Three Essays in International Economics

by

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DEDICATION

This dissertation is dedicated to my family, those by blood and those by choice.

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PREFACE

This dissertation uses the weakly anonymous Establishment History Panel (Years 1992 - 2014). 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/or remote data access. Data documentation by Alexandra Schmucker, Johanna Eberle, Andreas Ganzer, Jens Stegmaier, Matthias Umkehrer (2018): Establishment History Panel 1975-2016. FDZ-Datenreport, 01/2018 (en), Nuremberg. DOI: 10.5164/IAB.FDZD.1801.en.v1. The conclusions drawn from these data are mine and do not reflect the views of the German Federal Employment Agency.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABSTRACT

The dissertation consists of three essays. The first essay presents a model where policies that reduce frictions in the labor market affect the distribution of welfare changes stemming from trade. I evaluate this mechanism in the context of a set of labor market policies between 2003-2005 in Germany known as the Hartz Reforms. Using establishment-level data from the German Federal Employment Agency, I show how the intersectoral mobility of workers rose in the period following these reforms. I use a multi-sector trade model with heterogeneous workers and intersectoral mobility to quantify the welfare changes from increased Chinese import pressure between 2005-2012. I find that, in the absence of the reforms, the gap in welfare gains between the worst-off and best-off labor markets would have more than doubled.

The second essay is co-written with my adviser, Javier Cravino, and focuses on the empirical fact that aggregate price levels are positively related to GDP per capita across countries. We propose a mechanism that rationalizes this observation through sectoral differences in intermediate input shares. As productivity and income grow, so do wages relative to intermediate input prices, which increases the relative price of non-tradables if tradable sectors use intermediate inputs more intensively. We show that sectoral differences in input intensities can account for about half of the observed elasticity of the aggregate price level with respect to GDP per capita. The mechanism has stark implications for industry-level real exchange rates that are strongly supported by the data.

The final essay concerns the correlation between the advent of the Internet and the global growth in services exports over the last three decades. I present a gravity model with bilateral measures of Internet connectivity to formalize this correlation. To establish bilateral connectivity, I construct a novel dataset based on the undersea fiber-optic cable network responsible for 99% of international data traffic. I measure the degree of bilateral connectivity using information on the capacities of these cables in order to estimate the effect of that connection on export growth between pairs of digitally connected countries. I estimate a positive relationship between Internet connectivity and bilateral exports in data-intensive industries with an elasticity of 0.25 to 2.25 over a variety of possible settings.

Chapter I: Trade Shocks and Labor Mobility in Germany

1 Introduction

Policymakers often want to know how trade will affect various workers in different ways. A growing literature started by Autor, Dorn, & Hanson (2013, henceforth ADH) has shown that the rise in Chinese import penetration has had an adverse effect on local labor markets with high manufacturing employment. Dauth, Findeisen, & Suedekum (2016, henceforth DFS) have corraborated this finding in Germany, concluding that rising imports from China have pushed workers out of manufacturing. The fall in manufacturing employment in the West has led politicians to seek policies that can alleviate the losses of workers forced to change their sector of employment due to rising trade penetration. But frictions in the labor market make it difficult for many of these workers to find jobs in other sectors.

This paper presents a structural model with a simple mechanism through which labor market liberalization policies can affect the distribution of welfare changes stemming from trade by reducing frictions in the labor market. I use the model to evaluate how a set of labor market policies between 2003-2005 in Germany known as the Hartz Reforms affected the response of the German economy to rising manufacturing import pressure from China. Specifically, I study the question, "How would the gains from trade with China between 2005-2012 have been distributed in the absence of the Hartz Reforms?" Using establishment-level data from the German Federal Employment Agency, I show how the intersectoral mobility of workers rose in the period following these reforms. I use this result to motivate a counterfactual exercise where, in absence of the Hartz Reforms, labor supply curves are steeper and hinder the degree to which workers can reallocate away from falling wages in import-competing sectors. By complementing my data with trade flows from the World Input-Output Database (WIOD)[1] and simulating the counterfactual world using the structural model, I find that the reforms shrank the counterfactual gap in welfare gains between the worst-off and best-off labor markets by more than 50%.

In the model, countries differ in their production technologies as in Eaton & Kortum (2012, hereafter EK), and heterogeneous workers select into different sectors in accordance with prevailing wages and their productivities draws as in Roy (1951). Due to the dispersion in productivity draws, local labor markets differ (potentially) in their labor allocation to each sector. In particular, this dispersion determines the slope of the labor supply curve in each market: low (high) levels of dispersion imply workers are (not) very substitutable and will (not) switch sectors from small movements in wages. The labor supply curve will also be shaped by the prevalence of frictions that inhibit worker responses to changes in wages, with lower (higher) levels of frictions flattening (steepening) the slope. Between two equilibria, shocks to trade costs or technologies can change country-sector-specific wages and induce worker reallocation. Since average worker income is equalized across sectors (but not across markets) in the model, I can characterize the change in welfare across different markets in Germany.[2]

By mandating improvements to employer/employee matching technology, reducing firm hiring and firing costs, and subsidizing firms to employ hard-to-place workers, I interpret the Hartz Reforms in the model as a reduction in frictions and a flattening of the labor supply curve. Using the structure of the model, I quantify the changes in worker income

[1]See Timmer et al. (2015) for details.

[2]In the quantitative exercise of this paper, welfare will be defined by average real income in order to capture effects on the overall price level of the market.

stemming from increased import pressure from China between 2005-2012 under different levels of frictions. In a world where frictions make workers completely immobile, and the model predicts welfare changes consistent with one where labor in each sector is a specific factor. In order to evaluate how the Hartz Reforms impacted local German labor markets' response to trade, I need a model-consistent trade shock and estimates for the slope of the labor supply curve in each market before and after the reforms.

I take the model to the data under the assumption that each labor market in Germany shares the same labor supply elasticity. The structure of the model delivers an equation for the change in a market's average level of real income that depends on the changes in its labor productivities, its labor allocations to each sector, and the country-sector-specific wages between two equilibria. Heterogeneity in the initial levels of worker productivities across markets – and thus labor allocations to each sector across markets – exposes each market to a different demand shock for the same change in wages stemming from increased trade pressure.[3] I instrument for the endogenous relationship between changes in income and changes in labor allocations with the rise in Chinese import pressure in countries similar to Germany in terms of size and openness. In particular, suppose that rising Chinese manufacturing imports in (e.g.) the UK are correlated with rising imports in Germany, and rising manufacturing imports in Germany incentivize worker outflow from manufacturing. Then observed changes in UK imports from China will provide exogenous variation in the changes in German market-level income through the worker reallocation channel. By measuring the strength of this channel, I can estimate the value of the labor supply elasticity. Intuitively, in a market with lower frictions, one would expect the same negative shock to manufacturing wages to induce greater flows out of the manufacturing sector. I estimate this elasticity between 1992-2002 and 2005-2012 using the German data and my instrument constructed from separate trade flow data. I find that labor supply became roughly twice as elastic after the reforms compared to the pre-period.

