, BS = Basic Services, AS = Advanced Services

curves. In particular, with constant relative prices, an economy that is growing exogenously richer will transition from spending most of its income on the primary sector towards basic goods and services and eventually start consuming an increasingly large share of its income in advanced manufacturing and advanced services goods.

Our finding of a non-homothetic preference structure is in line with a growing literature that relies on other demand systems with non-homothetic properties (Fieler (2011), Herrendorf et al. (2013), Uy et al. (2013) Caron et al. (2014), Caron et al. (2017)).

2.4.3 Inverting the Model: Changes in Technology and Trade Costs

In this subsection we demonstrate how we can use observed allocations to uniquely back out the change in sectoral technology levels in consumption goods $\{T^n_{s,t}\}$ and investment goods $\{T^n_{I,t}\}$ as well as trade costs across intermediate, final and investment goods that make the observed allocations an equilibrium outcome of the model. In particular, we will back out the paths of these variables in order to exactly match the following moments in the data over the period 1995 to 2011: (1) changes in sectoral expenditure shares in each country, (2) changes in the Head-Mayer statistics for final goods and intermediates, and (3) changes in investment in each country.

The following proposition states that this inversion can be done and is furthermore unique. The proof is provided in the appendix.

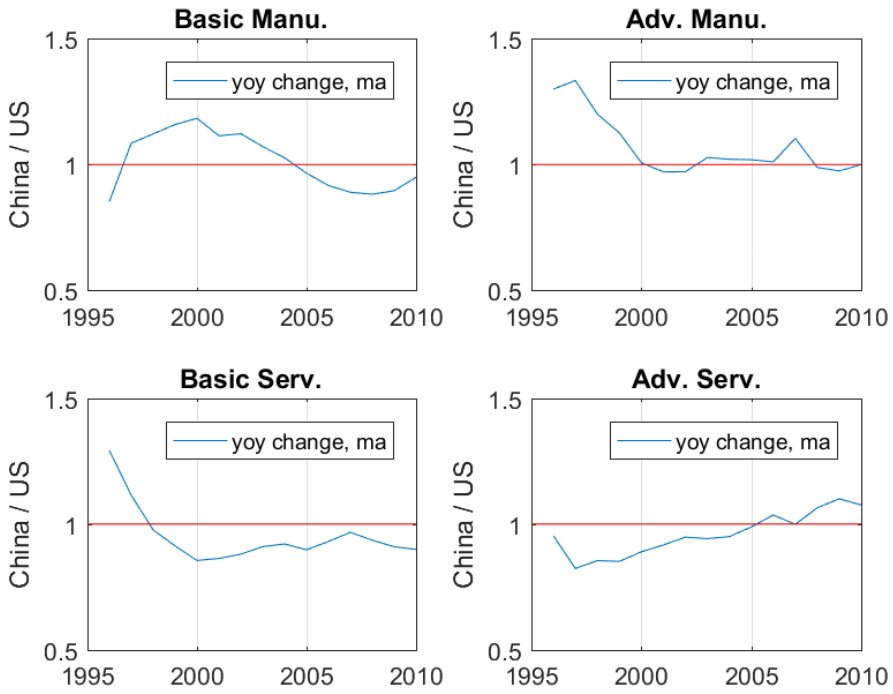
Proposition 2.7. *Assume that preference parameters $\{\mu, \eta, \varepsilon_s, \chi\}$, production cost shares $\{\alpha^n_{ss'}, \vartheta^n_s, \beta^n_s\}$ as well as dispersion parameters and the capital depreciation rate $\{\theta_s, \delta\}$ are known. Then given time series on investment growth, population growth, labor and capital compensation as well as expenditure and trade shares, there exists a unique set $\{\hat{\tilde{\tau}}^{kn}_{s's}, \hat{\tau}^{kn}_s, \hat{\tau}^{kn}_{I,s}, \hat{T}^n_s, \hat{T}^n_I\}^{k,n\in\mathcal{N}}_{s,s'\in\mathcal{S}}$, such that the observed allocations are consistent with an equilibrium of the model.*

We can, thus, calibrate our model so that it exactly replicates observed paths of observable moments, in particular sectoral labor compensation shares and the evolution of value-added. Naturally, the proposition implies that our structural estimates of preferences and trade elasticities are consequential for the inversion.

Figure 2.3 illustrates one outcome of our estimation. We plot for the manufacturing and services sectors the relative growth in technological efficiency in China and the U.S., where efficiency is defined as $T^{n\,1/\theta_s}_s/q^n_s$. Besides trade costs, these are the relevant variables entering the trade share expressions $\pi^{\text{CHN,US}}_{s',s}$ and $\lambda^{\text{CHN,US}}_s$. As

expected, during the Chinese export boom, Chinese efficiency growth was higher in the manufacturing sectors, while the opposite is true for services sectors. The more recent trends, however, are less sharp.

Figure 2.3: Relative efficiency growth: China vs U.S.

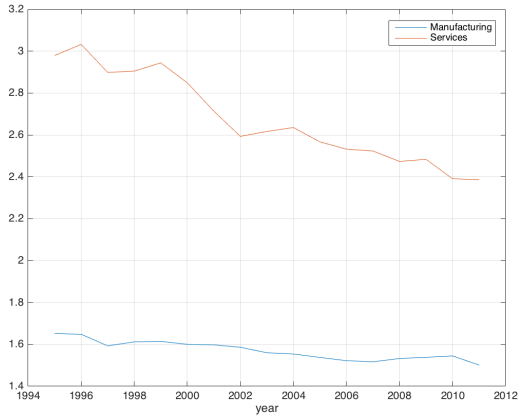


For the following exercises, we will rely changes in trade costs, which we can fully infer from the data. However, it is also interesting to get a sense of the relative levels of trade costs for manufacturing and service sectors. Figure 2.4 shows the evolution of the average bilateral trade costs between China and the U.S. in manufacturing and services sectors.[17] We observe that trade costs in services remain significantly higher than those in manufacturing, but interestingly, these costs have decreased at a faster pace.[18]

[17] Knowing the trade elasticities, this average can be easily computed from the Head-Ries statistic.

[18] Eckert (2019), in line with out estimates, finds that trade costs in business services have declined sharply over the last decades.

Figure 2.4: Trade Costs in Manufacturing vs. Services, U.S. and China



Notes: Red: Average trade costs in manufacturing industries between the US and China. Blue: Average trade costs in services between the US and Cina.

2.5 Application

In section 3.2., we undertook a simple reduced-form exercise suggesting that changes in trade shares accounted for a third of the observed decrease in US manufacturing, the equivalent of more or less 1.5 million jobs. Of course, the exercise undertaken there by nature was only suggestive, as the drivers of the changes in the underlying trade shares will affect other allocations through general equilibrium effects. Hence, in this section, we revisit our reduced form exercises from section 2 by asking to which degree changes in trade costs can rationalize the suggestive evidence that increased competition in international markets contributed significantly to the recent reduction in manufacturing employment.

2.5.1 Changes in Trade Costs of Goods and Services and the Decline of US Manufacturing

Having estimated all structural parameters of the model and having backed out the paths of technologies and trade costs that exactly rationalize the evolution of

expenditure shares, trade shares and investment in the data, we are now undertake counterfactual exercises.

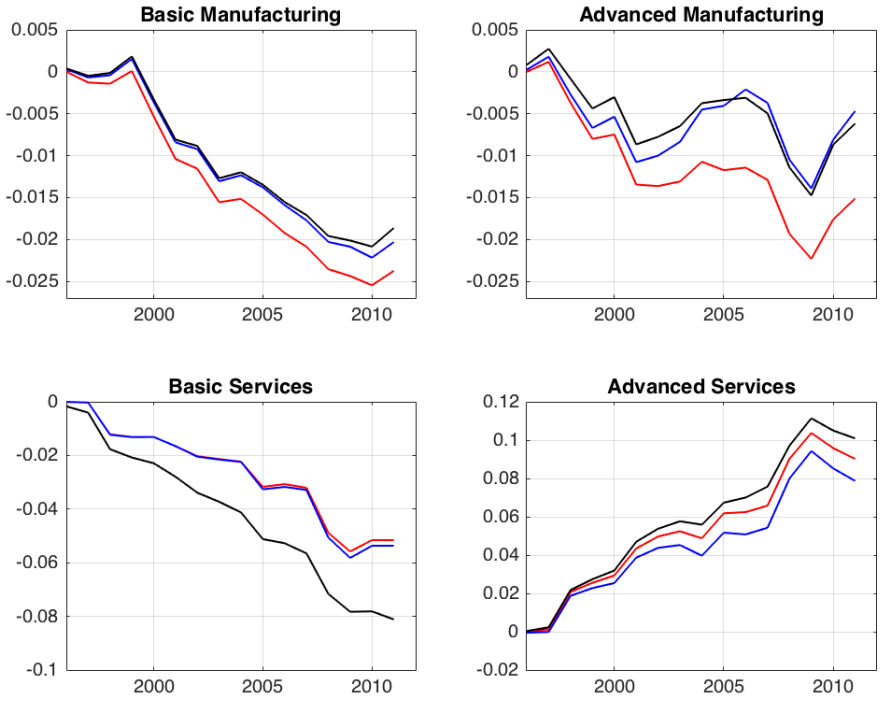
In particular, we ask by how much do global trade costs in manufacturing *or* services have to change compared to their observed path in order to save the 1.5 million U.S. manufacturing jobs that the reduced-form exercise attributed to trade? That is, taking the backed out paths of technologies as given, we assess the impact of uniformly changing trade frictions on the observed US structural transformation. To do so, we match the 1995 equilibrium observed in the data and then solve our model forward in changes until 2011, aiming to match the final employment shares in manufacturing that would have prevailed if trade shares had remained at their 1995 level, but demands and incomes had evolved as in the data. To this end, the first exercise uses the measured technological paths as well as the paths for trade costs and allows for uniform yearly changes over the observed changes in trade costs in basic and advanced manufacturing goods around the world. The second exercise allows for uniform changes in the observed changes in trade frictions related to both basic and advanced services. Undertaking this exercise, we find that the equivalent of a global increase over the observed *changes* in trade costs in manufacturing goods of 45% over these 17 years achieves this goal. This accumulated increase corresponds to a yearly increase of 2.2%. Noting that developed countries decreased their tariffs by about 40% on industrial products in the five years following the 1995 multilateral WTO agreements alone, this provides further support for the well-established hypothesis that falling trade costs in manufacturing goods have increased the competition that US manufacturing faced both at home and abroad, driving employment into the services sector.

The results of the second exercise suggest that accelerated decreases in service trade costs could have saved the same number of manufacturing jobs. It suggests that an overall uniform *decrease* over the observed changes in trade costs in the

services sector of about 60% would have resulted in saving the equivalent number of manufacturing jobs. This decrease in trade costs corresponds to a yearly decrease of about 5.3% over these 17 years. That is, falling trade costs and thus increased levels of trade in services have the potential to slow down the decline in manufacturing employment. This occurs through two effects: On the one hand, decreasing trade costs in services, similar to increases in trade costs for manufacturing goods, put downward pressure on prices of services relative to manufacturing. Given that our parameter estimates of preferences imply that sectors are complements, this, in turn, drives relative nominal expenditures out of the services sector, towards manufacturing goods. The other channel works through the income effects. While rising trade costs in manufacturing reduce real incomes in the US, falling trade costs in services increase real incomes. Through income effects demand shifts out of basic services into sectors with high income elasticities - advanced manufacturing goods and advanced services.

The results of our exercises are depicted in Figure 2.5. Both the increase in trade costs in manufacturing goods as well as the decrease in trade costs in service goods help US manufacturing recover an aggregated 1.5 million jobs. However, both exercises differ in terms of their effect on the service sector. While an increase in trade costs in manufacturing goods reduces employment in advanced services, it leaves employment in basic services virtually unchanged. These pattern partly reflect the discussed income effects and price effects: The increase in trade costs in manufacturing goods increases the price of manufacturing relative to services while increasing the trade share of the US with itself. As a result, both expenditures on final and intermediate goods, as well as production patterns shift towards manufacturing. The decrease in the labor compensation of advanced services results from income effects in demand and the effect of input-output linkages. On the one hand, as real incomes fall in the counterfactual, consumers demand less high-income elastic goods, causing them to abandon advanced service goods in favor of less income-elastic goods. On the other

Figure 2.5: Counterfactual Exercises: Change in the Employment Share Relative to 1995



Notes: Red: Data, obtained through solving our model for the implied evolutions of trade cost and technology. Blue: uniform increase of 2.2% yoy over observed change in trade frictions in manufacturing goods. Black: Uniform decrease of 5.3% yoy over observed change in trade frictions in in service goods.

hand, as shown in Johnson and Noguera (2012), sectors that we classify as advanced services are increasingly integrated into global value chains. Therefore, rising trade costs in manufacturing effectively reduce the demand for advanced services.

A decrease in trade costs in services, on the other hand, while having virtually the same effect on employment shares in manufacturing, dramatically reduces employment in essential services and instead increases employment in the advanced services sector. While falling relative prices in services tend to decrease expenditure shares for these sectors, income effects and increasing demand for advanced services from

abroad disproportionally increase the labor compensation in advanced relative to basic services.

While both rising trade costs in manufacturing and falling trade costs in services have comparable effects on sectoral labor demands, the welfare consequences differ across both scenarios. Falling trade costs in services increase real incomes in the US while rising trade costs in manufacturing reduce real incomes.

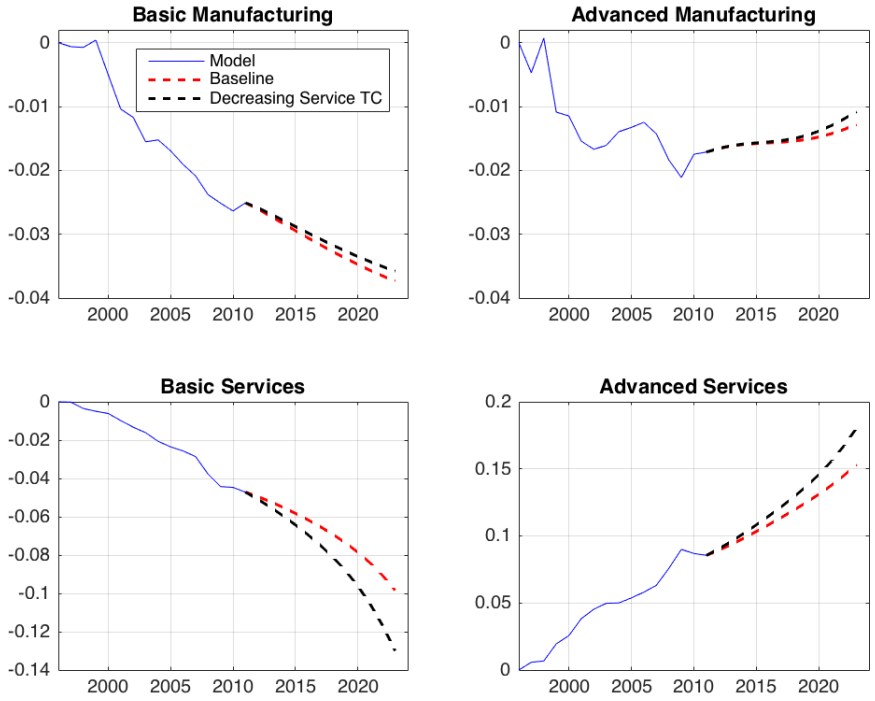
Together, these findings provide a novel perspective on the role of trade in services in structural transformation: If some parts of services are likely to become increasingly more traded in the future, then this may act as a force countering the observed decline in US manufacturing. It also suggests that those who wish to revive US manufacturing may have two options: On the one hand, they could close the economy up to foreign trade in manufacturing goods, reducing competition for the domestic manufacturing sector, but simultaneously reducing domestic welfare. On the other hand, they may try to increase trade in services through further supporting research in technology or removing other barriers, such as taxes on banking transactions, which according to our results, would increase both manufacturing employment and welfare.