[3] Rising Chinese imports in the textile sector, for example, will put more pressure on markets specialized in textiles.

To quantify how the Hartz Reforms impacted the distribution of welfare changes stemming from trade, I need to simulate the model's response to rising Chinese import pressure using my estimated pre-Hartz and post-Hartz values for the labor supply elasticity. Doing so first requires taking a stance on the nature of the shock that incentivized greater inflows of Chinese manufactured goods. Using data on the changes in trade shares between Germany and China, I show how to back out the implied change in trade costs between the two countries that is consistent with those trade flows. This approach has the benefit of not needing to calibrate the model to a given level of the labor supply elasticity, i.e. I can recover the trade shock independent of my estimation of the elasticity. By feeding this shock to trade costs into the model under my two estimates for the labor elasticity, I can compare the market-level welfare changes from 2005-2012 to those in a counterfactual world where the reforms never changed the labor supply elasticity. I quantify that in the absence of the reforms, the difference between the welfare changes of the worst-off and best-off markets would have more than doubled (from 0.24% to 0.57%), but aggregate welfare would have grown by 20% more (by 0.212% rather than 0.176%).

Intuitively, this result is driven by the pattern of worker selection in Germany following greater competition in manufacturing from China. Cheaper Chinese goods lowered the wages for German workers in manufacturing, leading to the least productive workers in each sector to select into their next-best sector of comparative advantage. This selection induces greater competition in (e.g.) the non-manufacturing sector, which lowers wages in that sector as well. In the case where frictions induce total factor immobility, wage losses are concentrated in the manufacturing sectors and workers in the non-manufacturing sector gain from lower prices. As the labor market becomes more elastic, workers can more easily reallocate from impacted sectors and therefore narrow the distribution of welfare changes. In the case of an infinitely elastic supply (i.e. where workers are identical and there are zero frictions), the model predicts that welfare changes for all workers would be equal (as in the model of EK).

While the model delivers this intuitive result, some caveats remain. In particular, by assuming that removing frictions can make labor supply more elastic I imply that policy can change the dispersion of labor productivities across workers and markets. In practice, this is not quite right. While policy can determine the degree to which workers can *act* upon their varying productivities, it is unlikely that governments control the true *dispersion* of those productivities. When estimating the labor supply elasticities, I can only capture the combination of the productivity dispersion and prevailing labor policies. My post-reform elasticity measurement, therefore, could be contaminated by changes in the dispersion of productivity over time rather than changes in policy since both effects would be observationally equivalent. That being said, worker flows out of manufacturing in the early 1990s stemming from German reunification is likely to bias my results in the opposite direction, as does choosing a smaller adjustment window in the second period (7-year vs. 10-year). With the magnitude of the result I still find, I believe it unlikely that frictions do not play an important role.

I also take a reduced-form approach to the labor frictions in a static model in order to simplify the mechanism of adjustment. To be sure, there are many ways to model labor frictions in EK and trade settings,[4] and research on dynamic trade models with unemployment frictions is growing.[5] But taking a stance on the source and type of labor frictions is infeasible, as the compact timing and universality of the reforms across Germany would make it impossible to quantify each channel separately. I use a static framework without unemployment for tractibility, but research suggests that the Hartz Reforms may not have been the source of employment changes in the early 2000s.[6] This paper does not make the claim that its model is the only way to construct the exercise properly, but rather that the model provides an intuitive setup for analyzing the intersection of labor policy and trade shocks.

My work contributes to several growing strands of literature. First, I complement empiri-

[4]See, e.g., Hsieh et al. (2013) and Artuc & McLaren (2015), respectively.
[5]See, e.g., Carrère et al. (2015).
[6]See Akyol et al. (2013).

cal papers focusing on the local labor market outcomes arising from national trade shocks. In addition to ADH and DFS, see for example Dix-Carneiro & Kovak (2017) or Borjas (1997). I also add to studies on the distributional effects of trade, including Cravino & Sotelo (2017), Helpman et al. (2017), and Bursein & Vogel (2017) who all find increases in the skill premium as a result of trade. Consistent with their work, I find that labor markets with higher concentrations of untrained workers in the manufacturing sector tend to gain less from trade than do those with more qualified workers. Through my simulation exercise, I show how increasing lower frictions can narrow the welfare gains from trade, mitigating the losses to groups left worse off in the wake of increased Chinese import penetration.

The Roy model employed in this paper is similar to those in Artuc et al. (2010), Dix-Carneiro (2014), and Adão (2015), but my focus is on the China shock rather than exogenous changes in the terms of trade in small economies. While Caliendo et al. (2015), Lee (2018), and Adão et al. (2018) quantify aggregate and distributional welfare impacts from trade, my model follows the approach of Galle et al. (2017, henceforth GRY) in order to incorporate an analysis of labor policy tools more easily.

My model is a simpler approach to labor mobility than that of Artuc & McLaren (2015), but it also speaks to the presence of frictions in the labor market that inhibit intersectoral reallocation. Their paper indicates that a worker's industry of employment is primary in deciding whether trade harms or benefits her. This paper builds on that result by modeling how policy might alleviate worker outcomes in affected industries.

Lastly, my paper is related to the wide body of analyses on the Hartz Reforms including Jacobi & Kluve (2006), Akyol et al. (2013), and Dlugosz et al. (2014). In the macroeconomic search model vein, Krause & Uhlig (2012), Krebs & Scheffel (2013), and Launov & Wälde (2013) conclude that the cuts to unemployment benefits by Hartz led to reduced unemployment. Tackling the effects of Hartz I and III,[7] Fahr & Sunde (2009) and Hertweck & Sigrist (2013) find important positive effects on matching efficiences. Giannelli et al. (2016) study

[7]As will be explained in the following section, the Hartz Reforms are categorized into four stages.

how job duration and wages evolved in Germany in 1998-2010, finding that the median wage of workers reentering from unemployment declined in the post-Hartz years. I add to this large strand of literature by incorporating the Hartz Reforms into the context of larger trade models. My approach allows me to simulate and evaluate counterfactual scenarios in which Germany is impacted by trade shocks in the absence of the Reforms' effect, giving me the ability to speak to the effect of the trade and reform channels separately.

The rest of the paper is structured in the following way. Section 2 describes the Hartz Reforms and their role in the model. Section 3 presents the model. Section 4 descibes the data. Section 5 details my instrumental variable approach and provides results of the estimation procedure for the elasticity of labor supply. Section 6 performs simulation exercises and evaluates welfare changes from policy. Section 7 concludes.

2 German Social Welfare and the Hartz Reforms

The Hartz Reforms, which came into effect from 2003-2005, were intended as a remedy to the economic problems facing Germany at the turn of the century. The German welfare system had become strained by the influx of East German beneficiaries following reunification, its expenditure accounting for about a third of national GDP by 2000. By the early 2000s, the unemployment rate in Germany was well above the OECD average, 9.8%-11.2% versus the 6.6% average in 2003-2006. The economy had stagnated with growth figures of 1.4% in 2002, 1.0% in 2003, and 1.4% in 2005. With an aging population on the horizon, the "sick man of Europe" faced increasing pressure to make vast changes to labor institutions and the social welfare system.

The reforms, in part designed by eponymous Peter Hartz, consisted of thirteen "innovation modules" for reshaping the German labor market that were gradually put into practice beginning in 2003. As detailed in Table 1.1, the reforms took place in several stages and are collectively known as Hartz I-IV. Hartz I-III supported further vocational education,

Table 1.1: Hartz Reforms Timeline

Law	Adoption of Law	Effective Date	Measures
Hartz I	1 December 2002	1 January 2003	Setting up of new Personnel Service Agencies
			Support for further vocational education from the German Federal Labor Agency
			Deregulation of temporary work sector
Hartz II	1 December 2002	1 January 2003	Introduction of subsidy for one-person companies (Me-inc)
			Introduction of low paid jobs (mini and midi-jobs) exempt from most social security taxes
			Threshold size for firms subject to layoff rules raised from five to ten workers
Hartz III	1 December 2003	1 January 2004	Restructuring of the Federal Labor Office
Hartz IV	1 December 2003	1 January 2005	Shortening of the duration of unemployment benefits
			Merging of unemployment assistance and social assistance, with benefit set at the lower level of social benefits (unemployment benefit II)
			A new definition of acceptable jobs with sanctions for refusal of an acceptable job

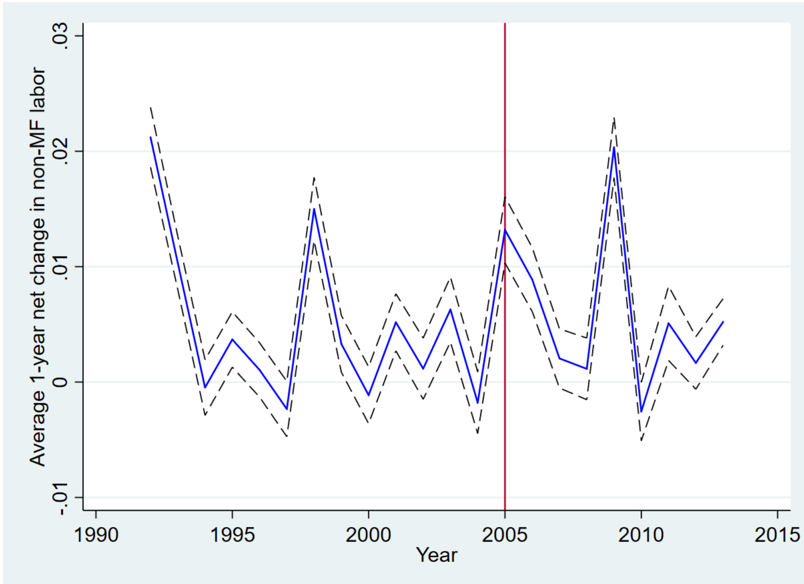
Source: Eichhorst & Marx (2011), Dlugosz et al. (2014), and Engbom et al. (2015).

entrepreneurship, and a rise in the number of Jobcentres in Germany.[8] These stages sought to increase job search efficiency and employment flexibility. In particular, employers were given more flexibility to vary employment levels without incurring hiring or firing costs and received subsidies for employing hard-to-place workers, changes that motivates my model's focus on intersectoral reallocation.

Hartz IV mainly reduced benefit payout. The German unemployment insurance system comprised three layers before the reforms: unemployment benefits (UB), unemployment assistance (UA), and social assistance (SA). UB provided benefits equal to 60% of previous net earnings for 12 months (32 months for older workers), after which the still-unemployed moved to the UA's 53% rate. SA, the last line of support, provided a means-tested lump-sum transfer to those ineligible for either UB or UA. After the reforms, the German system became two layers with UA effectively removed: many workers eligible for UA before the reforms had to rely on a lower lump-sum transfer system provided by the newly-christened Unemployment Benefit II. Unemployment Benefit I was UB with a new label. In sum, Hartz

[8]Jobcentres coordinate between firms looking to hire and labor searching for work. They are jointly administered by the Federal Agency for Labor and the respective local government in order to reduce coordination issues.

Figure 1.1: Changes in the Non-manufacturing Share of German Employment



Notes: Data from the IAB-Establishment History Panel (see Section 4 for details). Values are net changes in the share of non-manufacturing employment in total employment. The dashed lines are the standard error for a 95% confidence interval. The upward spike in 1998 is due to a 1999 change in procedure that included more workers as full-time.

IV disincentivized reliance on the welfare state with the goal of returning more citizens to – and retaining as many workers in – the labor force.

Collectively, these recommendations relaxed certain restrictions on the firing of workers, eased regulation of the temporary labor market, boosted employment flexibility, and weakened unemployment insurance benefits. As a result, I interpret the reforms as a reduction in labor market frictions. Figure 1.1 presents the average change in the non-manufacturing share of employment – the largest fraction of the economy – from 1992-2012 in Germany. As can be seen, net movements accelerate concurrently with the Hartz Reforms. One might expect large movements into non-manufacturing following import pressure from China's accession to the WTO in 2001 (similar to the spike in the early 1990s), but it isn't until after the reforms that intersectoral reallocation appears to be a margin for adjustment in the 2000s.

In the empirical section of this paper, I focus on worker movements into this aggregated non-manufacturing sector. While the Hartz Reforms were not intended to move workers strictly out of manufacturing, I focus on this margin for a few reasons related to the data. In this model of trade, I will show that estimation of the labor supply elasticity will require at most two sectors. At the two-sector aggregation level, focusing on manufacturing vs. non-manufacturing is equivalent. However, I disaggregate data in the manufacturing sector in order to capture more accurately the import penetration from China, which has been shown to differ across sectors (e.g. the pressure in textiles is not the same as that in automobiles). Import penetration is very fine at this level of disaggregation, but as a result the reallocation in any particular small sector can be very noisy. As such, I rely on the aggregated non-manufacturing sector for identification as its large size makes it less sensitive to any individual's reallocation, a fact that I will return to in Section 5.