2.5.2 Predictive Exercises: Structural Change in the US up to 2023

In this subsection, we undertake various preditive exercises. In particular, we assume the recent trends in change of technologies and trade costs continue and study how the US economy will evolve for 12 years beyond our sample -- 2011 to 2023 --assuming that deficits and population growth around the world follow their past trends. This will constitute a baseline prediction. We then revisit the hypothesis that decreases in the change in trade costs in the service sector have the potential to recover parts of the US manufacturing sector. To do so, we assume an additional 5.3\% year on year decrease over the trend in the change in trade costs in services from 2011 onwards and

study the evolution of US sectoral employment shares. Figure 2.6 plots the results of our exercise.

Figure 2.6: Predictive Exercises: Structural Change in the U.S. up to 2023



Notes: This figure depicts prediceted changes in employment shares. Blue: Data, obtained through solving our model for the implied evolutions of trade cost and technology. Red: Using past trends in technologies and trade costs to predict the future evolution. Black: An additonal uniform decrease of 5.3% yoy over predicted change in trade costs in services.

In the baseline scenario, we predict that US manufacturing will decrease further in its employment share by about 0.7%, or the equivalent of about another 800.000 US jobs. Advanced manufacturing, due to income effects stabilizes around its 2011 level, whilst basic services decrease by another 4%. In our baseline analysis these losses are largely absorbed by the advanced services sector which benefits from income effects as well as relative declines in the prices in the manufacturing sector.

Under the assumption of accelerated decreases in the change in trade costs in services in magnitude equivalent to the decrease that would have saved 1.5 million US manufacturing jobs in the previous subsection, we find that this decline in manufacturing slows down by about 48%, implying that a further decrease in trade costs in services would save about 400.000 US jobs by 2023. This finding is in line with our observation from the previous section. Under such a scenario, advanced services would gain an extra 3% in employment share, with basic services declining considerably, transferring jobs into the advanced manufacturing sector.

These findings reconfirm the perhaps surprising conclusion that further increases in the tradability of services have the potential to slow down the decrease in US manufacturing employment, even if the magnitudes required to bring about such a change are considerable.

2.6 Conclusion

In this chapter, we have been interested in explaining the interactions of structural change and trade in the two recent decades. We started by conducting decompositional exercises suggesting that about one-third of the reallocation of labor compensation shares from manufacturing to service sectors in the US is due to changes in trade patterns.

We constructed a dynamic, general equilibrium model of trade that accommodates both classical forces of structural change -- price and income effects, as well as dynamic accumulation of capital and sector-biased technological progress -- and multi-sectoral, multi-country frictional trade. We estimated the model and showed in particular that there exists a unique way to "invert the model" in order to obtain paths for changes in technologies as well as trade costs that rationalize the evolution of observed expenditure shares, trade shares and investment decisions as an equilibrium

outcome of the model. We showed, in line with conventional wisdom, that Chinese technological growth in the manufacturing sector has outpaced the U.S. in these recent years, while the opposite is true for services. Moreover, trade costs -- as measured by the Head-Ries statistic -- have decreased in the latter faster than in manufacturing, suggesting that trade in services plays or is likely to play a more important role in trade.

We then went back to our reduced-form exercise and asked the following question: by how much do global trade costs in manufacturing have to increase in order to save the 1.5 million U.S. manufacturing jobs that the reduced-form exercise attributed to trade? We showed that calibrating our model to 1995 data and taking the estimated paths of technological change as given, a uniform increase of 2.2 percent year on year over observed changes manufacturing trade costs is enough to recover 1.5 million jobs. We then asked a more innovative question: can an equivalent change in trade costs in services bring about the same result? We find that a decrease of about 5.3 percent year on year over the same period generates a similar recovery. Intuitively, rising trade in services acts as a technological boost for that sector, pushing it's the relative price and hence relative demand down, amid a negative substitution effect. Predictive exercises suggest that in our baseline scenario, another 800,000 jobs in the US will be reallocated from manufacturing to service sectors between 2011 and 2023. A decrease in trade costs in services over the fitted trends of 5 percent would save a little less than half of these jobs. This leads us to conclude that the opening of trade in services can be seen as a potential tool to revive manufacturing, with the likely additional benefit of raising welfare -- as opposed to increasing tariffs in manufacturing.

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Appendix

2.A Equilibrium Equations

We re-state here the main equations of the model. Then, we re-write the same equations but in changes between two equilibria, in the spirit of Deckle et al. (2007). Note that this way of writing the model in changes can be used not only to conduct counterfactuals but also to solve the model over time, given paths (exogenous or endogenous) of parameters and factor allocations.

2.A.1 Main equilibrium equations in levels

$$q_s^n = \Psi_s^n \left((w^n)^{\beta_s^n} (r^n)^{1-\beta_s^n} \right)^{\vartheta_s^n} \left(\prod_{s'} (Q_{s's}^n)^{\alpha_{s's}^n} \right)^{1-\vartheta_s^n} . \tag{2.27}$$

$$q_I^n = \frac{1}{T_I^n} \Psi_I^n \prod_s \left(P_{I,s}^n \right)^{\alpha_{I,s}^n} ., \tag{2.28}$$

$$P_{I,s}^n = \left(\int_\omega p_{I,s}^n(\omega)^{1-\nu} d\omega \right)^{\frac{1}{1-\nu}} \tag{2.29}$$

$$= \gamma_s \Phi_{I,s}^{n^{-1/\theta_s}} \tag{2.30}$$

$$Q^n_{s's} = \left(\int_\Psi q^n_{s's}(\varpi)^{1-\nu} d\varpi \right)^{\frac{1}{1-\nu}} \tag{2.31}$$

$$= \gamma_{s'} \Phi^{n^{-1/\theta_{s'}}}_{s',s}, \tag{2.32}$$

$$P^n_s = \left(\int p^n_s(\omega)^{1-\sigma_s} d\omega \right)^{1/(1-\sigma_s)} \tag{2.33}$$

$$= \gamma_s \Phi^{n^{-1/\theta_s}}_s, \tag{2.34}$$

$$P^n_I = \frac{1}{T^n_I} \Psi^n_I \prod_s \left(P^n_{I,s} \right)^{\alpha^n_{I,s}} \tag{2.35}$$

$$e^{n,j}_{s,t} = \frac{\zeta_s \left(C^{n,j}_t \right)^{\varepsilon_s - \eta} \left(P^n_{s,t} \right)^{1-\eta}}{\sum_{s'} \zeta_{s'} \left(C^{n,j}_t \right)^{\varepsilon_{s'} - \eta} \left(P^n_{s',t} \right)^{1-\eta}} \tag{2.36}$$

$$E^{n,L}_t = w^n_t + \frac{D^n_t}{\chi^n_t L^t_n} \tag{2.37}$$

$$E^{n,K}_t = \frac{r^n_t K^n_t - P^{n,I}_t I^n_t}{(1-\chi^n_t) L^n_t}, \tag{2.38}$$

$$C^{n,j}_{s,t} = \frac{\zeta_s \left(P^n_{s,t} \right)^{-\eta}}{\left(P^n_t \right)^{\varepsilon_s - \eta}} \left(E^{n,j}_t \right)^{\varepsilon_s}, \tag{2.39}$$

$$\left(E^{n,j}_t \right)^{1-\eta} = \sum_{s \in \mathcal{S}} \zeta_s \left(C^{n,j}_t \right)^{\varepsilon_s - \eta} \left(P^n_{s,t} \right)^{1-\eta} \tag{2.40}$$

$$\pi^{ln}_{s's} \equiv \frac{I^{ln}_{1,s's}}{I^n_{1,s's}} = \frac{I^{ln}_{s's}}{I^n_{s's}} \tag{2.41}$$

$$= \frac{T^l_{s'} (q^l_{s'} \bar{\tau}^{ln}_{s',s})^{-\theta_{s'}}}{\sum_k T^k_{s'} (q^k_{s'} \bar{\tau}^{kn}_{s',s})^{-\theta_{s'}}}, \tag{2.42}$$

$$\lambda^{ln}_s = \frac{T^l_s (q^l_s \tau^{ln}_s)^{-\theta_s}}{\sum_k T^k_s (q^k_s \tau^{kn}_{s'})^{-\theta_s}}. \tag{2.43}$$

$$\lambda_{I,s}^{ln} = \frac{T_s^l (q_s^l \tau_{I,s}^{ln})^{-\theta_s}}{\sum_k T_s^k (q_s^k \tau_{I,s}^{kn})^{-\theta_s}}. \tag{2.44}$$

$$F_s^n = \sum_{l \in \mathcal{N}} \lambda_s^{nl} \left(e_s^{l,L} \left(w^l \chi^l L^l + D^l \right) + e_s^{l,K} \left(r^l K^l - P_I^l I^l \right) \right) + \sum_{l \in \mathcal{N}} \lambda_{I,s}^{nl} \alpha_{I,s}^l P_I^l I^l. \tag{2.45}$$

$$\mathcal{I}_s^n = \sum_{l \in \mathcal{N}} \sum_{s' \in \mathcal{S}} (1 - \vartheta_{s'}^l) \alpha_{s,s'}^l \pi_{ss'}^{nl} \left(F_{s'}^l + I_{s'}^l \right) \tag{2.46}$$

$$w^n \chi^n L^n = \sum_{s \in \mathcal{S}} \beta_s^n \vartheta_s^n \left(\mathcal{I}_{\mathcal{I},s}^n + F_s^n \right) \tag{2.47}$$

For capital, we have:

$$r^n K^n = \sum_{s \in \mathcal{S}} (1 - \beta_s^n) \vartheta_s^n \left(\mathcal{I}_{\mathcal{I},s}^n + F_s^n \right) \tag{2.48}$$

$$K_{t+1}^n = \mu \left(\frac{r_t^n}{P_{I,t}^n} + (1 - \delta^n) \right) K_t^n \tag{2.49}$$

2.A.2 Main equilibrium equations in changes

Denote $\hat{x} = \frac{x'}{x}$, where x' denotes the next period's value of x.

$$\hat{q}_s^n = ((\hat{w}^n)^{\beta_s^n} (\hat{r}^n)^{1-\beta_s^n})^{\vartheta_s^n} \left(\prod_{s'} (\hat{Q}_{s',s}^n)^{\alpha_{s',s}^n} \right)^{1-\vartheta_s^n} \tag{2.50}$$

$$\hat{Q}_{s',s}^n = \left\{ \sum_{k \in \mathcal{N}} \pi_{s',s}^{kn} \hat{T}_s^k \left(\hat{q}_{s'}^k \hat{\bar{\tau}}_{s',s}^{kn} \right)^{-\theta_s} \right\}^{-1/\theta_s} \tag{2.51}$$

$$\hat{P}_s^n = \left\{ \sum_{k \in \mathcal{N}} \lambda_s^{kn} \hat{T}_s^k \left(\hat{q}_s^k \hat{\tau}_s^{kn} \right)^{-\theta_s} \right\}^{-1/\theta_s} \tag{2.52}$$

$$\hat{P}_I^n = \frac{1}{\hat{T}_I^n} \prod_s \left(\left\{ \sum_{k \in \mathcal{N}} \lambda_{I,s}^{kn} \hat{T}_s^k \left(\hat{q}_s^k \hat{\tau}_{I,s}^{kn} \right)^{-\theta_s} \right\}^{-1/\theta_s} \right)^{\alpha_{I,s}^n} \tag{2.53}$$

Next, we can compute the changes in shares:

$$\hat{\pi}_{s',s}^{kn} = \hat{T}_s^k \left(\frac{\hat{q}_s^k \hat{\tau}_{s',s}^{kn}}{\hat{Q}_{s's}^n} \right)^{-\theta_{s'}} \tag{2.54}$$

$$\hat{\lambda}_s^{kn} = \hat{T}_s^k \left(\frac{\hat{q}_s^k \hat{\tau}_s^{kn}}{\hat{P}_s^n} \right)^{-\theta_s} \tag{2.55}$$

$$\hat{\lambda}_{I,s}^{kn} = \hat{T}_s^k \left(\frac{\hat{q}_s^k \hat{\tau}_{I,s}^{kn}}{\hat{P}_{I,s}^n} \right)^{-\theta_s} \tag{2.56}$$

$$\hat{e}_s^{n,j} = \frac{\left(\hat{C}^{n,j}\right)^{\epsilon_s - \eta} \left(\hat{P}_s^n\right)^{1-\eta}}{\left(\hat{E}^{n,j}\right)^{1-\eta}} \tag{2.57}$$

Where the changes in per capita income are:

$$\hat{E}^{n,L} = \frac{\hat{w}^{n,L} \hat{L}^n w^n L^n + \frac{D'^n}{\chi'^n}}{w^{n,L} L^n + \frac{D^n}{\chi^n}} \frac{1}{\hat{L}^n} \tag{2.58}$$

$$\hat{E}^{l,K} = \frac{\hat{r}^l \hat{K}^l r^l K^l - \hat{P}_I^l \hat{I}^l P_I^l I^l}{r^l K^l - P_I^l I^l} \frac{1}{\hat{L}^l} \tag{2.59}$$

And the change in invesment is:

$$\hat{I}^l = \frac{\mu \hat{r}^l r^l / \hat{P}_I^l P_I^l - (1-\delta)(1-\mu)}{\mu r^l / P_I^l - (1-\delta)(1-\mu)} \tag{2.60}$$

Given this we can compute the new demands for final and intermediate goods:

$$F_s'^n = \sum_l \hat{\lambda}_s^{nl} \lambda_s^{nl} \left(\hat{e}_s^{l,L} e_s^{l,L} \left(\chi^l \hat{w}^l w^l \hat{L}^l L^l + \hat{D}^l D^l \right) + \hat{e}_s^{l,K} e_s^{l,K} \left(\hat{r}^l \hat{K}^l r^l K^l - \hat{P}_I^l \hat{I}^l P_I^l I^l \right) \right) + \sum_{l \in \mathcal{N}} \hat{\lambda}_{I,s}^{nl} \lambda_{I,s}^{nl} \alpha_{I,s}^l \hat{P}_I^l \hat{I}^l P_I^l I^l \tag{2.61}$$

$$\mathcal{I}_s'^n = \sum_{l,s} (1 - \vartheta_{s'}^l) \alpha_{s,s'} \hat{\pi}_{s,s'}^{nl} \pi_{s,s'}^{nl} \left(F_{s'}'^l + \mathcal{I}_{s'}'^l \right) \tag{2.62}$$

And hence the changes in wages & incomes are:

$$\hat{w}^n w^n \chi \hat{L}^n L^n = \sum_s \beta_s^n \vartheta_s^n \left(F_s'^n + \mathcal{I}_s'^n \right) \tag{2.63}$$

$$\hat{r}^n \hat{K}^n r^n K^n = \sum_s (1 - \beta_s^n) \vartheta_s^n \left(F_s'^n + \mathcal{I}_s'^n \right) \tag{2.64}$$

Finally, changes in real consumption aggregates $\hat{C}^{n,j}$ solve:

$$\left(\hat{E}^{n,j} \right)^{1-\eta} = \sum_s e_s^{n,j} \left(\hat{C}^{n,j} \right)^{\epsilon_s - \eta} \left(\hat{P}_s^n \right)^{1-\eta} \tag{2.65}$$

2.B Derivations and Proofs

2.B.1 Nonhomothetic CES Demand

Under the parametric restrictions given in the main text the Marshallian demands can be derived by solving the following Lagrangran:

$$\mathcal{L} = C + \lambda \left(\sum_{s \in \mathcal{S}} \zeta_s^{\frac{1}{\eta}} C_s^{\frac{\eta-1}{\eta}} C^{\frac{\varepsilon_s - \eta}{\eta}} - 1 \right) + \rho \left(E - \sum_s P_s C_s \right),$$

where λ and ρ denote Lagrangean multipliers. Taking the derivative with respect to C_s yields:

$$\lambda \frac{\eta - 1}{\eta} \zeta_s^{\frac{1}{\eta}} C_s^{-\frac{1}{\eta}} C^{\frac{\varepsilon_s - \eta}{\eta}} = \rho P_S.$$

Multiplying by C_s and summing over all s, we obtain:

$$\rho \sum_s P_s C_s = \lambda \frac{\eta - 1}{\eta} \sum_s \zeta_s^{\frac{1}{\eta}} C_s^{\frac{\eta-1}{\eta}} C^{\frac{\varepsilon_s - \eta}{\eta}}.$$

Since $\sum_s \zeta_s^{\frac{1}{\eta}} C_s^{\frac{\eta-1}{\eta}} C^{\frac{\varepsilon_s - \eta}{\eta}} = 1$ and $\sum_s P_s C_s = E$, this implies that $E = \frac{\lambda(\eta-1)}{\rho\eta}$. Substituting this into and rearranging the first-order condition we obtain the Marshallian

demand for C_s :

$$C_s = \zeta_s P_s^{-\eta} E^{\eta} C^{\varepsilon_s - \eta}. \tag{2.66}$$

Define the ideal price index as P such that $PC \equiv E$. Substiute this into equation (2.66) to obtain the expression for sectoral demands in the main text:

$$C_s = \zeta_s \frac{P_s^{-\eta}}{P^{\varepsilon_s - \eta}} E^{\varepsilon_s}. \tag{2.67}$$

To derive the price index P, we note that $\sum_s P_s C_s = PC$ and use equation (2.67):

$$PC = \sum_s \zeta_s P_s^{1-\eta} P^{\eta} C^{\varepsilon_s} \Leftrightarrow P = \left(\sum_s \zeta_s P_s^{1-\eta} P^{\eta} C^{\varepsilon_s - 1} \right)^{\frac{1}{1-\eta}}.$$

To obtain sectoral expenditure shares, we use equation (2.66):

$$e_s \equiv \frac{P_s C_s}{\sum_{s'} P_{s'} C_{s'}} = \frac{\zeta_s P_s^{1-\eta} C^{\varepsilon_s - \eta}}{\sum_{s'} \zeta_{s'} P_{s'}^{1-\eta} C^{\varepsilon_{s'} - \eta}}. \tag{2.68}$$

2.B.2 Capital Accumulation

Proposition 2.8. *Taking prices $P_{I,t}^n$ and r_t^n as given, investors optimal decisions imply that next period's aggregate capital stock in country n, K_{t+1}^n, is given by:*

$$K_{t+1}^n = \mu \frac{\left(r_t^n + P_{I,t}^n (1-\delta) \right)}{P_{I,t}^n} K_t^n \tag{2.69}$$

Proof. Taking FOC results in the following Euler equation:

$$1 = \mu \frac{P_t^{n,C} C_t^{n,K}}{P_{t+1}^{n,C} C_{t+1}^{n,K}} \left(\frac{r_{t+1}^n + (1-\delta) P_{t+1}^{n,I}}{P_t^{n,I}} \right)$$

Guess and verify the following policy function:

$$P_t^{n,C} C_t^{n,K} = (1-\mu)\left(r_t^n + (1-\delta)P_t^{n,I}\right) K_t^n$$
$$P_t^{n,I} K_{t+1}^n = \mu\left(r_t^n + (1-\delta)P_t^{n,I}\right) K_t^n$$

Plug the consumption policy function into the Euler equation and re-arrange to obtain:

$$\mu \frac{\left(r_t^n + (1-\delta)P_t^{n,I}\right) K_t^n}{P_t^{n,I} K_{t+1}^n} = 1.$$

Clearly, under the conjectured investment policy rule, this equation holds, as desired.

□

2.B.3 Proofs

Analytical Tools

The following results will be used repeatedly throughout the proofs.

Theorem 2.1 (Schauder's Fixed Point Theorem)**.** *Let K be a nonempty convex subset of R^n. Then any T which is a continuous mapping of K such that $T(K) \subseteq K$ is compact has a Fixed Point.*

Theorem 2.2 ("Inada" Fixed Point Theorem)**.** *Let $T : R_+^n \to R_+^n$ be a mapping that satisfies the following assumptions:*

1. $T(\vec{0}) \geq 0_{n\times 1}$
2. $T(\cdot) \in C^1$
3. *Let $\nabla T(x)$ the $n \times n$ matrix of partial derivatives. Then:*
   (a) $\nabla T(x) \geq 0_{n\times n}$

(b) $\nabla T(0_{n\times 1})_{ii} > 1$ *for all* i *[That is, all diagonal elements of* ∇T *evaluated at* $\vec{0}$*.]*

(c) *There exists* $x_0 \in R^n_{++}$ *such that* $\lim_{s\to\infty} \frac{s}{T_j(sx_0)} = \infty$ *for all* j

Then $T(x)$ *has at least one fixed point* $x^* > 0_{n\times 1}$.

Proof. By 1., 2., 3a. and 3b. there exists $\underline{x}$ such that $T(\underline{x}) \geq \underline{x}$. By 2. and 3c, there exists $\bar{x}$ such that $T(\bar{x}) \leq \bar{x}$. Denote $K = \{x : \underline{x} \leq x \leq \bar{x}\}$. By continuity $T(K)$ is a compact subset, and because $T(\cdot)$ is increasing given 3a, $T(K) \subseteq K$. Hence we conclude by Schauder's FPT that there exists a fixed point $T(x^*) = x^*$. □

Now suppose we're looking for a solution $f(x^*) = 0$ to an equilibrium system characterized by $f(\cdot)$. The following results borrow from Allen et al. (2015b), henceforth AAL.

Corollary 2.1 (AAL existence)**.** *Suppose* $F : R^{n+1}_{++} \to R^n$ *satisfy the following:*

1. *For all* $i = \{1, ..., n\}$, $f_i(x) = F_i(x, x_i)$
2. *For all* $x' \in R^n_{++}$, *there exists* x_i *such that* $F_i(x', x_i) = 0$
3. $\frac{\partial F_i(x', x_i)}{\partial x_i} \frac{\partial F_i(x', x_i)}{x'_j} < 0$ *for all* j
4. *There exists* x' *such that for* x_i *defined in* $F_i(sx', x_i) = 0$, $x_i = o(s)$.

Then $f(x)$ *has a solution* $f(x^*) = 0$.

Proof. Define $T : x' \mapsto x$ where x_i satisfies $F_i(x', x_i) = 0$. It is easily checked that $T(\cdot)$ given the assumptions satisfy all the assumptions of the "Inada" FP theorem. □

Theorem 2.3 (AAL Uniqueness Theorem)**.** *Assume (i)* $f(x)$ *satisfies gross substitution and (ii)* $f_i(x)$ *can be decomposed as* $f_i(x) = \sum_{j=1}^{\nu_f} g_i^j(x) - \sum_{k=1}^{\nu_g} h_i^k(x)$, *where* $g_i^j(x), h_i^j(x) \geq 0$ *are homogeneous of degree* α_j *and* β_k *with* $\max \alpha_j \leq \min \beta_k$. *Then*

- *there is at most one up-to-scale solution to* $f(x) = 0$.

- *if for some j, k, $\alpha_j \neq \beta_k$, there is at most one solution.*

Proof. See AAL. □

Lemma 2.1. *Define* $\mathbf{S}$ *to be a* $n \times n$ *diagonal matrix with strictly positive diagonal elements. Define* $\mathbf{T}$ *to be a weakly positive* $n \times n$ *matrix. Let* $\mathbf{A} := \mathbf{S} - \mathbf{T}$.

1. *If* $\sum_j t_{ij} < s_{ii}$, *then the inverse* $\mathbf{A}^{-1}$ *exists and* $\mathbf{A}^{-1} \geq 0$.

2. *If furthermore* $\mathbf{T} > 0$, *then* $\mathbf{A}^{-1} > 0$.

Proof. See AAL (2014). □

Existence and Uniqueness of the Equilibrium

The structure of our model ensures that for any time t and K_t and L_t, the existence and uniqueness of the static trade equilibrium for that period ensure the existence and uniqueness of the entire path.

Proposition 2.2, Existence. We prove the result in multiple steps.

Step 1: Given (w, r), prices are unique.

Lemma 2.2. *Given* w *and* r, *there exist unique functions* $Q^n_{s',s}(w,r)$, $q^n_s(w,r)$, $P^n_s(w,r)$, $P^n_{I,t}(w,r)$ *and that solve equations (2.27), (2.31), (2.33) and (2.35). Moreover, these functions are continuous.*

Proof. Consider $Q^n_{s's} = \gamma_s \left(\sum_l T^l_s (q^l_{s'} \bar{\tau}^{ln}_{s's})^{-\theta_{s'}}\right)^{-1/\theta_s}$. Substitute in for the unit cost and write:

$$G^n_s\left(\tilde{Q}, Q^n_s\right) = \gamma_s \sum_l T^l_s \left(\left(\left(w^l\right)^{\beta^l_s}\left(r^l\right)^{1-\beta^l_s}\right)^{\vartheta^l_s} \prod_{s'}\left(\left(\tilde{Q}^l_{s's}\right)^{\alpha_{s's}} \bar{\tau}^{ln}_{s's}\right)\right)^{-\theta_s} - \left(Q^n_s\right)^{-\theta_s}$$

Proving the existence of a (w, r) solving for Q amounts to verifying that the scaffold function G_s satisfies the conditions of corollary 1. (i) and (ii) holds as by definition,

$G_s^n(Q, Q_s^n) = 0$, for all s'. (iii) is easy to verify. For (iv), note that we can write

$$G_s^n(aQ, Q_s^n) = \gamma_s \sum_l T_s^l a^{-(1-\vartheta_s^l)\theta_s} \left(\left(\left(w^l\right)^{\beta_s^l} \left(r^l\right)^{1-\beta_s^l} \right)^{\vartheta_s^l} \prod_{s'} \left(\left(\tilde{Q}_{s's}^l \right)^{\alpha_{s's}} \bar{\tau}_{s's}^{ln} \right) \right)^{-\theta_s} - (Q_s^n)^{-\theta_s},$$

which implies $Q_s^n \propto s^{\iota_s}$ with $\iota_s \in (0,1)$, implying that $Q_s^n = o(s)$. Corollary 1 then implies the existence of a fixed point Q_s^n. To ensure uniqueness, define $f_s^n(Q) = g_s^n(Q) - \sum_{l=1}^N h_{s,n}^l(Q)$, where $g_s^n(Q) = (Q_s^n)^{-\theta_s}$ and $h_{s,n}^l = \gamma_s T_s^l \left(\left(\left(w^l\right)^{\beta_s^l} \left(r^l\right)^{1-\beta_s^l} \right)^{\vartheta_s^l} \prod_{s'} \left(Q_{s's}^l\right) \bar{\tau}_{s's}^{ln} \right)^{-\theta_s}$. Gross substitution holds and g_n^s is homogeneous of degree $-\theta_s$, $h_{s,n}^l$ is homogeneous of degree $-(1-\vartheta_s^l)\theta_s$. $\vartheta_s^n < 1$ then ensures that $-\theta_s < \min_l -(1-\vartheta_s^l)\theta_s$. These steps ensure that given (w,r), there exists unique functions Q_s^n, q_s^n satisfying the postulated equilibrium conditions. Given that all other prices and unit cost functions are functions of first stage production prices and unit costs, this simultaneously ensures their respective existence and uniqueness. Continuity follows directly from uniqueness. □

Step 2: Given (w,r), consumption indices exist and are unique.

Lemma 2.3. *Suppose we normalize $\sum_n w^n + r^n = 1$. Then, given any set of parameters, all endogenous variables are bounded.*

Proof. Wages and rents have to be strictly positive. Otherwise, a country with a zero factor cost will necessarily have a positive demand for its product and hence receive payments for them. Hence the set of prices under the above normalization is bounded, $w^n, r^n \in (0,1)$ for all n. Thus prices solving equations (2.27), (2.31), (2.33) and (2.35) are necessarily bounded, as Lemma 2.2 above and the proof of Theorem 2.2 shows. Therefore, $C^{n,j}$ solving equation (2.40) is also bounded above and away from zero. The market-clearing conditions then ensure that quantities produced are also bounded above and away from zero for any country n and sector s. □

Lemma 2.4. *Given w, r there exist unique $C^{n,j}$ that solve equation (2.40). Moreover, these functions are continuous.*

Proof. Given the assumption and Lemma 2.3, the RHS of equation (2.40) is strictly increasing in C with $C \in [0, \infty)$ mapping into $[0, \infty)$. As it is also continuous, the Intermediate Value Theorem ensures that there exists a unique $C^n \in (0, \infty)$ solving each equation. Moreover, since it is unique and equation (2.40) is continuous, $C^n(w, r)$ is also continuous for all n. □

Step 3: Given (w, r), there exist unique output functions

Lemma 2.5. *Given w, r, there are exist unique functions $\mathcal{I}_s^n(w, r)$, $F_s^n(w, r)$ and $I_s^n(w, r)$ that solve equations (2.46) and (2.45). Moreover, these functions are continuous.*

Proof. It is obvious that any (w, r) maps into a unique F_s^n (since it maps directly into prices and consumption indices), which in turn maps into a unique $I_{F,s}^n$. We can then, as in AAL, stack and re-write the expressions for gross intermediates as

$$I_I = AI_I + \mathbf{b},$$

where I_I is a $NJ \times 1$ vector with $\{I_I\}_{(n-1)*S+s} = I_s^n$, A is a $NS \times NS$ matrix with entries $a_{(n-1)S+s,(i-1)S+k} = (1 - \nu_{1,k}^i)\alpha_{1,sk}^i \pi_{sk}^{ni}$. $\mathbf{b}$ in turn is a $NS \times 1$ vector of strictly positive constants. The summation along the column of matrix A is:

$$\sum_s \sum_n a_{(n-1)S+s,(i-1)S+k} = \sum_s \sum_n (1 - \nu_{1,k}^i)\alpha_{1,sk}^i \pi_{sk}^{ni} = \sum_s (1 - \nu_{1,k}^i)\alpha_{s,k}^i = 1 - \nu_{1,k}^i < 1.$$

Lemma 2.1 then implies that there exists a unique $I_I = (I - A)^{-1}\mathbf{b}$ for any set of wages and rents. □