3 Model

In this section, I present a multi-sector,[9] multi-country Ricardian model of trade with heterogenous workers as in GRY.[10]

Suppose there are N countries indexed by i, j and S sectors indexed by s, and labor is the only factor of production. These sectors are modeled as in EK, i.e. there are CES preferences across a continuum of goods within a given sector s with elasticity of substitution σ_s, and preferences across sectors are governed by a Cobb-Douglas process with shares β_{is}. Technologies have constant returns to scale and productivities are drawn from a Fréchet distribution with shape parameter $\theta_s > \sigma_s - 1$ and level parameter T_{is} for all $s \in S,\ i \in N$. Iceberg trade costs of $\tau_{ijs} \geq 1$ are applied to all goods originating from i and sent to j in sector s, with $\tau_{iis} = 1\ \forall i$ and $\forall s$.

On the labor supply side, workers are ex-post heterogenous in ability draws but ex-ante identical within each group, as in Roy (1951). Denote G_i as the set of worker groups in

[9]As in Levchenko & Zhang (2014), welfare gains are substantially higher in the multi-sector formula. One-sector formulas tend to understate gains in countries with dispersion in sectoral productivities.

[10]See Appendix 6 for the full derivation.

country i.[11] A worker from group g draws her productivity in s in the form of efficiency units Z distributed by an $\{i, g\}$-specific Fréchet distribution with shape parameter $\kappa_{ig} > 1$ and level parameters A_{igs}. The market is perfectly competitive, and labor is supplied inelastically. A fixed number of workers L_{ig} in group g in country i choose the most profitable sector s to work in, whereafter they suppy their entire labor endowment. Workers cannot move between groups,[12] but they can reallocate between sectors between different equilibria.

This model setup is valuable due to its ability to nest into several other prominent models. If $\kappa_{ig} \to \infty \ \forall g \in G_i$ and $A_{igs} = 1 \ \forall \{i, g, s\}$, the model is isomorphic to the Costinot et al. (2012) formation of EK. If there is no trade (i.e. $\tau_{ijs} = \infty \forall j \neq i$) and a single group of workers (i.e. $G_i = 1$), the model is isomorphic to Lagakos & Waugh (2013) and Hsieh et al. (2013). In the case where $\kappa_{ig} = 1 \ \forall g \in G_i$, the model is isomorphic to the Ricardo-Viner model where labor is a specific factor.

In what follows, I highlight how the Fréchet distributions deliver useful relationships for the model in equilibrium, taking special care to note the role of κ_{ig} where appropriate.

3.1 Equilibrium

To solve for equilibrium in the model, it is best to tackle the labor demand and supply individually. The EK side of the model determines the *demand* for labor in each sector as a function of wages while the Roy side determines the *supply* of labor in each sector as a function of wages. The equilibrium will be the set of wages that equalize the demand and supply.

On the EK side, recall that technologies are national (the T_{is} are i-level rather than g-level for each sector). While sector productivity heterogeneity will result in an upward-

[11] In the empirical portion of this paper, groups will be defined by a German local labor market and dichotomous skill variable (untrained vs. trained) pair. Together, this definition yields 210 market-skill pairs in order to estimate model parameters.

[12] Movement between groups implies movement across skill or labor market. As to the former, a limitation of the data is that it does not accurately capture when or if workers change their education or skill level. As to the latter, inter-regional flows are not a large margin for adjusting to trade pressure in Germany. See, for example, DFS who conclude "mobility across regions plays a minor role in the response to import shocks."

sloping supply curve (governed by κ_{ig}) and wages that differ across sectors, wages cannot differ across *groups*.[13] Denote by w_{is} the wage per efficiency unit in country i and sector s. The EK solution in this setting for the demand for efficiency units in $\{i, s\}$ is given by

$$\frac{1}{w_{is}} \sum_j \lambda_{ijs} \beta_{js} X_j, \tag{3.1}$$

where X_j denotes total expenditure in country j and λ_{ijs} denotes sectoral trade shares from i into j,

$$\lambda_{ijs} = \frac{T_{is}(\tau_{ijs} w_{is})^{-\theta_s}}{\sum_k T_{ks}(\tau_{kjs} w_{ks})^{-\theta_s}}. \tag{3.2}$$

As it will be helpful to reference later, the price index can be expressed by the system of equations,

$$P_{js} = \frac{1}{\gamma_s} \left[\sum_{i=1}^{N} T_{is}(\tau_{ijs} w_{is})^{-\theta_s} \right]^{-1/\theta_s}, \tag{3.3}$$

where $\gamma_s \equiv \left[\Gamma(1 + \frac{1-\sigma_s}{\theta_s})\right]^{\frac{1}{1-\sigma_s}}$ and Γ is the gamma function.[14]

On the Roy side, workers choose the sector in which they earn their highest income, and their choice of sector determines labor supply. More formally, define a set of productivities $\boldsymbol{Z} = (Z_1, Z_2, ..., Z_S)$ and let $\Omega_s \equiv \{\boldsymbol{Z} \text{ s.t. } Z_s w_{is} \geq Z_r w_{ir} \ \forall r \in S\}$. Any worker with productivity vector $\boldsymbol{Z}$ will choose to work in sector s if and only if $\boldsymbol{Z} \in \Omega_s$. Denote by $F_{ig}(z)$ the joint probability distribution of $\boldsymbol{Z}$ for workers in group g in country i. As in Lagakos & Waugh (2013) and Hsieh et al. (2013), the share of workers in $\{i, g\}$ that choose to work in sector s is given by

$$\pi_{igs} \equiv \int_{\Omega_s} dF_{ig}(z) = \frac{A_{igs} w_{is}^{\kappa_{ig}}}{\Phi_{ig}^{\kappa_{ig}}}, \tag{3.4}$$

[13] Workers are paid a country-sector-specific wage for each efficiency unit of supply. Country-specific sectoral technologies imply that no group has a comparative advantage in a particular sector even if that group has an absolute advantage. If the per-efficiency-unit wage were larger in a particular group, firms would enter elsewhere.