Step 4: Existence of wages and rents solving the market clearing conditions

Proposition 2.9. *Given the price functions, the consumption functions, and the output functions, there exists w, r that solves equations (2.47) and (2.48), and hence an equilibrium exists.*

Proof. The excess demands for factors L and K in country m are given by:

$$Z_L^m(w,r) = \frac{\sum_{s\in\mathcal{S}}\left[\beta_s^n\vartheta_s^m\left(\mathcal{I}_{,s}^m + \mathcal{I}_{\mathcal{I},s}^m\right) + \beta_s^m\vartheta_s^m F_s^m\right]}{w^m} - L^m \tag{2.70}$$

$$Z_K^m(w,r) = \frac{\sum_{s\in\mathcal{S}}\left[(1-\beta_s^m)\vartheta_s^m\left(\mathcal{I}_{,s}^m + \mathcal{I}_{\mathcal{I},s}^m\right) + (1-\beta_s^m)\vartheta_s^m F_s^m\right]}{r^m} - K^m \tag{2.71}$$

WeW verify conditions i) to v) of Proposition 17.C.1. in Mas-Colell et al. (1995). $Z_m(w)$ is continuous given that all functionals entering the above equation were proven to be continuous. Next, all prices are homogeneous of degree 1 and hence $Z_m(w)$ is homogeneous of degree 0 in w, as no shares move. iii) is immediate as is iv) given Lemma 2.3. We are left to prove v), namely that if wages converge to a point where one wage is zero, at least one excess demand goes to infinity. Intuitively, this is clear in the current setting, since as the wage of a single country goes to zero, prices also go to zero while its trade shares converge to one. Rewrite the model in changes as in appendix 2.A.2. Let n index the elements of a sequence. Without loss of generality assume $\hat{w}_n^m \sim n^{-1}$ while $\hat{w}_n^{m'} = O(1)$ for $m' \neq m$ and $\hat{r}_n^m = O(1)$. Now it is clear that $\hat{\mathbf{Q}}_n \to 0$, and by the uniqueness shown in Lemma 2.2, it is enough to find just one rate of convergence that works given the sequence $\hat{\mathbf{w}}_n$. Observe that $n\hat{\mathbf{Q}}_n$ converges to constants bounded away from zero, showing that $\hat{\mathbf{Q}}_n \sim n^{-1}$. This is intuitive: as the cost of country m converge to zero, every country sources their intermediates from m, meaning that only its unit costs matter for the price indices, which hence inherit the speed of convergence of $\hat{w}^m$. Also observe that $\hat{\mathbf{P}}_n \sim n^{-1}$ too. Now using this in the expression for $\hat{\mathbf{q}}_n$, one observes that $\hat{q}_{s,n}^{m'}/\hat{P}_{s,n}^{m'} \to \infty$ for $m' \neq m$, meaning that the

final good trade shares of every other country goes to zero, and hence that those of country m goes to one. Intuitively, its unit costs converge faster to zero than that of the others. This immediately implies that its excess demand exploses to infinity, as the numerator equation (2.70) stays bounded while the denominator goes to 0, which concludes the proof. □

The above results ensure the existence of an equilibrium under the stated parameter restrictions. □

Proof of Equilibrium Uniqueness. In the previous proof, we have demonstrated that given (w, r), C^w and C^K, all prices and output functions are uniquely determined. Treating equations (2.47) and (2.48) as an excess demand system in $2N$ variables, we then show that there exist unique wages and rents clearing this excess demand system. First, observe that this system is homogeneous of degree 1 in (w, r). Hence one proof reduces to showing that under the stated assumptions, gross substitution is satisfied: that is, rising one factor price while keeping others constant raises all other excess demands. For formal intuition, note that it is sufficient to show that $d\mathcal{I}_s^n, dF_s^n$ are all strictly positive for $n \neq k$ where $dw^k > 0$ or $dr^k > 0$. Consider for concreteness the change in F_s^n. Write $\hat{x} \equiv d\log(x)$. We have:

$$dF_s^n = \sum_{l,j} \lambda_s^{nl} e_s^{l,j} E^{l,j} \left(\hat{\lambda}_s^{nl} + \hat{e}_s^{l,j} + \hat{E}^{l,j} \right) + \sum_l \lambda_{I,s}^{nl} \alpha_{I,s}^l P_I^l I^l \left(\hat{\lambda}_{I,s}^{nl} + \widehat{P_I^l I^l} \right). \quad (2.72)$$

To obtain $dF_s^n > 0$, it is hence sufficient to show that $\hat{\lambda}_s^{nl} + \hat{e}_s^{l,j} > 0$ as well as $\hat{\lambda}_{I,s}^{nl} + \widehat{P_I^l I^l} \geq 0$ for $n \neq k$. We first focus on the first inequality. Note first that with constant expenditure shares $\hat{e}_s^{l,j} = 0$. Next, note that with no-linkages, the increase in another countries' factor costs does not affect unit costs of productions at either stages of other countries. Hence the trade shares of these countries necessarily all rise, so $\hat{\lambda}_s^{nl} > 0$. Therefore $dF_s^n > 0$, but then the demand for all intermediates within the country raises too, as there are no-country linkages in intermediate inputs. Now look

at the second inequality. Again, with no-linkages, the rise in $\hat{\lambda}_{I,s}^{nl}$ is unambiguous, and moreover, with $\mu = 1$, the change in $\widehat{P_I^l I^l}$ is weakly positive. From there, it is easy to realize that, because all endogenous variables are continuous in all parameters, and moreover are bounded if such parameters live in compact sets, equilibrium uniqueness will follow immediately by limiting the strength of the three problematic forces (varying expenditure shares, linkages, and moving investment). This can be formally seen by "unpacking" the derivatives $\hat{\lambda}_s^{nl} + \hat{e}_s^{l,j}$ and $\hat{\lambda}_{I,s}^{nl} + \widehat{P_I^l I^l} \geq 0$, but it is immediate to see and we omit it. □

***Proof of Proposition 2.6**: Checking Gross Substitution Numerically.* The logic of the proof consists in bounding endogenous variables and changes therein using the observed equilibrium as well the assumed knowledge of the maximum dispersion in factor returns. Intuitively, we make use of the fact that our model can be re-written in changes and hence, should more than one equilibrium exists, one should be able to "switch" between them using the model written in changes despite no changes in structural parameters. Using the fact that the observed data is one such equilibrium – whose existence is insured – this allows one to compute the minimum values of many endogenous variables, and hence to check of gross-substitution hold globally – or, alternatively, compute the bounds $\bar{T}, \underline{\eta}, \underline{\mu}$ that insure the latter.[19] Denote by $\bar{w}, \underline{w}, \bar{r}, \underline{r}$ the minimum and maximum observed relative wages and rents. We are interested in bounding the endogenous levels of trade shares, expenditure shares as well as changes in prices and unit costs. First, we chain two changes to the observed equilibrium to get to the largest and lowest possible increase stemming from a wage increase in one other countries. This can be done by using the current intermediate trade shares and by plugging respectively the change it would take to get from the current factor prices to the maximum and minimum values respectively. This can

[19] These will necessarily be looser, however, because one would require that $\hat{\lambda}_s^{nl} + \hat{e}_s^l$ holds for each n, for a given change in w^m for all $m \neq n$ and all n and s.

be done uniquely since we know that the price fixed points can be solved uniquely. For gross substitution we will be interested in the impact of one single wage increase. This one has to be given by starting from the lowest possible wage and increasing this other country's factor cost to the highest possible level. To get there, we use the new trade shares implied by the previous undertaken changes (which can be obtained from knowing the current levels as well as the implied change in unit costs) and compute the corresponding change. It is easy to see that this has to be the maximum possible increase in unit costs for country n in sector s coming from a singular wage (or rent) increase in any other country. This way, for each supposed change, we can bound the responses in unit costs in all countries for that change above and below. Using these, we can use the fact that $\frac{dP_s^n}{P_s^n} = \hat{P}_s^n = \sum_k \lambda_s^{kn} \hat{q_s^n}$ and the obtained minimum and maximum values to bound the highest and lowest increase in each price index, again.

Thus, we can bound $\hat{P}_s^n$ *globally* for any individual change. We use these to obtain bounds on the minimum and maximum feasible levels in trade shares. In particular, note that we can write $\frac{d\lambda_s^{nl}}{\lambda_s^{nl}} = \hat{\lambda}_s^{nl} = -\theta_s(1-\lambda_s^{nl})\hat{q}_s^n + \sum_k \theta_s \frac{\lambda_s^{kl}}{\lambda_s^{nl}} \hat{q}_s^k$. Using the bounds on changes in unit costs obtained in the previous step, we can bound the maximum change in λ_s^{nl} and given that we know the current level, we can compute the upper and lower bounds in *levels*. Similar steps will allow us to bound intermediate and investment trade shares using the observed equilibrium as well as the known maximum dispersion in wages and rents. Finally, we are interested in finding upper and lower bounds on the change in expenditure shares. Note that the change in expenditure shares can be written:

$$\hat{e}_s^n = -\left(\left(\frac{\sum_{s'} e_{s'}^n (\varepsilon_s - \varepsilon_{s'})}{\sum_{s''} e_{s''}^n (\varepsilon_{s''} - \eta)}\right) \sum_s e_s^n \hat{P}_s^n + \hat{P}_s^n\right)(1-\eta).$$

Using the previously obtained bounds, we can bound this change again from below and above. Then, taking the observed lower bounds, we can empirically compute the differentials in (2.70), as in (2.72), and check whether GS holds globally. □

Uniqueness of Parameter Inversion

Proof of Proposition 2.7 (Uniqueness of inversion). The proof consists of two steps: The first is to establish that for a given observed change in aggregate expenditure shares, there is a unique set of domestic price indices $\hat{P}_s^n$ rationalizing this change. Given this, the required change in technologies and trade costs an be calculated uniquely in closed-form, as we will demonstrate.

First note that from observed changes in incomes we can use market clearing conditions to solve for the changes in wages $\hat{w}^n$ and rents $\hat{r}^n$ that the equilibrium will have to respect. Here uniqueness is immediate from the fact that our model will perfectly match value-added data as well as investment growth – and hence the implied capital growth.

Step 1: Given changes in expenditure shares and incomes, there exists a unique set $\{\hat{P}_s^n\}$ rationalizing these changes.

From our model in changes, the observed expenditure shares $e_s^{\prime n}$ are jointly determined by the following sets of equations (omitting time subscripts for simplicity) for $j \in \{K, L\}$:

$$\left(\hat{E}^{n,j}\right)^{1-\eta} = \sum_s e_s^{n,j} \left(\hat{C}^{n,j}\right)^{\varepsilon_s - \eta} \left(\hat{P}_s^n\right)^{1-\eta}$$

$$e_s^{\prime n} = \left(\hat{P}_s^n\right)^{1-\eta} \left(\frac{\left(\hat{C}^{n,K}\right)^{\varepsilon_s - \eta}}{\left(\hat{E}^{n,K}\right)^{1-\eta}} e_s^{n,K} \text{IncShare'}_K + \frac{\left(\hat{C}^{n,L}\right)^{\varepsilon_s - \eta}}{\left(\hat{E}^{n,L}\right)^{1-\eta}} e_s^{n,L} \text{IncShare'}_L \right)$$

First, fix consumption indices. It is then not hard to see that there exists a unique set $\hat{P}_s^n$ consistent with the observed change in expenditure shares. Then it is easy to show that holding the consumption index of workers fixed, the right hand side of the

change in investors income is a strictly increasing function of the consumption index of investors. The last step then has to establish that the right hand side relating to the change of income for workers is an increasing function in the aggregate consumption index of workers. But again, for the sake of a contradiction, suppose that it was not. Then for a given increase in workers income, prices would have to decrease – which cannot be. With this established, we next show of we can uniquely pin down changes in technologies and trade costs.

Step 2: Given $\{\hat{P}_s^n\}$ and changes in the Head-Mayer statistics, there exist unique changes in trade costs and technology shifters rationalizing these as an equilibrium outcome of the model.

The key here is to realize that we can, using the required change in price indices, back out the change in technologies independently of the change in trade costs. The change in trade costs can then be separately solved for to match the change in the Head-Mayer statistics. This clear separation greatly facilitates the proof. The key is to realize that we can write:

$$\left(\hat{P}_s^n\right)^{-\theta_s} = \frac{\hat{T}_s^n \left(q_s^n\right)^{-\theta_s}}{\hat{\lambda}_s^{nn}}.$$

Using the observed changes in trade shares $\hat{\lambda}_s^{nn}$, we can calculate the required $\hat{T}_s^n \left(q_s^n\right)^{-\theta_s}$ consistent with that change. To disentangle $\hat{T}_s^n$ from $\hat{q}_s^{n^{-\theta_s}}$, we can first calculate:

$$\left(\hat{Q}_{s's}^n\right)^{-\theta_s} = \frac{\hat{T}_{s'}^n \left(\hat{q}_{s'}^n\right)^{-\theta_s}}{\hat{\pi}_{s's}^{nn}},$$

Note that we have wages and rents from market clearing and the observed equilibrium, we computed $\hat{T}_s^n \left(\hat{q}_s^n\right)^{-\theta_s}$ in the previous step and know the change in trade shares in

intermediates. Thus we can solve for $\hat{q}_s^n$:

$$\hat{q}_s^n = ((\hat{w}^n)^{\beta_s^n}(\hat{r}^n)^{1-\beta_s^n})^{\vartheta_s^n}\left(\prod_{s'}\left(\hat{Q}_{s's}^n\right)^{\alpha_{s',s}^n}\right)^{1-\vartheta_s^n}.$$

And then back out $\hat{T}_s^n$. None of this used knowledge of the change in any trade cost, as this is summarized in the change in trade shares with oneself, which is a sufficient statistic for that. Using this, we can write the Head-Mayer statistics, which for final goods are given by:

$$\frac{\hat{\lambda}_s^{kn}}{\hat{\lambda}_s^{nn}} = \frac{\hat{T}_s^k\left(\hat{q}_s^k\right)^{-\theta_s}}{\hat{T}_s^n\left(\hat{q}_s^n\right)^{-\theta_s}}\left(\hat{\tau}_s^{kn}\right)^{-\theta_s}.$$

$\hat{\tau}_s^{kn}$ is the only unknown in this equation, given that the other elements are either taken from the data or pinned down in the previous steps. In a similar way, we can uniquely solve for the changes in trade costs in intermediates $\hat{\tilde{\tau}}_{s's}^{kn}$ as well as in investment goods, $\hat{\tau}_{I,s}^{kn}$. Knowing all of this, the change in the price in investment goods is pinned down and we can pick investment technological changes $\hat{T}_I^n$ uniquely so as to match the evolution of investment $\widehat{P_I^n I^n}$ observed in the data, which completes the inversion. □

Chapter 3

Trade in Services and Innovation

3.1 Introduction

Trade integration not only provides firms with greater access to foreign export markets but also improves their access to foreign output of research, innovation, and development activity. While the effect of the first channel on the innovation activities of firms is well studied, the latter aspect has received little attention, partly due to a measurement problem. In this paper, we assemble a unique data set that allows us to track firm-level international transactions of German firms related to the purchase and usage of foreign technology and knowledge, patents and innovation output, as well as an array of measures of firm-level innovation as well as firms' exports and input cost structure. Our data allow us to document and test for the impact of trade on innovative activity through technology access relative to traditional channels such as export market size and competition. A key contribution of this chapter, therefore, is to assess theoretically and empirically how international trade affects innovation incentives by altering both the cost and returns of innovative activities.

We combine our data with a new theory of trade and innovation tailored to connect with we can observe in the data to provide insights into how services trade and

innovation effort interact at the firm level. Given that the formation of platforms for the mutual and simplified exchange of property rights protected technology, business services, and other non-tangible goods appear equally important in the negotiation and formulation of recent trade agreements, an assessment of the effects of these policies on firm-level innovation is of high interest to policymakers.

This chapter merges confidential firm-level data from the Deutsche Bundesbank (German Central Bank) and the ZEW – Leibniz Centre for European Economic Research. The data allow us to track firm-level imports and exports of innovation services and contain detailed information regarding firms' innovation activities, sales, and exports of final goods. Beyond providing information on a firm's R&D and overall innovation expenditures, we observe a broad set of outcomes related to innovative activity: reductions in unit cost, increases in product quality, and the sales accounted for by improved and new products.

As a first step, we document several salient empirical facts about the nature of firm-level innovation activities and trade in innovation services that motivate our theoretical and empirical analysis. Similarly to prominent empirical patterns found for trade in goods in e.g. Bernard et al. (2007), few firms import innovation services. Importing firms tend to import these services every year, and appear to be more productive, as indicated by higher revenue to labor ratios, higher wages paid, and higher skill-intensity.

Innovation expenditures are a more comprehensive measure of innovation activity than R&D expenditures, which capture less than two-thirds of overall innovation-related expenses. This suggests that common innovation measures based on R&D spending miss a sizeable share of innovation activity. Variance decompositions of aggregate innovation activity further suggest that within-sector differences in innovative activity between firms are the dominant driver of aggregate trends in innovation activity. This fact motivates our focus on studying how international trade interacts with

the determinants of within-industry differences in innovation outcomes across firms. Lastly, we document that there is suggestive evidence of selection complementarities between innovating, importing innovation services, and exporting.

To guide our empirical analysis, we develop a heterogeneous firm model that is consistent with these facts and features trade in final goods, imperfect competition in product markets, and trade in innovation-related services.[1] In the model, firms devote resources separate from production to innovative activities, which aim to improve profitability. The model remains parsimonious as to whether innovation primarily affects demand (product innovation) or costs (process innovation). In final good markets, the incentives to innovate depend negatively on endogenous profit margins (competition) and positively at the size of output markets scaling the returns to innovation. The efficiency at which firms generate innovation outcomes increases through the integration of foreign innovation services. By integrating foreign innovation output, through trade in innovation services, some firms thus gain a competitive advantage in their innovation efficiency. Our model of innovation service imports adopts the model developed in Halpern et al. (2015).

The model makes testable predictions mapping directly into quantities that we can observe in the data. Specifically, the model predicts that firms with access to larger markets via exports, exposed to less competition, and higher imports of foreign innovation services are more innovative. Further, the model admits measurable sufficient statistics for the firm-level pass-throughs of trade shocks into innovation efforts: The levels of output in each destination market, sales shares in output markets, and the share of innovation service imports of total innovation expenditures.

[1]The model is designed to speak directly to the data and is closer to models of oilgopoly and innovaton in industrial organization, e.g. Spencer and Brander (1983), Bloom et al. (2013), than to the literature that deploys Schumpeterian growth theory to understand how innovation interacts with competition and trade - see, for example, Aghion et al. (2005), Aghion and Howitt (1992), and Grossman and Helpman (1991). See Aghion et al. (2014) for a review of this literature.

To test the core predictions of the model, we investigate how differences in innovation service imports, exports, and exposure to competition affect differences in innovative activity and outcomes between firms. To do so, we construct novel firm-level instruments using a shift-share design building on Bartik (1991) and recent work in Lileeva and Trefler (2010); Garin and Silvero (2018). The instruments, which are valid within our structural model, allow us to identify the causal effects of access to foreign innovation services, market size, and competition on the innovation activities of German firms within the same industry.

Our estimates confirm the key predictions of our model and provide direct evidence on the impact of trade in innovation services on firms' incentives to innovate. We find that firms who are more exposed to positive supply shocks in foreign innovation services undertake more substantial innovation efforts, as measured by both overall innovation spending and total R&D spending. We also find that these firms achieve better innovation outcomes across all our measures relating to product and process innovation. As our core theoretical mechanism postulates that foreign innovation services improve the efficiency with which firms produce innovations, we interpret these findings as lending direct empirical support to this assumption.

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

wender (2015)). However, our results indicate that the effects might differ across process and product innovation, as in Dhingra (2013).

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

How important might firm-level responses in innovative behavior be for the aggregate effect of changes in trade costs on a country's innovation activity? To answer this question, we re-visit our model and show that the effect of trade on aggregate innovation activity depends on the microstructure of the economy. To make this point, we characterize the elasticity of firm-level innovation activities with respect to various trade shocks. We show that our model admits the following sufficient statistics as determinants of how firms' relative innovation incentives respond to change in trade costs: Initial output shares in final goods markets, initial output levels across all markets, as well as initial import intensities of foreign innovation services. This result highlights the interplay between complementarities in selection into innovating, importing innovation services and exporting, and the aggregate effects of trade on innovation.

Literature Our study is related to a large and growing literature on the interlinkages of trade and innovation, and in particular, to Steinwender (2015), Aghion et al. (2018), Fieler and Harrison (2018) and Lim et al. (2018), all of which study the effect of trade in goods on firm-level innovation activity. Shu and Steinwender (2019) provide a comprehensive overview of the empirical literature, which the interested reader is referred to. Relative to the existing empirical literature, we make two contributions. First, we provide the first causal evidence on the impact of trade in services on firm-level innovation activity. Second, much of the literature, including Aghion et al. (2009, 2005) relies on patents or inferred total factor productivity to measure innovation activities of firms. This chapter complements the empirical literature by providing direct measures of innovation activities.

Similarly to our theoretical framework, in Aghion et al. (2005, 2015) and Akcigit et al. (2018) the gains from innovation are non-monotonic in firm productivity. While these models feature homogeneous goods and production by the most productive firm only, our framework is closer to quantitative frameworks with differentiated varieties, market size effects, and international trade in goods and services.

A large early literature on positive knowledge spillovers from innovation, reviewed in Griliches (1992), argues that a firm's innovation effort might impose positive externalities on other firms. Bloom et al. (2013), in turn, argue that since product market rivalry creates negative effects from innovation efforts of one firm on the profits and value of another, knowledge spillovers and product market rivalry need to be analyzed jointly. We do not explicitly model product market spillovers. However, our quantitative model can be extended to accommodate strategic complementarities and external spillovers between firms' innovation behavior.

While previous work has largely considered market size and competition effects to operate in isolation, our findings suggest that aggregate effects crucially depend on the interaction of these channels at the micro-level. Our results indicate that the

potentially detrimental effects of import competition depend on the extent to which the most innovative firms are simultaneously large exporters. Taking into account the role of selection complementarities, we provide a new perspective on ambiguous findings regarding the relationship between innovation and import competition in the literature. Accounting for the role of these micro-level channels for the aggregate impact of trade on innovation is a novel contribution of this chapter.

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

3.2 Trade in Services

3.2.1 Background

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

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

2. Mode 2 captures service consumption abroad – a member of territory A provides a service to a member of territory B within the borders of territory B. An example for such a case is when a French firm based in France providing innovation services to a subsidiary of a German firm located in France.

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

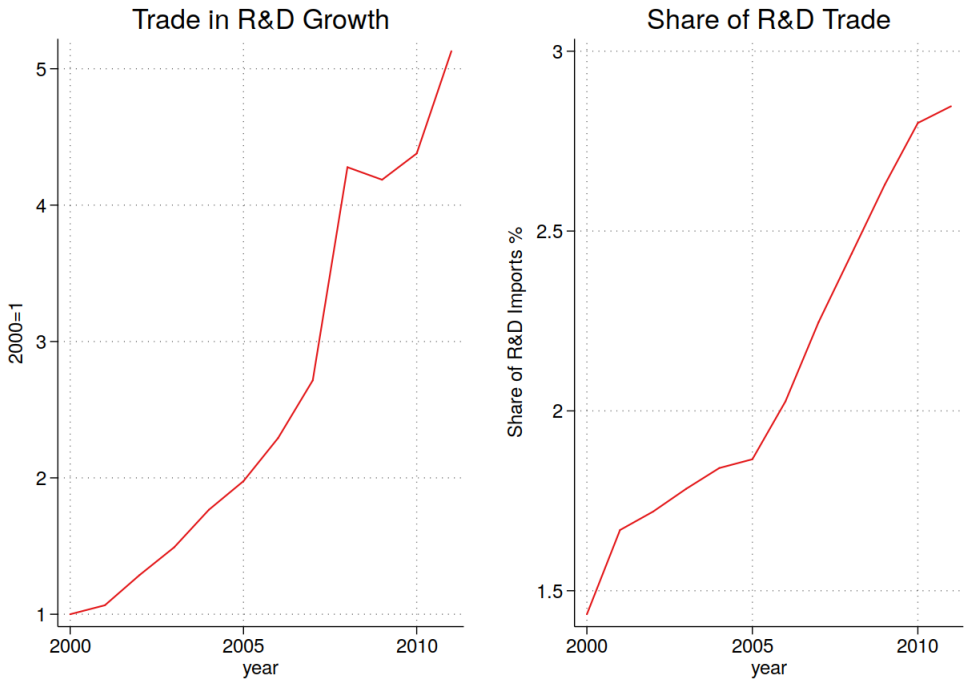
4. Mode 4 corresponds to services provided through individual persons: a service that is provided by a person living in territory A to a firm or person located in territory B., For example, a French freelance engineer traveling to Germany to provide innovative services to German firms.

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

Aggregate Trends in Trade in Services

Services trade has increased sizeably over the last decades. We use the World Bank's Trade in Services Database to construct aggregate statistics on world imports of R&D related services. Figure 3.1 shows that international flows in R&D services have increased by nearly five-fold between 2000 and 2011. Further, world trade in R&D is outgrowing the overall trade in services. The share of R&D imports in total service imports has increased from one to three percent in the same period.

Figure 3.1: World Trade in R&D services



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

A key hypothesis of this chapter is that the changes in the observed trade volumes of services reflect falling trade barriers. However, in contrast to the determinants of trade costs of tangible goods, the determinants of trade costs of services are less well understood. Therefore, we proceed by providing examples aimed to illustrate the various barriers to trade in services.

Barriers to Trade in Innovation Services

Significant barriers to trade in innovation services include communication costs that affect the ease with which findings can be shared across distant locations as well as

international copyright laws. All information in this section is taken from public data sources (see relevant footnotes).

Improvements in information and communication technologies over several decades have vastly improved firms' capabilities to engage in service trade. File sharing and cloud storage services have become easily accessible, allowing companies to implement professional business solutions, and to heighten their security and privacy standards. Further, all members of the WTO have committed to ensuring minimum standards of international copyright protection that do not discriminate against foreign inventors. We give two concrete examples of firms that engage in international R&D services trade.

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

However, IP protection is still far from perfect. Despite the developments in communication technologies, concerns surrounding IP still pose a significant barrier to trade in services. An anecdotal example is the experience of the German roller coaster manufacturer Gerstlauer. The manufacturer has been expanding heavily in

[2]All information on WuXi is taken from its public Wikipedia page: https://en.wikipedia.org/wiki/WuXi_AppTec.

China. However, it never shares research-manufacturing plans digitally with potential clients. Instead, a firm representative travels to China to present physical copies.[3]

3.2.2 Firm Level Data from Germany

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

Firm-level service imports The Statistics on International Trade in Services (SITS)[4] database, described in great detail in Biewen and Lohner (2017), provides information on the service transactions of German firms. Access to the data is provided through the Research and Data and Service Centre (RDSC) of the Deutsche Bundesbank. The database is used to compile Germany's Balance of Payments Statistics,[5] and thus, each firm must report all service transactions whose joint volume exceeds the amount of 12,500 Euro for a given month, country, and service type. The data, therefore, practically includes all service trades of German firms. For our analysis, we extract the yearly values of firms' reported service transactions classified according to its service type, its direction, and the involved foreign country. In total, we label four types of service imports as innovation-related: (i) R&D, (ii) patents, licenses, and innovations, (iii) artistic copyrights, and (iv) other rights (such as franchises, trademarks, and marketing rights). R&D accounts for the bulk of these transactions and is the main focus of our analysis.

[3] See https://honestversion.com/global-roller-coaster-market-oppurtunity-analysis-competitor-landscape-growth-trends-forecast-2018-2023/le for more details.

[4] DOI: 10.12757/Bbk.SITS.0116.01.01.

[5] Aggregate statistics on services trade in other countries are also compiled from data collected for Balance of Payments Statistics.

Innovation Data The Mannheim Innovation Panel (MIP)[6] is gathered in the form of yearly surveys by the ZEW – Leibniz Centre for European Economic Research and constitutes the German contribution to the European Commission's Community Innovation Survey. The MIP is our primary source of information on firms' innovation activities and other firm-level outcomes, such as employment, goods exports, and internal R&D activities.

The data contain information on firms' expenditures on innovation activities broadly and R&D in particular. Moreover, it contains data about the introduction of new products, services, and processes and their success. Firms are asked to declare whether their innovation activities yielded product innovations, defined in the questionnaire as the market introduction of a new or significantly improved good or service, as well as the revenue share accounted for by these products. Firms are asked to distinguish further the revenue share accounted for by products that are (i) new to the firm, (ii) new to the firm and the market, and (iii) new to the firm without a predecessor product.[7] Related to process innovation, firms state whether they introduced new or significantly improved processes and by how much these process innovations reduced unit costs or raised revenues by improving product quality.

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

Multinational Activity For information on FDI activity in Germany, we access the Microdatabase Direct Investment (MiDi),[8] described in detail in Schild and Walter (2017),[9] which contains information on all inward and outward FDI stock relations

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

[7]Except for (iii), the data does not allow us to distinguish between product innovation through the introduction of new varieties (i.e., barcodes) and significant improvements on existing products.

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

[9]The data report can be found under https://www.bundesbank.de/resource/blob/604664/7007c46fa1bda49529bd5 01-midi-data.pdf.

that German companies are involved in and considered as economically relevant for aggregate FDI statistics. Access to the data is provided by the Research and Data Services Centre (RSDC) of the Deutsche Bundesbank.[10]

Merging The merging of the Mannheim Innovation Panel (MIP) with the Trade in Services Statistics (SITS) and the Microdatabase Direct Investment (MiDi) took place at the Research and Data Service Centre (RDSC) of the Deutsche Bundesbank and relied on the mapping tables described in Schild et al. (2017).[11]

3.3 New Facts on Innovative Activity and Trade in Innovation Services in Firms

In this section, we collect novel descriptive facts that motivate our theoretical and empirical analysis.

3.3.1 Facts on Firm-level innovation activities

Fact 3.1. *Not all active firms within the same sector of production are innovators, R&D only captures two-thirds of overall innovation activity, and innovation service imports account for a sizeable share of innovation expenditures.*

The fact motivates two modeling choices: First, in the model, firms select into being innovators based on underlying productivity differences. Second, we model innovation activity as a process where firms combine internal factors (for example,

[10] A common concern in the trade in services literature is the phenomenon of profit shifting where firms use non-tangible transactions between subsidiaries in different countries to shift taxable income. To tackle this concern, we use the information in the MiDi to control for a firm's multinational status and to test whether the presence of foreign subsidiaries predicts service trade flows.