[14] And the overall price level in j can be given by $P_j \equiv \left(\sum P_{js}^{1-\sigma_s}\right)^{1/(1-\sigma_s)}$.

where $\Phi_{ig}^{\kappa_{ig}} \equiv \sum_r A_{igr} w_{ir}^{\kappa_{ig}}$. The supply of efficiency units in $\{i, g, s\}$ can be given by

$$E_{igs} \equiv L_{ig} \int_{\Omega_s} z_s dF_{ig}(z) = \eta_{ig} \frac{\Phi_{ig}}{w_{is}} \pi_{igs} L_{ig}, \tag{3.5}$$

where $\eta_{ig} \equiv \Gamma(1 - \frac{1}{\kappa_{ig}})$.

Rearranging Equation 3.5 allows for the simpler expression,

$$\frac{E_{igs} w_{is}}{L_{ig} \pi_{igs}} = \eta_{ig} \Phi_{ig}.$$

For the left-hand side of this expression, the numerator computes the total income (efficiency units $\times$ wage) while the denominator gives the number of workers in $\{i, g, s\}$ (number of workers in $\{i, g\}$ $\times$ share of $\{i, g\}$ workers in s). Since this equation holds for all s, the income level per worker is equal across sectors for $\{i, g\}$. Due to the special properties of the Fréchet distribution, the share of income for $\{i, g\}$ in s is also given by the share of $\{i, g\}$ workers in s, namely

$$\frac{E_{igs} w_{is}}{\sum_r E_{igr} w_{ir}} = \pi_{igs}.$$

Summing across all sectors, total income for $\{i, g\}$ can be defined by

$$Y_{ig} \equiv \sum_s E_{igs} w_{is} = L_{ig} \Phi_{ig} \sum_s \pi_{igs} = L_{ig} \Phi_{ig},$$

and summing across all *groups*, total income for country i can be defined by

$$Y_i \equiv \sum_{g \in G_i} Y_{ig} = \sum_{g \in G_i} L_{ig} \Phi_{ig}.$$

Combining the EK and Roy pieces, I can write a system of equations for excess labor demand in each country-sector. First, define the country-level income-expenditure relationship as

$$Y_i = X_i - D_i,$$

where the D_i are possible trade deficits between countries, and the sum of the transfers are such that $\sum_i D_i = 0$. Then use Equation 3.1 and sum across g in Equation 3.5 to define excess labor demand as

$$ELD_{is} \equiv \frac{1}{w_{is}} \sum_j \lambda_{ijs}\beta_{js}X_j - \sum_{g\in G_i} E_{igs}. \tag{3.6}$$

Equilibrium is given by the matrix of wages $\boldsymbol{w_{is}}$ that solves the system of equations $ELD_{is} = 0 \; \forall\{i,s\}$ for some numeraire.

3.2 Comparative Statics

For comparative statics, I use the "exact hat" algebra as in Dekle et al. (2008), originally proposed by Jones (1965). Denote the proportional change of a variable x by $\hat{x} \equiv \frac{x'}{x}$ where $'$ denotes the value in the counterfactual equilibrium, and the unmarked denotes the original equilibrium. As above, the counterfactual state of the world is in equilibrium whenever $ELD'_{is} = 0 \; \forall\{i,s\}$. The goal is to estimate the proportional change of the endogenous outcome variables (e.g. $\hat{Y}_{ig}$), using shocks to trade costs, trade imbalances, group-sector productivity levels, and/or sector productivity levels (the $\hat{\tau}_{ijs}$, $\hat{D}_j$, $\hat{A}_{igs}$ and $\hat{T}_{is}$, respectively).[15] In order to form the estimating equation, recall from above that $E_{igs} = \frac{\eta_{ig}\Phi_{ig}}{w_{is}}\pi_{igs}L_{ig}$ (with $\hat{\eta}_{ig} = 1$) and $Y_{ig} = L_{ig}\Phi_{ig}$. I can write the equation for $ELD'_{is} = 0$ from Equation 3.6 as

$$\sum_j \hat{\lambda}_{ijs}\lambda_{ijs}\beta_{js}\left(\sum_{g\in G_j} \hat{Y}_{jg}Y_{jg} + \hat{D}_jD_j\right) = \sum_{g\in G_i} \hat{\pi}_{igs}\hat{Y}_{ig}\pi_{igs}Y_{ig}, \tag{3.7}$$

with

$$\hat{Y}_{ig} = \left(\sum_r \pi_{igr}\hat{A}_{igr}\hat{w}_{ir}^{\kappa_{ig}}\right)^{1/\kappa_{ig}}, \tag{3.8}$$

$$\hat{\lambda}_{ijs} = \frac{\hat{T}_{is}(\hat{\tau}_{ijs}\hat{w}_{is})^{-\theta_s}}{\sum_k \lambda_{kjs}\hat{T}_{ks}(\hat{\tau}_{kjs}\hat{w}_{ks})^{-\theta_s}}, \tag{3.9}$$

[15] As detailed earlier, the Hartz Reforms will alter the estimate of κ_{ig}. The central *shock*, however, will be $\hat{\tau}_{ijs}$. In Section 6, I detail how to back out a model-consistent shock to trade costs between Germany and China.

and

$$\hat{\pi}_{igs} = \frac{\hat{A}_{igs}\hat{w}_{is}^{\kappa_{ig}}}{\sum_r \pi_{igr}\hat{A}_{igr}\hat{w}_{ir}^{\kappa_{ig}}}. \tag{3.10}$$

To solve for the proportional change in sector-specific wages, $\hat{\boldsymbol{w}}_{\boldsymbol{is}}$, I can use the above system of equations provided I have: 1) Data on group-level income levels (Y_{ig}), trade imbalances (D_i), trade shares (λ_{ijs}), expenditure shares (β_{is}), labor allocation shares (π_{igs}), and labor endowments (L_{ig}); 2) Parameter values for the shape parameters on sectoral technologies (θ_s) and labor productivities (κ_{ig}); and 3) A measure of the shocks from trade costs ($\hat{\tau}_{ijs}$), trade imbalances ($\hat{D}_i$), group-sector productivity levels ($\hat{A}_{igs}$), and/or sector technology levels ($\hat{T}_{is}$). Once I have the $\hat{\boldsymbol{w}}_{is}$ matrix, I can use Equations 3.9 and 3.10 to solve for the proportional changes in trade shares and sector employment shares.