[11] The technical report is available here: www.bundesbank.de/resource/blob/604828/f3227be248777d3f414b89b395e data-company-data-data.pdf.

R&D scientists) and external inputs (for example, imported innovation services) to produce an innovation outcome that increases profits in product markets.[12]

Specifically, Table 3.4 shows that sixty-four percent of firms in our sample are innovators, which we define as firms that have strictly positive innovation expenditures. Table 3.5 shows that R&D expenditures on average account for about two-thirds of total innovation expenditures. Further, only 82 percent of firms that innovate conduct continuous R&D. Average R&D imports of firms with positive innovation expenditures account for 5 percent of average total innovation expenditures.

Fact 3.2. *The majority of the variation in innovation expenditures across firms is within sectors.*

The above fact motivates us to focus on understanding how trade affects the relative innovation incentives of firms active within the same sector of production. To establish this fact, we provide a decomposition of the aggregate variation in innovation expenditures into a between-sector and a within-sector component. To do so, we regress innovation expenditures, IE, on a set of sector-year fixed effects $\alpha_{s,t}$:

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

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

$$\text{Var}\left(IE_{f,t}\right) = \underbrace{\text{Var}\left(\alpha_{s,t}\right)}_{\text{Between Sectors}} + \underbrace{\text{Var}\left(\varepsilon_{f,t}\right) + 2\text{CoVar}\left(\alpha_{s,t}, \varepsilon_{f,t}\right)}_{\text{Within Sectors}}. \tag{3.2}$$

We estimate the fixed effects in equation 3.1 and decompose the sample variance in innovation expenditures according to (3.2). Table 3.1 displays the results and

[12] In other words, we explicitly model the cost of producing innovation outcomes. A key contribution of this chapter is to show that international trade in services affects innovation incentives by altering the cost and the returns of innovative activities.

Table 3.1: Variance Decomposition of Sample Innovation Activity

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

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

shows that the lion share of the overall sample variation in innovation expenditures stems from within-industry rather than between-industry heterogeneity in innovation activities.

3.3.2 Facts on Trade in Innovation Services

Fact 3.3. *Few firms import foreign innovation services, and innovation service importers appear to be more productive.*

Consistent with this fact, firms in the model select into becoming an innovation service importer based on exogenous productivity differences. Selection is the central mechanism in much of the modern heterogeneous firm literature on international trade, and our model of R&D service imports inherits qualitatively similar features.[13]

To establish the first part, Table 3.4 displays the composition of firms in our sample. In total, 3 percent of manufacturing firms in our sample import foreign R&D. To establish the second part, we assess the conditional correlation between R&D service imports and a simple empirical measure of firm productivity. We regress firm $f's$ innovation service importer status in year t $\left(1_{f,t}^{\text{IMP}}\right)$ on its labor revenue productivity ($\text{LRP}_{f,t}$) - the ratio of revenues to employment. We control for the share

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

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

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

Table 3.6 displays the results and shows that importers of innovation services have higher measured labor revenue productivity and are more skill-intensive.[14]

Fact 3.4. *Foreign innovation services are a variable input into the generation of innovation.*

Consistent with this fact, we model foreign innovation services as a variable input in the production of innovation outcomes.[15] To establish this fact, we observe that an average of 69 percent of firms that import foreign R&D services in one year also import R&D services in the following year. For comparison, an average of 88 percent of firms that export in one year also export in the following year.

Fact 3.5. *Innovation service importers are more active and effective innovators.*

This fact motivates how we model firms' incentives to import foreign innovation service imports. In the model, firms import foreign innovation services to improve the efficiency at which they produce innovative outcomes.

To establish the above fact, we observe that importers of innovation services are significantly more active innovators than the average firm. As shown in Table 3.5, R&D service importers outspend the average innovating firm by a factor of five on both total innovation and R&D expenditure. Further, R&D service importers also outspend the average multinational firm by a factor of two on both margins.

These differences in expenditures translate into better innovation outcomes. Table 3.5 shows that revenues accounted for by new products equal 23 percent for importers

[14] For reference, the remaining columns of Table 3.6 display the results of estimating equation (3.3) with exporter and innovator status as dependent variable.

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

of R&D services, relative to 20 percent across the whole sample of innovators, while the revenue shares accounted for by new products accounts for 14 percent relative to 11 percent for the whole sample.

3.4 A Model of Foreign Knowledge Imports, Trade, and Innovation

We develop a new model of trade in goods, innovation services, and innovation featuring oligopolistic competition in product markets, heterogeneous firms, and selection into exporting, importing R&D, and innovation. The model captures the role of competition, market structure, and market size as central determinants of the returns of innovation while featuring innovation service imports as a determinant of the cost of innovating. It is specifically tailored to connect with what we can observe in the data, which allows to test its predictions directly and provides grounds for quantitative analyses.

3.4.1 Model Overview

Single-product firms[16] in a home market H - Germany in the application - are associated with an industry s and have the option to purchase innovation services as an input to their innovative activities. Firms can sell products on domestic and foreign markets, which we denote by m. Events take place across three stages.

In the first stage, firms randomly draw a (multi-dimensional) parameter $\Theta \in \mathbb{R}_+^n$ from a cumulative distribution function $G(\Theta)$. Θ might capture exogenous differences in total factor productivity, innovation efficiency, product appeal, and fixed cost. Throughout the chapter, it is easiest to think of Θ as a one-dimensional parameter.

[16] As we focus on single product firms, our model does not capture product innovation in the form of adding new product lines. However, the model readily extends to this case without changing the qualitative results.

Firms incur fixed costs to enter product markets, to set up the capacity to innovate, and to import foreign innovation services. Firms maximize expected profits anticipating outcomes of the upcoming two stages.

In the second stage, firms choose their innovation efforts and import foreign innovation services. Innovation efforts do not materialize until the final stage.

In the last stage, innovation efforts materialize, and firms compete in all product markets that they chose to enter during the first stage.

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

3.4.2 Demand and Competition in Goods Markets

To characterize the outcome of product market competition in the final stage, we drop subscripts for industries s and individual markets m. N is the number of active firms, and active firms are denoted by $f \in \{1, ..., N\}$.

Demand is given by an invertible, homothetic demand system that can be written as $q_f \equiv \log Q_i = q\left(\mathbf{p_f}, \boldsymbol{\xi}_f, \mathcal{A}\right)$, where $\mathbf{p}_f \equiv (p_f; \mathbf{p}_{-f})$ is the vector of prices of firm f and the other $N-1$ active firms, and $\boldsymbol{\xi}_f \equiv (\xi_f, \boldsymbol{\xi_{-f}})$ is a vector of non-price firm characteristics affecting demand.[17] $\mathcal{A}$ is a vector of aggregate demand shifters that is taken as given by all firms.

We characterize the equilibrium in product markets under full-information simultaneous price-setting without any restrictions on the nature of competition. Amiti et al. (2018) derived the key properties of the product market equilibrium in this set-up, which we restate in the following proposition.

Proposition 3.1. *Assume that sectoral log expenditures z are a sufficient statistic for firm's perceived demand elasticities, $\sigma_f \equiv \frac{dq_f}{dp_f} = \sigma\left(p_f - z, \boldsymbol{\xi}_f\right)$. Then under any*

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

competition structure, the equilibrium price of firm f is a mark-up over marginal cost MC_f and solves the following fixed point:

$$p_f = \log\left(\frac{\sigma_f}{\sigma_f - 1}\right) + \log MC_f. \tag{3.4}$$

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

$$d\log\left(\frac{\sigma_f}{\sigma_f - 1}\right) = \Omega\left(S_f\right) d\log S_f. \tag{3.5}$$

Proof. See Amiti et al. (2018). □

Propposition 3.1 implies that if the log expenditure function summarizes all necessary information about the pricing behavior of competitors, then market shares are a sufficient statistic for firms' mark-ups.

The characterization of the final goods market competition nests many existing frameworks. In particular, the assumption hothat log expenditures are a sufficient statistic for a firm's perceived demand elasticity is satisfied by the nested-CES demand structure used in Atkeson and Burstein (2008). To a first order, this assumption holds for Kimball demand Kimball (1995) or the broad homothetic family of demand functions considered in Matsuyama and Ushchev (2017). Hence, the results derived in the upcoming sections apply to a broad set of models that study the implications of market power and imperfect competition in product markets.

3.4.3 Innovation Decision and Import of Foreign Innovation Services

In the second stage, firms have incurred fixed costs to serve final goods markets, and to set up their capacity to innovate. Firms that did not choose to set up

innovative capacity move on to the next stage. Innovating firms simultaneously choose the optimal amount of innovation x_f *non-strategically and without spillovers.* That is, there is no external knowledge spillovers and no direct complementarities in innovation efforts. Firms simultaneously choose their intensive margin sourcing strategy for foreign innovation services, which directly affects the cost of innovative effort $\Gamma_f(x;\Theta_f)$.

A firm with access to a set of markets $\mathcal{M}_f$, and unit cost of serving market m given by $C_{m,f}$ chooses innovation intensity x to maximize profits Π:[18]

$$\Pi(x;\Theta_f) = \sum_{m\in\mathcal{M}_i} \{P_{m,f}Q_m(x,\Theta_f) - C_m(x;\theta_f)\,Q_m(x_f;\Theta_f)\} - \Gamma_f(x_f;\Theta_f), \quad (3.6)$$

subject to the outcome of the product market game summarized by the optimal pricing decision in (3.4). $C_m(x;\theta_f)$ denote the cost of selling a unit of output in market m. It is understood that $\Gamma_f(x;\Theta_f)$ is conditional on an importing strategy for innovation services.

Production functions are constant returns to scale for any given innovation effort x.

Assumption 3.1.

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

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

Shipping goods to market m is subject to iceberg trade cost, which are denoted by $\tau_m \geq 1$. By assumption 3.1 the marginal cost $MC_{m,f}$ of serving market m equal are equal to $MC_{m.f} = \tau_m C_f$.

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

By the envelope theorem, the optimal amount of innovation effort x_f solves the following first-order condition:

$$\sum_{m \in \mathcal{M}_f} \left(\frac{1}{\sigma_{m,f} - 1} \right) C_{m,f} \frac{\partial Q_{m,f}}{\partial x_f} - \frac{\partial C_f}{\partial x_f} Q_f = \frac{\partial \Gamma_f(x_f; \Theta_f)}{\partial x_f}, \tag{3.7}$$

where $Q_f \equiv \sum_{m \in M_f} \tau_m Q_{m,f}$ is total output of firm f.

It is worth pausing to discuss how this simple condition relates to the channels that affect firms' incentives to innovate. Focusing on the first term, we observe that higher unit costs C_f and profit margins $\frac{1}{\sigma_{mf}-1}$ increase the returns to innovative activity that operate through increasing the demand for a product.[19] The second term, on the other hand, summarizes the returns to process innovation - summarized in the reduction in unit cost $\frac{\partial C_{m,f}}{\partial x_f}$. These scale with a firms' total output Q_m. Lastly, the impact of foreign innovation services on innovation materializes through the marginal cost of innovation, which is firm-specific and depends on the sourcing strategy of foreign R&D. We now turn to describing the cost of producting innovative activity x.

Production of Innovative Activity and Intensive Margin Sourcing Choice Firms produce innovation x by combining factors F, and intermediate inputs M according to a Cobb-Douglas production function:

$$x_f = \chi(\Theta_f) M^{\phi} F^{m\,1-\phi}_{f}. \tag{3.8}$$

$\chi(\Theta_f)$ governs firm heterogeneity in innovation efficiency. The factor F can be purchased at a price W that is taken as given by firms.

[19] As discussed earlier, product innovation in our data captures both the introduction of new products, but also significant improvements with respect to a product's capabilities or user-friendliness. The latter effect is captured by our model as an innovation that directly raises the demand for a firm's product.

Intermediate inputs in innovation production consist of a bundle of innovation services indexed by $j \in [0,1]$- for example, basic research or product testing - which are aggregated according to Cobb-Douglas technology:

$$M_f = \exp\left\{\int_0^1 \alpha_j \log X_{f,j} dj\right\}, \tag{3.9}$$

where $\int_0^1 \alpha_j dj = 1$.

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

$$X_{f,j} = \left[Z_{f,j}^{\frac{\zeta}{1+\zeta}} + \sum_{m\in\mathcal{M}} a_{j,m}^{\frac{1}{1+\zeta}} M_{f,j,m}^{\frac{\zeta}{1+\zeta}}\right]^{\frac{1+\zeta}{\zeta}}, \tag{3.10}$$

where $Z_{f,j}$ and $M_{f,j,m}$ denote the quantities of domestic and imported varieties from source country m. $a_{j,m}$ is a measure of technological advantage that foreign services may have over domestic ones.

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

In stage 2 firms have chosen the set of varieties that they wish to import, $J_f = \{j \in [0,1], m \in \mathcal{M} : M_{f,j,m} > 0\}$, and are left with choosing the quantities $M^*_{f,j,m}$,$Z^*_{f,j}$ and F^*_f. The cost of innovation is given by:

$$\Gamma(x_f|J_f^*) = WF^* + \int_0^1 V_f Z_f^* dj + \sum_{m\in M}\int_{J_f^*} \left(\tau_m^{R\&D} U_{j,m} M^*_{f,j,m} + W f_m\right) dj. \tag{3.11}$$

In Appendix 3.B, we show that the variable part of total innovation cost, conditional on a set of imported varieties J_f^* is given by:

$$\Gamma(x_f|J_f^*) = \frac{C}{B_f^{\phi}\chi\left(\Theta_f\right)}x_f, \tag{3.12}$$

C is a cost-index for firms that do not import innovation services as part of their innovation activities.[20] B_f is a cost-reduction factor that summarizes how foreign innovation services improve the efficiency at which a firm produces innovation activities: $B_f = B\left(J_f\right) = \exp\left\{\int_{J_f}\alpha_j \log b_j\left(J_m\right)dj\right\}$ and b_j given by:

$$b_j\left(J_m\right) \equiv \left[1 + \sum_{\{j,m\}\in J_f} a_{j,m}\left(\tau_m^{R\&D}U_{j,m}/V_j\right)^{-\zeta}\right]^{1/\zeta}.$$

A contribution of the model is to characterize innovation responses to changes in trade costs $\tau^{R\&D}$ in terms of few easily computable sufficient statistics. The import intensity of foreign innovation services from country m is a key statistic for this purpose and defined as follows:

$$\varphi_{f,m} \equiv \frac{\int_J \tau_m U_{j,m}M_{f,j,m}^* dj}{\Gamma(x, J_f)} = \phi\int_0^{J_f}\alpha_j a_{j,m}\left(\tau_m^{R\&D}U_j/V_{j,m}\right)^{-\zeta}dj. \tag{3.13}$$

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

Proposition 3.2. *(i) Within sectors, firms with larger total innovation expenditures have a larger overall import intensity* $\varphi_f \equiv \sum_m \varphi_{f,m}$. *(ii) The partial elasticity of marginal innovation cost with respect changes in the variable trade cost of foreign innovation services* $\tau_m^{R\&D}$ *equals* $\frac{\partial \log \Gamma'(x_f|J_f^*)}{\partial \log \tau_m^{R\&D}} = \varphi_{f,m}$ *if the set of imported varieties is*

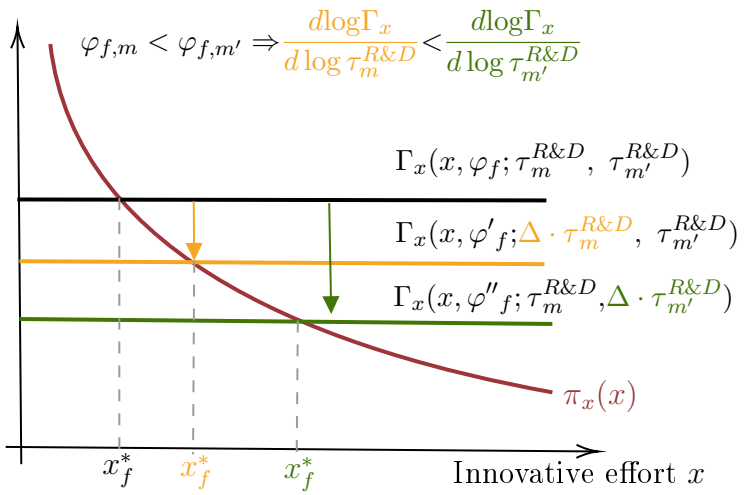
[20] This index is given by: $C = \left(\frac{U}{\phi}\right)^{\phi}\left(\frac{W}{1-\phi}\right)^{1-\phi}$ with $U \equiv \int_0^1 \alpha_j \log\left(\frac{U_j}{\alpha_j}\right)dj$.

fixed and $\frac{\partial \log \Gamma'(x_f)}{\partial \log \tau^{R\&D}} = \kappa \varphi_{f,m}$ *to a first order if the set of imported varieties adjusts as well.* κ *is a constant specified in the appendix.*

Proof. See Appendix 3.B. □

Figure 3.2 visualizes the key implication of Proposition 3.3. The effect of changes in service trade costs on the marginal cost of innovation depends on the initial import intensities of firms. So not only do firms with higher import intensity of innovation services have larger total innovation expenditure they will also respond more to changes in trade costs for these services.[21]

Figure 3.2: Import Intensity of Innovation Services and Innovation



Notes: This figure visualizes the key implication of Proposition 3.2. π_x denotes the marginal benefit of innovation, and is given by the LHS of equation (3.7). $\varphi_{f,m}$ denotes the import intensity of innovation services sourced from country m of firm f, and Γ_x denotes the marginal cost of innovation activity. The graph shows that firms with higher import intensity innovate more, and that the marginal cost of innovation activity respond more to changes in trade costs the more a firm sources innovation services.

3.4.4 Selection and Entry

In the first stage, an exogenous number of firms M each choose which subset $\mathcal{M}_f$ of the markets $\{H, \mathcal{M}\}$ to enter and whether or not to build the capacity to innovate,

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

1_I. The associated fixed costs, F_H^E, F_m^E and F^I, respectively, are produced by an aggregate factor with price normalized to 1. Firms also choose the set of innovation services J_f that they would like to import by anticipating the outcomes of the second and third stages of the game.

The problem of each firm in the first stage reads:

$$\max_{\mathcal{M}_f, J_f, 1_f} \Pi\left(\mathcal{M}_f, J_f, 1_f; \Theta_f\right) - \sum_{m \in \mathcal{M}_f} 1\left\{m \in \mathcal{M}_f\right\} F_f^E - 1_{I,f} F^I, \tag{3.14}$$

where Π denotes profits in the final stage.

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

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

In the appendix, we show that this choice can be uniquely characterized. and that firms with higher innovation effort x_f a larger set of innovation services.

3.4.5 Key Predictions

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

Proposition 3.3. *The model implies the following relationships:*

1. Imports of innovation-related services: Firms with higher levels of foreign innovation imports have larger overall innovation expenditures and innovate more.

2. Exports: Firms with higher levels of exports (both on the extensive and intensive margin) innovate more.

3. Competition: Firms with higher profit margins innovate more.

Proof. Please see Appendix 3.B. □

Proposition 3.3 provides testable implications for the relationship between firms' innovation activity, foreign innovation service imports, exports, and competition. The first prediction is borne out of the relationship between foreign innovation imports and the cost of innovation. The second prediction stems from a standard market size effect. The last prediction implies that increased levels of competition reduce innovation activity if profit margins respond negatively to competition.[22]

3.5 Empirical Evidence

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

3.5.1 Specification

The model predicts that firms with higher imports of foreign innovation services, larger market size, and higher profit margins undertake greater innovation efforts. The following empirical model directly tests these predictions. Letting f index firms, s index 2 digit NACE Rev. 1 manufacturing industries and t index years. We consider regressions of the following form:

$$y_{f,t} = \alpha \cdot \log\left(1 + \text{InnovImp}\right)_{f,t} + \beta \cdot \log\left(1 + \text{Exp}_{f,t}\right) + \gamma \cdot \text{Comp}_{f,t} + \boldsymbol{\delta} \cdot \boldsymbol{X}_{f,t} + \omega_{s,t} + \epsilon_{f,t}, \quad (3.15)$$

[22] However, mark-ups and in particular, their elasticitiy with respect to more innovation activity may be non-monotone in sales market shares. As a consequence, the model predicts no linear relationship between changes in competition and changes in innovation activity. Fieler and Harrison (2018) stress that increases in competition may cause more innovation through an import-competition escape effect. While we don't model this excplicitly, our model does not rule such mechanisms out.

where $y_{f,t}$ denotes innovation-related outcomes of interest: innovation expenditures, R&D expenditures, and measures related to innovation outcomes. $\text{InnovImp}_{f,t}$ and $\text{Exp}_{f,t}$ are the values of firm-level innovation service imports and exports. In the model, profit margins depend on a firm's market share in product markets (though the nature of this dependence is theoretically ambiguous). $Comp_{f,t}$ is a measure for a firm's competitive environment that we describe shortly and captures this relationship.

Industry-year fixed effects are denoted by $\omega_{s,t}$. $\boldsymbol{X}_{f,t}$ is a vector of time-varying firm characteristics. It contains three binary variables: one indicating if a firm is part of an FDI relation, one indicating if a firm is located in a state formerly belonging to East Germany, and one indicating if a firm performs internal R&D at least occasionally. Moreover, it includes a firm's number of employees as a proxy for size as well as the average wage of a firm's industry within East- or West Germany as a proxy for cost shocks.

The coefficients of interest are α, β, and γ which measure the impact of trade in innovation services, exports and profit margins on firm-level innovation activity. The identification of these parameters is threatened by reverse causality: For example, large volumes of exports might be driven by succesfull innovation efforts. To identify causal effects, we construct firm-level instrumental variables for goods exports and service imports.

3.5.2 Instrumental Variables

Imports of Foreign Innovation Services

Firms might be more innovative because they import more innovation services. However, firms might also import more innovation services because they innovate more. To address this reverse causality, we construct a firm-level supply shock.

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

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

$$\text{Z}_{f,t}^{\text{InnovImp}} = \sum_{n} \omega_{f,n,t_o}^{\text{InnovImp}} \text{IMP}_{n,f,t}^{Innovation}. \tag{3.16}$$

Aggregate innovation service imports serve as a measure of aggregate supply shocks. The initial shares provide variation in firms' exposure to these supply shocks. The exclusion restriction requires that the instrument is not systematically correlated with unobserved heterogeneity in firms' innovation import capacities. The model, in turn, implies that initial import intensities are sufficient statistics for the relevant dimensions of heterogeneity among firms, and, to the degree that aggregate supply shocks are exogenous to an individual firm's behavior, motivates the construction of the instrument.

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

Exports

Firms might export more because they are more successful innovators relative to firms with less exporting activity. Therefore, we construct firm-level demand shocks that are exogenous to firms' innovation efforts. The logic of the instrument is symmetric to the supply shocks constructed in the previous section.

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

$$\text{bartik}_{f,t}^{\text{EXP}} = \omega_{f,t_0}^{\text{EXP}} \cdot \text{IMP}_{s(f),t}^{\text{World}}. \tag{3.17}$$

The exclusion restriction requires that the instrument is neither systematically correlated with firm's innovation efforts in year t, nor with unobserved changes to firms' capacities to innovate. To this end, the changes in the aggregate import demand of a given industry intend to proxy for export demand shocks. Borusyak et al. (2018) show that the exclusion restriction requires that aggregate shocks are exogenous to changes in the innovation activity of individual German firms. Weighting the industry-level shocks with a firm's initial export shares generates variation in exposure to the export demand shock across firms.[23] Goldsmith-Pinkham et al. (2018) show that the exclusion restriction is satisfied if initial export shares are a sufficient statistic for unobserved dimensions of heterogeneity that drive differences in a firm's exporting behavior and not correlated with future changes in these variables.

Competition Measure

Following Lim et al. (2018), we measure competition in an industry by the number of active domestic firms in a given two-digit NACE Rev. 1 industry. To generate

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

variation in competition exposure across firms within a given industry, we interact with this measure a firm's position in its industry's domestic sales distribution in the year t_0 where we first observe it in our data. Firms located in higher deciles of their industry's sales distribution have higher market shares, which, according to our framework, directly affects their exposure to competition.

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

$$\text{comp}_{f,t} = \tilde{d}_{f,s,t_0} \times \log\left(n_{s,t}\right). \tag{3.18}$$

Our empirical competition measure of competition takes higher values for smaller firms that are active in industries with more competitors. If firms take the total number of firms in any given year as given, and past sales shares are not correlated with unobserved future shocks to productivity, then this measure is exogenous. As we observe industries at the two-digit level, we think that the former requirement is likely to be satisfied. Further, to ensure that a firm's position in its industry's sales distribution is not correlated with unobserved factors affecting innovation, we hold this variable's value fixed at the value that it attained in the first year t_0 in which f is observed and exclude the firm-year observation in t_0 from the sample.

3.5.3 Results

OLS

Table 3.2 presents the results of estimating the full specification in (3.15) via OLS across all innovation outcomes of interest.

Innovation Inputs Our theoretical framework predicts that firms with higher levels of innovation service imports and exports are more active and successful innovators. The first two columns of Table 3.2 show that this prediction is borne out of the conditional correlations in the data. Firms with higher levels of innovation imports and exports spend larger overall amounts on both innovation activities as a whole and R&D in particular.

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

Table 3.2: OLS Results

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

Notes: This table presents the OLS results of estimating equation (3.15) on the baseline sample of German manufacturing firms. t-statistics are in parentheses and clustered at the firm level. *** indicates significance at the 1%, ** at the 5% and * at the 10% level. Source: Reasearch Data and Service Centre (RDSC) of the Deutsche Bundesbank, Trade in Service Statistics (SITS), Microdatabase Directinvestment (MiDi); Leibniz Centre for European Economic Research Mannheim Innovation Panel (MIP), 2002-2011, own calculations.

Innovation Outcomes Higher levels of innovation service imports are positively related to all measures of innovation success. Exports correlate positively with revenues generated by new products. However, we cannot detect a statistically

significant relationship between higher levels of exports and better process innovation outcomes.

Exposure to competition correlates with better product innovation outcomes, but is negatively correlated with process innovation outcomes. As such, these results may shed light on the ambiguous effects that the literature assigns to competition as a determinant of firm-level innovation activity. As argued in Fieler and Harrison (2018), competitive pressure might induce firms to innovate on products in order to escape competition. Interpreted through the lens of our model, higher levels of competition may reduce the incentives for firms to invest in cost-saving technologies in order to gain market shares and increase profit margins.

Second Stage

Table 3.8 displays the first-stage regressions of the full set of instruments on innovation service import intensities and exports. We find a strong first stage for both, as evident by the F-statistics.[24]

Table 3.3 presents the estimates of the second stage. We find support for the hypothesis that access to foreign innovation services leads to higher innovation activity, as well as overall better innovation outcomes. We find statistically significant effects on near all innovation outcomes. This finding also lends support to our modeling assumption that foreign innovation services provide firms with greater overall innovation efficiency, independently of whether innovative efforts target product or process innovation.

[24]The correlation structure between the instrumented variables is displayed in Table 3.9. Evidently, the fitted values entering the second stage regression are far from collinear.

Table 3.3: Second Stage Results

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

Notes: Second stage IV results of estimating equation (3.15) on our baseline sample of German manufacturing firms. t-statistics are displayed in paentheses. Standard errors are clustered at the firm level. *** indicates significance at the 1%, ** at the 5% and * at the 10% level. Source: Reasearch Data and Service Centre (RDSC) of the Deutsche Bundesbank, Trade in Service Statistics (SITS), Microdatabase Directinvestment (MiDi); Leibniz Centre for European Economic Research Mannheim Innovation Panel (MIP), 2002-2011, own calculations.

In line with previous findings in the literature, we find that firm-level export demand shocks lead larger innovation efforts. We find that higher exposure to demand shocks incentivizes firms to adopt or develop new products, as indicated by increased revenues from these product categories. Conversely, we do not find that market size has a statistically significant effect on process innovation.

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

therefore disincentivize firms to undertake innovations that allow them to undertake competitor's prices.

3.5.4 Robustness

We check the robustness of our baseline results across multiple dimensions. First, we augment the construction of our instruments. Second, we show that our empirical results are robust to variations in the baseline sample, and remain effectively unaltered when only years before the financial crisis are considered.

Alternative Instruments

A recent literature investigates the sources of exogeneity in shift-share instruments. First, Goldsmith-Pinkham et al. (2018) show that if the shift-shares are exogenous to current unobserved factors affecting the outcome of interest, then the instrument will indeed be valid. Second, Borusyak et al. (2018) and Adao et al. (2018) show that the necessary exclusion restriction can be satisfied even if shift shares are correlated with unobserved factors affecting the outcome of interest. Applied to our setting, the arguments in these papers imply that so long the aggregate shocks are exogenous to the individual firm, sufficient variation over destination and origin countries provides valid exogenous variation.

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

Consistent with the evidence that firms select into exporting based productivity, we include a firm's past position in the distribution of labor revenue productivities,

as a predictor for a firm's propensity to export/import. Further, consistent with the existence of initial fixed cost to participating in international trade, this probability also depends on a firm's history of exporting. Further, we consider sectors and regions as potential determinants of trade participation. Using these predictors, we run a Probit model to estimate a firm-specific predicted probability of exporting, denoted $p^x_{f,t}$:

$$1\left\{\text{Exports}_{f,t}>0\right\}=\Phi\left(\alpha_{East}+\beta\text{Pos}_f\left(\frac{\text{Sales}_{f,t_0}}{L_{f,t_0}}\right)+\gamma 1\left\{\text{Exports}_{f,t-1}>0\right\}+\epsilon_{f,t}\right). \tag{3.19}$$

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

$$1\left\{\text{Imports}^{Innov}_{f,t}>0\right\}=\Phi\left(\alpha_{East}+\beta\text{Pos}_f\left(\frac{\text{Sales}_{f,t_0}}{L_{f,t_0}}\right)+\gamma 1\left\{\text{Imports}^{Innov}_{f,t-1}>0\right\}+\epsilon_{f,t}\right). \tag{3.20}$$

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

$$\widetilde{Z}^{\text{EXP},a}_{f,t}=p^x_{f,t}\log\left(1+\text{bartik}^{\text{EXP}}_{f,t}\right). \tag{3.21}$$

$$\widetilde{Z}^{\text{InnovImo}}_{f,t}=p^I_{f,t}\log\left(1+\text{bartik}^{\text{InnovImp}}_{f,t}\right). \tag{3.22}$$

We re-estimate our empirical model using this new set of instruments. The results are displayed in Table 3.10. We again find a strong first stage and second stage estimates that are qualitatively and quantitatively similar to our baseline estimates.