3.3 Group-Level Welfare Effects

I define welfare as real income, $W_{ig} \equiv \frac{Y_{ig}}{L_{ig}P_i}$, which is equivalent for all workers in group $\{i, g\}$.[16] In my welfare evaluations, I am interested in the change in W_{ig} resulting from increased import penetration from China. Cobb-Douglas preferences imply

$$W_{ig} = \frac{Y_{ig}}{\prod_s P_{is}^{\beta_{is}}},$$

from which it easy to show

$$\hat{W}_{ig} = \frac{\hat{Y}_{ig}}{\prod_s \hat{P}_{is}^{\beta_{is}}}. \tag{3.11}$$

Using Equations 3.3 and 3.9 and assuming $\hat{T}_{is} = 1 \ \forall s$ in i, it follows that $\hat{P}_{is} = \hat{w}_{is}\hat{\lambda}_{iis}^{1/\theta_s}$. Using Equations 3.8 and 3.10, I can write $\hat{Y}_{ig} = \hat{w}_{is}\hat{\pi}_{igs}^{-1/\kappa_{ig}}$. Together, these results imply

$$\hat{W}_{ig} = \prod_s \hat{\lambda}_{iis}^{-\beta_{is}/\theta_s} \cdot \prod_s \hat{\pi}_{igs}^{-\beta_{is}/\kappa_{ig}}. \tag{3.12}$$

[16]Recall that the Fréchet distibution implies that the share of income in $\{i, g, s\}$ is equal to the share of labor in $\{i, g, s\}$, which delivers an equivalence for workers in $\{i, g\}$ regardless of their sector of employment.

Equation 3.12 comprises two terms, $\prod_s \hat{\lambda}_{iis}^{-\beta_{is}/\theta_s}$ and $\prod_s \hat{\pi}_{igs}^{-\beta_{is}/\kappa_{ig}}$. The first term is identical to the multi-sector welfare formula from trade shocks in Arkolakis et al. (2012), and it measures the change in welfare given wages. The second term contains all of the group-specific variation in welfare, and it measures the change in real income coming exclusively from changes in wages (for group $\{i, g\}$ in sectors $s \in S$). The changes in wages, $\hat{w}_{is}$, incentivize workers in $\{i, g\}$ to specialize (possibly) in different sectors in response to the shock. The heterogeneity in $\hat{\pi}_{igs}$ resulting from the impact of trade on local labor markets allows me to differentiate the welfare changes across groups.

Intuitionally, this second term captures the selection that occurs in the wake of import penetration. Manufacturing competition abroad depresses wages in the manufacturing sectors, inducing workers to reallocate to maximize their income. A worker flows into the non-manufacturing sector when the income loss from the drop in manufacturing wages outweighs her lower productivity in the non-manufacturing sector. As more labor shifts out of manufacturing, workers in the non-manufacturing sector face more competition, leading to wage losses in that sector as well. Some groups benefit disproportionately from the drop in overall prices while others lose disproportionately from the steep fall in manufacturing wages. The κ_{ig} governs, in part, the degree to which workers can move intersectorally to avoid losses due to trade pressure. All things equal, higher κ_{ig} (as from lower frictions) will tend to increase intersectoral mobility, which in turn will both improve welfare for the worst-off groups and lower welfare for the best-off groups.

3.4 Aggregate Welfare Effects

Using Equation 3.12, it follows that ex-ante change in aggregate welfare can be expressed by

$$\hat{W}_i = \prod_s \hat{\lambda}_{iis}^{-\beta_{is}/\theta_s} \cdot \sum_{g \in G_i} \left(\left(\frac{Y_{ig}}{Y_i} \right) \prod_s \hat{\pi}_{igs}^{-\beta_{is}/\kappa_{ig}} \right). \tag{3.13}$$

Shocks affecting w_{is} will have aggregate welfare effects through impact on both income and sector-level prices. The second term of aggregate welfare is given by the weighted sum of the group-level changes in welfare. Intuitionally, the second part of the right-hand side shrinks as workers can more easily substitute for one another. In the limit, $\kappa_{ig} \to \infty$ implies identical workers in a frictionless environment, at which point the group-level differences tend to zero and the welfare gains are simplified to the Arkolakis et al. (2012) term, $\prod_s \hat{\lambda}_{iis}^{-\beta_{is}/\theta_s}$.

A seemingly counterintuitive implication of this welfare expression is that aggregate gains from inter-sectoral trade are strictly higher for $\kappa_{ig} < \infty$ than the gains that arise in the limit for $\kappa_{ig} \to \infty$. To illustrate why, suppose that country i consists of a single group, i.e. $G_i = 1$, and is in full autarky. Then expenditure shares and income shares would be equal in the original equilibrium, i.e. $\beta_{is} = \pi_{igs}$. When moving from autarky, $\hat{W}_i$ depends in part upon $\prod_s \hat{\pi}_{igs}^{-\beta_{is}/\kappa_{ig}}$ with $\hat{\pi}_{igs} = \frac{\pi'_{igs}}{\beta_{is}}$ for some new allocation π'_{igs}. By rewriting this expression as $\prod_s \hat{\pi}_{igs}^{-\beta_{is}/\kappa_{ig}} = \exp\left(\frac{1}{\kappa_{ig}}\left(\sum_s \beta_{is} \ln(\beta_{is}/\pi'_{igs})\right)\right)$ it can be seen that higher values of κ_{ig} will shrink the magnitude of the welfare gains. GRY's Proposition 2 proves that this property holds for $G_i > 1$.

To intuit why this property is true, consider the case where $G_i = 1$ and country i engages in inter-sectoral trade, i.e. $\pi_{igs} \neq \beta_{is}$ for some s. Suppose this country closes to trade and returns to autarky, and we are interested in the total change in welfare for this transition, $\hat{W}_i^A$. Finite κ_{ig} introduces greater "curvature" to the PPF and makes it harder for the economy to adjust as it moves to autarky while keeping expenditure shares (β_{is}) constant. In the limit for $\kappa_{ig} \to \infty$, the economy is able to shift most easily to its new labor allocations, i.e. higher κ_{ig} tends to shrink $\hat{W}_i^A$. If we define the gains from trade as $GFT_i \equiv 1 - \hat{W}_i^A$, it is easy to see why opening to trade would yield higher aggregate welfare changes in country i the lower is the value of κ_i.

4 Data

For the empirical analysis, I combine data from a few sources. As my setting is in Germany, the most important source is labor market data at the regional and sectoral level. The IAB-Establishment History Panel (BHP)[17] includes the universe of all German establishments with at least one employee subject to social security. These administrative data are restricted to information relevant for social security,[18] but they annually cover around 2.7 million panel observations from 1975 to the present for West Germany, and from 1992 for East Germany. The data for regional employment by sector is available only from 1978 onward. Sector information is based on NACE Rev. 1 classifications.

I use trade data from the United Nations Statistical Division (UNSD) Commodity Trade (COMTRADE) database to measure import penetration in manufacturing between Germany, China, and a group of countries economically similar to Germany between 1992-2012.[19] Trade flows are deflated to 2010 USD values using data from the World Bank. In order to match the trade data and establishment data, I translate the SITC Rev. 3 product codes from COMTRADE to ISIC Rev. 3 to NACE Rev. 1 at the two-digit level via the correspondence tables provided by the UNSD and Eurostat RAMON.