Financial Crisis

The financial crisis in 2008 was followed by a global decrease in international trade volumes (Kortum et al. (2016)). However, trade volumes in services trade have seen a

significantly lower decrease during the financial crisis, as documented in Ariu (2016). We investigate whether our results are driven by the impact of the great recession by re-estimating our baseline specification on a restricted sample that only includes years before the financial crisis. Table 3.11 displays the results and confirms that our baseline results are robust to this sample restriction.

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

In section 3.5 we have shown that a significant share of the variation in innovation expenditures occurs within sectors. In the previous section, we have confirmed the key prediction of our theoretical model. Here, we show how firm heterogeneity might shape the aggregate relationship between international trade and a country's innovation activity.

We compare changes in firms' innovation activities in response to trade shocks predicted by the model. Changes of equilibrium outcomes that are beyond the control of the firm in the model - such as aggregate income levels, factor prices, demand shifters, and prices of innovation services - are treated as realizations of random variables. We take expectations over the joint realizations of these random variables and characterize the expected pass-through of changes in trade costs into firms' innovation efforts, $\mathbb{E}\left[\frac{d\log x_f}{d\log \tau}\right]$.[25]

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

[25] As we condition on firms that do not change decisions on the extensive margin - whether or not to export, innovate or import innovation services at all - we do not characterize the entry margin effect of falling trade cost. Naturally, the extensive margin of firm entry may be important for quantitative magnitudes.

Assumption 3.2. *Changes in trade cost are uncorrelated with changes in relative firm characteristics Θ_f and import prices for foreign innovation services of any two firms within the same industry.*

This assumption allows arbitrary correlation structures between changes in trade costs and changes in aggregate general equilibrium objects. Note that relative import prices for foreign innovation services between any two firms might differ because firms import decisions differ on the extensive margin.[26]

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

Proposition 3.4. *In addition to assumption 3.2, assume that the elasticity of demand and unit cost with respect to innovation effort x is constant. Then market shares, import intensities and output size in each market $\left\{\{S_{m,f}, Q_{m,f}\}_{m\in\mathcal{M}_f}, \varphi_f\right\}$ are first-order sufficient statistics for the firm-level elasticity of innovation activity with respect to trade cost $\mathbb{E}\left\{\frac{d\log x_i}{d\log\tau}\right\}$.*

In particular, for $\tau \in \{\tau_m, \tau_H\}$ we have that, omitting sector subscripts:

$$\mathbb{E}\left(\frac{d\log x_f}{d\log\tau}\right) = \alpha^\tau + \sum_{m\in\mathcal{M}_f}\beta_m^\tau S_{f,m} + \sum_{m\in\mathcal{M}_f}\gamma_m^\tau Q_{f,m}, \tag{3.23}$$

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

$$\mathbb{E}\left(\frac{d\log x_m}{d\log\tau}\right) = \alpha_m^\tau + \varphi_f\left\{\alpha_m^{\tau,\varphi} + \sum_{m\in\mathcal{M}_f}\beta_m^\tau S_{f,m} + \sum_{m\in\mathcal{M}_f}\gamma_m^\tau Q_{f,m}\right\}. \tag{3.24}$$

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

[26] As shown in the appendix, formaly we require that the following firm-specific term is uncorrelated with trade costs:

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

where $\bar{U}$ and $\bar{V}$ denote some weighted average of foreign and domestic prices for innovation services.

Proof. See Appendix 3.B. □

Equation (3.24) shows that the effect of a change in trade costs of innovation services on a firm's innovation effort depends on its previous import intensity of innovation services. Importantly, the effects of a reduction in innovation services import cost on firm-level innovation activity also depend on a firm's exposure to market size and competition in final goods markets. Firms with large sales volumes in many markets are bound to react differently from firms with only a few destination markets.

Similar considerations hold for shocks to final goods trade costs. Equation (3.23) shows that market shares are a primary driver of heterogeneity in firms' innovation responses to import competition shocks. This is intuitive: An import-competition induced reduction in the profit margins in the home market is less consequential for a firm that has access to other markets, potentially less competitive markets.

These results suggest that the aggregate effects of trade integration on innovation efforts may depend on the microstructure of the economy. Further, it suggests that understanding the effects of trade integration as a whole may require a joint assessment of how the innovation incentives generated by trade in innovation services interact with the innovation incentives arising from trade in goods. We leave a quantification of this mechanism to future research.

3.7 Conclusion

This chapter has investigated the connection between trade integration and innovation. We use an unusually detailed dataset that allows us to study the relationship between trade in services, trade in goods, and firm-level innovation activity.

We provided novel descriptive statistics that suggest that firm-level differences in innovation activity are essential for shaping aggregate trends in innovation, that

document that trade in foreign knowledge exhibits similar properties to trade in goods and, lastly, that suggest the existence of complementarities in the selection of firms into innovating, exporting goods and importing foreign knowledge.

We then developed a new theoretical model of trade in services and innovation that is consistent with these facts, and that combines the well-known competition and market size effects of trade with a model of innovation service imports to make testable predictions that map into quantities that are readily observable in the data. While we have not leveraged the quantitative aspects of the model, it is well-suited for structural estimation and quantification of the various channels.

The model predicts that firms with access to larger markets via exports, with higher profits margins, and with higher import intensities of foreign innovation services undertake greater innovation efforts. Further, the model predicts that the responsiveness in innovation efforts to foreign demand and supply shocks differs across firms according to easily computable sufficient statistics. In the empirical part of the chapter, we took those predictions to the test and constructed model-motivated instruments to overcome identification challenges.

Our results imply that greater access to foreign innovation services raises the innovation efforts of firms. Similarly, greater access to larger export markets raises innovation efforts, while our results indicate that competition decreases innovative activity. We find that the estimated reduced-form coefficients capturing the effect of imported innovation services on innovation efforts are of similar magnitudes to the effects that operate through export opportunities and competition.

Further, we have highlighted that complementarities in selection at the firm-level may amplify the aggregate effects of trade integration on innovation through disproportionally incentivizing the largest and most productive firms to innovate more. We have formalized this intuition using our structural model to illustrate its potential

usefulness for quantifying the aggregate effects of trade on a country's innovation activity.

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Appendix

3.A Tables

Table 3.4: Sample Descritptive Statistics (unweighted)

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

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

Table 3.5: Innovation Activity in German Manufacturing Firms

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

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

Table 3.6: Firm Status and Productivity Measures

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

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

Table 3.7: Conditional Sample Composition

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

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

Table 3.8: Baseline First-Stage Results

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

Notes: First Stage results of projecting endogenous outcomes on the instruments constructed in Section 3.5.2. Standard errors are in parentheses and clustered at the firm level. *** indicates significance at the 1%, ** at the 5% and * at the 10% level. Source: Reasearch Data and Service Centre (RDSC) of the Deutsche Bundesbank, Trade in Service Statistics (SITS), Microdatabase Directinvestment (MiDi); Leibniz Centre for European Economic Research Mannheim Innovation Panel (MIP), 2002-2011, own calculations.

Table 3.9: Baseline: Correlations between instrumented independent variables

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

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

Table 3.10: Second-Stage IV Results for Alternative Instruments for Exports and Innovation Imports

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

Notes: Second stage results of estimating equation (3.15) on our baseline sample of German manufacturing firms. Standard errors are in parentheses and clustered at the firm level. *** indicates significance at the 1%, ** at the 5% and * at the 10% level. Firm controls include local labor cost, total employment, and indicator variables for whether a firm conducts R&D continuously, is located in former Eastern German States and is a multinational. Source: Reasearch Data and Service Centre (RDSC) of the Deutsche Bundesbank, Trade in Service Statistics (SITS), Microdatabase Directinvestment (MiDi); Leibniz Centre for European Economic Research Mannheim Innovation Panel (MIP), 2002-2011, own calculations.

Table 3.11: Second Stage IV Results for pre-2008 sample

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

Notes: Second stage results of estimating equation (3.15) on our baseline sample of German manufacturing firms. Standard errors are in parentheses and clustered at the firm level. *** indicates significance at the 1%, ** at the 5% and * at the 10% level. Firm controls include local labor cost, total employment, and indicator variables for whether a firm conducts R&D continuously, is located in former Eastern German States and is a multinational. Source: Reasearch Data and Service Centre (RDSC) of the Deutsche Bundesbank, Trade in Service Statistics (SITS), Microdatabase Directinvestment (MiDi); Leibniz Centre for European Economic Research Mannheim Innovation Panel (MIP), 2002-2011, own calculations.

3.B Derivations

Proposition 3.2

We first prove the following lemma:

Lemma 3.1. *The cost minimization problem for a given target level of innovation has a unique solution.*

Proof. We need to derive the entire cost function. These derivations follow closely some of the arguments in Amiti et al. (2018), adjusted for multiple input origins. First,

drop firm identifier i for simplicity. Conditional on a set of imported intermediaries J, the problem reads:

$$TC\left(x|J\right)=\min_{F,M,\left\{Z_{j,k},M_{j,k}\right\},X_j}\left\{WF+\int_0^1 V_jZ_jdj+\sum_k\int_J\left(\tau_kU_{j,k}M_{j,k}+Wf_k\right)dj\right\}.$$

Denoting by λ, ψ and ω the Lagrange multiplier on the constraints given by equation (3.8), (3.9) and (3.10) respectively, this yields the following first order conditions:

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

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

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

$$\begin{aligned}
V_jX_j&=\lambda\phi\alpha_jx\left(X_j/Z_j\right)^{\frac{1}{1+\zeta}}\\
\frac{\tau_kU_{j,k}M_{j,k}}{V_jZ_j}&=\alpha_j\left(\frac{\tau_kU_{j,k}}{V_j}\right)^{-\zeta}.
\end{aligned}$$

The last expression can be substituted into equation (3.10), which yields

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

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

$$V_jX_j=\lambda\phi\alpha_jxb_j,$$

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

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

where

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

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

The total cost function is then given by:

$$TC\left(x; J\right) = \lambda Y + \sum_k \int_j W f_k dj. \tag{3.25}$$

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

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

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

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

The optimal set J therefore must satisfy:

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

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

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

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

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

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

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

We also have that

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

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

Thus:

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

Proposition 3.3

Proof. The first assertion follows directly from Proposition 3.2 and inspecting the first order condition in equation (3.7). Firms with higher levels of imports of foreign innovation services have lower marginal cost of innovating. The left-hand side of equation (3.7) is concave in innovation effort x_f, which directly implies the statement.

The second part follows from a symmetric argument. Higher levels of exports raise the value of the left-hand-side of equation (3.7), implying that x_f has to increase to satisfy the first-order condition.

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

□

Proposition 3.4

First, we differentiate optimality condition (3.7). We thereby denote all aggregate variables, such as demand shifters and factor prices by aggregate vectors A, B and C. In the below, let $\Delta y_{i,t} = \frac{y_{i,t+1} - y_{i,t}}{y_{i,t}}$ for any variable y. This yields the folllowing expression:

$$\begin{aligned}
&\sum_k \left(\tfrac{1}{\sigma_{i,k,t}-1}\right)\tau_{k,t}C_{i,k,t}\tfrac{\partial Q_{i,k,t}}{\partial x_{i,t}}\left\{\frac{\partial \log\left\{\left(\frac{1}{\sigma_{i,k,t}-1}\right)\tau_{k,t}C_{i,k,t}\frac{\partial Q_{i,k,t}}{\partial x_{i,t}}\right\}}{\partial \log \tau_{k,t}}\Delta\tau_{k,t}^{EXP}+\frac{\partial \log\left\{\left(\frac{1}{\sigma_{i,k,t}-1}\right)\tau_{k,t}C_{i,k,t}\frac{\partial Q_{i,k,t}}{\partial x_{i,t}}\right\}}{\partial \log x_{i,t}}\Delta x_{it}+\right\}\\
&\sum_k \left(\tfrac{1}{\sigma_{i,k,t}-1}\right)\tau_{k,t}C_{i,k,t}\tfrac{\partial Q_{i,k,t}}{\partial x_{i,t}}\left\{\frac{\partial \log\left\{\left(\frac{1}{\sigma_{i,k,t}-1}\right)\tau_{k,t}C_{i,k,t}\frac{\partial Q_{i,k,t}}{\partial x_{i,t}}\right\}}{\partial \log \tau_{k,t}^{IMP}}\Delta\tau_{k,t}^{IMP}1_{k=home}+A_{k,s}\Delta A_{k,s}\right\}\\
&-\left(\tfrac{\partial C_{i,k,t}}{\partial x_{i,t}}\sum_k \tau_{k,t}Q_{i,k,t}\right)\left(\frac{\partial \log\left(\frac{\partial C_{i,k,t}}{\partial x_{i,t}}\sum_k \tau_{k,t}Q_{i,k,t}\right)}{\partial \log x_{i,t}}\Delta x_{it}+\frac{\partial \log\left(\frac{\partial C_{i,k,t}}{\partial x_{i,t}}\sum_k \tau_{k,t}Q_{i,k,t}\right)}{\partial \log \tau_{k,t}}\Delta\tau_{k,t}^{exp}\right)\\
&-\left(\tfrac{\partial C_{i,k,t}}{\partial x_{i,t}}\sum_k \tau_{k,t}Q_{i,k,t}\right)\left\{\frac{\partial \log\left(\frac{\partial C_{i,k,t}}{\partial x_{i,t}}\sum_k \tau_{k,t}Q_{i,k,t}\right)}{\partial \log \tau_{k,t}^{imp}}\Delta\tau_{k,t}^{IMP}1_{k=home}+B_{k,s}\Delta B_{k,s}\right\}\\
&=\varphi_i\Delta\tau_{IMP}^{R\&D}+C_{k,s}\Delta C_{k,s}+\epsilon_{i,t}^{\Gamma},
\end{aligned}\tag{3.26}$$

The last line uses the result in Proposition 3.2 and $\epsilon_{i,t}^{\Gamma}$ is an error term given by:

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

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

We can thus first order approximate all terms relating to these derivatives in each of the variables $\{S_{i,t},Q_{i,k,t},\theta_i,\omega_i,\chi_i\}_i$. Collecting the relevant terms and solving the resulting equation for $\Delta x_{i,t}$ then recovers equation (3.15) in the main text with the firm-specific error term:

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

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

We are left to show that this error term is uncorrelated with changes in trade cost, which will prove the stated result. Under assumption 3.2, we have that $\mathbb{E}\left(\epsilon_{i,t}\Delta\tau\right) = 0$ for all changes in trade cost, evaluating $\mathbb{E}\left(\frac{d\log x_{i,t}}{d\log\tau}\right)$ then implies that $\mathbb{E}\left(\frac{\epsilon_{i,t}}{d\log\tau}\right) = 0$ and thus that $\{S_{i,t}, Q_{i,k,t}, \varphi_{i,t}\}$ denotes a set of sufficient statistics that characterizes within sector heterogeneity in the elasticity of innovation expenditures with respect to changes in any trade costs.