In the counterfactual simulations, I use trade data from the World Input-Output Database (WIOD). I use this second source of international trade flows to measure both manufacturing and non-manufacturing flows in the world economy. The WIOD covers 40 countries, and a model for the rest of the world for the period 1995-2011. Data for 35 sectors are classified according to the ISIC Rev. 3, which I similarly correspond to NACE Rev. 1 at the two-digit

[17]This study uses the weakly anonymous Establishment History Panel (Years 1992 - 2014). 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/or remote data access. Data documentation by Alexandra Schmucker, Johanna Eberle, Andreas Ganzer, Jens Stegmaier, Matthias Umkehrer (2018): Establishment History Panel 1975-2016. FDZ-Datenreport, 01/2018 (en), Nuremberg. DOI: 10.5164/IAB.FDZD.1801.en.v1.

[18]I.e. the structure of the workforce by wage, sex, age, German/non-German status, occupation in certain classes, and a measurement of skill intensity.

[19]Specifically, the instrument group consists of Australia, Canada, Japan, Norway, New Zealand, Sweden, Singapore, and the United Kingdom.

level via the correspondence tables provided by the UNSD.

In order to avoid changes from the inclusion of East Germany, I use 1992 as the base year. I use the period 1992-2002 to estimate the value of κ_{ig} without the impact of Hartz, and the period 2005-2012 to estimate the value of κ_{ig} after the reforms.[20] See Appendix 6 for more details on the construction of variables.

5 Estimation and Empirical Exercise

The ultimate goal is to study how the Hartz Reforms impacted the group-level changes in welfare that stemmed from increased import penetration from China between 2005-2012. To that end, I want to simulate the German economy before and after the Reforms' effects on the labor supply elasticities, κ_{ig}. To do so, I need to estimate the labor supply elasticity in the two periods, 1992-2002 in the pre-Hartz period vs. 2005-2012 in the post-Harz period. This section details how I derive my estimates.

The estimation procedure is built from several pieces. First, I detail the construction of the ADH instrument for trade penetration. I next establish the relevance of the instrument for changes in employment shares in Germany, $\hat{\pi}_{igs}$, which in turn affect the changes in average group income per worker. I then demonstrate how to estimate κ_{ig} from a structural relationship in the model using the instrument. I present results under the assumption $\kappa_{ig} = \kappa$, and conclude by showing how the $\hat{\kappa}$ estimate changes with the arrival of the Hartz Reforms.

[20]For robustness, I consider 1993 as a possible base year, and 2002 and 2003 as the "start" of the Hartz period. Although the measurement of κ_{ig} has some small variation depending on the period used, results are similar. See Appendix 6 for details.

5.1 Instrumental Variable Approachas an instrument for the above import exposure, namely

In this section, I detail how to use data on Chinese import flows to serve as an instrument to estimate κ through changes in sectoral labor allocations. An ideal estimating equation is one where I can use variation in $\hat{\pi}_{igs}$ in order to estimate the κ parameter. To that end, define the change in earnings per worker in group g by $\hat{y}_{ig} \equiv \frac{\hat{Y}_{ig}}{\hat{L}_{ig}}$. Using this definition together with Equations 3.8 and 3.10 implies

$$\hat{y}_{ig} = \hat{w}_{is}\hat{\pi}_{igs}^{-1/\kappa}\hat{A}_{igs}^{1/\kappa}. \tag{5.1}$$

Note that this equation holds for each sector s. The problem with taking this equation directly to the data is the endogeneity between the change in employment share, $\hat{\pi}_{igs}$, and the change in average group level income per worker, $\hat{y}_{ig}$. In order to remedy this problem, I need an instrument that affects group-level income through its effect on changes in labor allocation, $\hat{\pi}_{igs}$. I follow ADH in their focus on the effects of increasing manufacturing import penetration from China on local labor markets.[21] To define how groups of workers are potentially affected by the rise of China during the time periods of interest, I construct a measure of trade exposure at the sector level. In particular, I measure

$$\Delta\,[\text{import exposure}]_{st}^{\text{CHN}} \equiv \frac{\Delta \text{IM}_{st}^{\text{DEU}\leftarrow\text{CHN}}}{L_{\text{DEU},st}}, \tag{5.2}$$

where $\Delta \text{IM}_{st}^{\text{DEU}\leftarrow\text{CHN}}$ denotes the change in the value of imports from China to Germany between t and $t+1$, and $L_{\text{DEU},st}$ denotes the number of workers in sector s at time t in Germany. Note that this regressor does not solve the endogeneity problem immediately, as unobserved supply or demand shocks could affect both $\hat{y}_{ig}$ and the import exposure in a way

[21] In a robustness exercise, I include the expansion of the Eastern European market after the fall of the Iron Curtain as in DFS. In line with their results in finding little "pull" effect, I do not find that the inclusion of the Eastern European channel greatly affects my results.

that would contaminate my estimation of the effect of trade shocks.

To that end, consider a group of countries economically similar to Germany in terms of openness and size.[22] Denote these countries by 'OTHER' with $\Delta \mathrm{IM}_{st}^{\mathrm{OTHER} \leftarrow \mathrm{CHN}}$ defined as above, with the exception that the trade flows are into these OTHER countries rather than Germany. I use these trade flows to define the instrument,

$$\Delta \left[\text{IV import exposure}\right]_{st}^{\mathrm{CHN}} \equiv \frac{\Delta \mathrm{IM}_{st}^{\mathrm{OTHER} \leftarrow \mathrm{CHN}}}{L_{\mathrm{DEU},st}}. \tag{5.3}$$

The intuition behind the instrument is straightforward. The rise of Chinese international trade is not an event that solely impacted Germany, and the rise in flows to the IV Group from (e.g.) China's accession into the WTO can serve as a valid instrument. Using these flows captures the exogenous components of the China shock while remaining netural to the potential shocks affecting both German region g's performance and trade flows. Through trade's impact on labor allocations, I can estimate κ through two-stage least squares.

I use the changes in the labor share of the aggregated non-manufacturing sector in each group, $\hat{\pi}_{ig,NM}$, to estimate κ. For robustness, I construct two different measures for labor allocation based on employment shares and earnings shares, $\pi_{ig,NM} = \frac{L_{ig,NM}}{L_{ig}}$ and $\pi_{ig,NM} = \frac{Y_{ig,NM}}{Y_{ig}}$ respectively.

Table 1.2 reports the results for the first stage. The F-stats are large, and the estimated coefficients are very similar whether the model uses employment shares or earnings shares. As expected, larger inflows of Chinese manufacturing goods predict larger labor shares in the non-manufacturing sectors: labor moves away from affected sectors into those less exposed to the trade shock.

[22] Again, this instrument group consists of Australia, Canada, Japan, Norway, New Zealand, Sweden, Singapore, and the United Kingdom.

Table 1.2: Instrumental Variable Results, 1992-2002

Measurement of IV uses:	Emp. Share	Earn. Share
$\hat{\beta}^{IV}$	0.0053***	0.0043***
	(0.0006)	(0.0006)
F-statistic	81.36	57.07
N	210	210
R^2	0.2812	0.2153

Notes: The independent variable for this regression is the instrument described in Equation 5.3. The dependent variable is is given by $\hat{\pi}_{ig,NM} = \frac{\hat{L}_{ig,NM}}{L_{ig}}$ and $\hat{\pi}_{ig,NM} = \frac{\hat{Y}_{ig,NM}}{\hat{Y}_{ig}}$, respectively. A group is the set of full-time employees for a particular local-labor-market-skill pair. The dichotomous skill variable measures "unskilled" full-time employees vs. all others. *** indicates significance at the 1% level.

5.2 Reduced-form Impact of the China Shock

I next show how changes in trade exposures affects group-level income. To that end, I run the regression

$$\ln \hat{y}_{ig} = \alpha + \beta^{RF} \ln \sum_{s \in M} \frac{L_{igst}}{L_{igt}} \Delta[\text{IV import exposure}]_s^{\text{CHN}} + \epsilon_{ig}, \tag{5.4}$$

where $\Delta[\text{IV exposure}]_s^{\text{CHN}}$ and $\hat{y}_{ig}$ are defined as above, and $\frac{L_{igst}}{L_{igt}}$ gives the group's relative exposure to the trade shock in the manufacturing sector (M).[23]

Table 1.3 presents the results. My findings are consistent with the stories proposed by ADH and DFS: Chinese import penetration tends to lower the average income of groups most exposed in the manufacturing sector.

5.3 Estimation of κ_{ig}

Having established the relevance of the IV strategy, it remains to be shown how I use this approach to estimate κ. From Equation 5.1, I can take logs to establish

[23] That is, for the same change in import values in s, the effect of the instrument on group g will be stronger the larger is g's total exposure to manufacturing sectors, $s \in M$. Note that the trade exposure to group g is necessarily zero for sectors outside of manufacturing.

Table 1.3: Reduced Form Results, 1992-2002

Measurement of IV uses:	Emp. Share	Earn. Share
$\hat{\beta}^{RF}$	-.0103***	-.0127***
	(0.004)	(0.003)
N	210	210
R^2	0.0610	0.0771

Notes: The independent variable for this regression is given by $\hat{\pi}_{ig,NM} = \frac{\hat{L}_{ig,NM}}{L_{ig}}$ and $\hat{\pi}_{ig,NM} = \frac{\hat{Y}_{ig,NM}}{\hat{Y}_{ig}}$, respectively. The dependent variable is given by $\hat{y}_{ig} = \frac{\hat{Y}_{ig}}{\hat{L}_{ig}}$. A group is the set of full-time employees for a particular local-labor-market-skill pair. The dichotomous skill variable measures "unskilled" full-time employees vs. all others. *** indicates significance at the 1% level.

$$\ln \hat{y}_{ig} = \ln \hat{w}_{is} - \frac{1}{\kappa} \ln \hat{\pi}_{ig,NM} + \frac{1}{\kappa} \ln \hat{A}_{ig,NM},$$

providing structual justification for the 2SLS regression equation,

$$\ln \hat{y}_{ig} = \alpha_i + \beta \ln \hat{\pi}_{ig,NM} + \epsilon_{ig}, \tag{5.5}$$

where $\hat{\pi}_{ig,NM}$ is instrumented by $\sum_{s \in M} \frac{L_{igst}}{L_{igt}} \Delta[\text{IV import exposure}]_s^{\text{CHN}}$.

The instrument, $\Delta[\text{IV exposure}]_s^{\text{CHN}}$, is a valid instrument so long as changes in the technology of the non-manufacturing sector are correlated with neither the share of manufacturing employment nor the change in trade between China and the "Other" countries. Formally, the exclusion restriction is that $E[Z_{ig}\epsilon_{ig}] = 0$ so long as $E\left[\hat{A}_{ig,NM}\pi_{ig,M}\right] = 0$ and $E\left[\hat{A}_{ig,NM}\Delta[\text{IV exposure}]^{\text{CHN}}\right] = 0$.

Table 1.4 presents the estimates for $\hat{\kappa} = -\frac{1}{\hat{\beta}}$ for the period 1992-2002. My estimates range from 1.377 to 1.595 and are significantly different from zero. This result is consistent with GRY (their estimates for the U.S. range between 1.95 to 2.15 in the baseline), as well as several other studies estimating sectoral and/or occupational elasticities. While they follow different methodologies than the one described here, [2], [53], and [?] estimate parameters of productivity dispersion between 1.1 and 2.2.

In the next section, I demonstrate how a looser labor market – as from the Hartz Reforms

Table 1.4: Estimates for κ, 1992-2002

Measurement of IV uses:	Emp. Share	Earn. Share
$\hat{\kappa}$	1.595***	1.377***
	(0.184)	(0.187)
First Stage F-statistic	81.36	57.07
N	210	210
R^2	0.1739	0.1258

Notes: The independent variable for this regression is the instrument described in Equation 5.3 for $\hat{\pi}_{igs} = \frac{\hat{L}_{igs}}{L_{ig}}$ and $\hat{\pi}_{igs} = \frac{\hat{Y}_{igs}}{\hat{Y}_{ig}}$, respectively. The dependent variable is $\hat{y}_{ig}$. A group is the set of full-time employees for a particular local-labor-market-skill pair. The dichotomous skill variable measures "unskilled" full-time employees vs. all others. *** indicates significance at the 1% level.

in Germany – can deliver $\hat{\kappa}' > \hat{\kappa}$, which motivates my simulation exercise and welfare analysis for different values of κ.

5.4 Estimation of κ Capturing the Hartz Reforms

Recall that the measurement of the sector productivity heterogeneity from shape parameter κ also depends on prevailing labor market institutions, with $\kappa_{ig} \to 1 \; \forall g$ representing the case where labor cannot move across sectors. Consider two equally extreme cases that could generate this phenomenon. First, consider the case where workers have any degree of heterogeneity, including the case where all workers are identical and there is no scope for comparative advantage as workers are equally substitutable across sectors, which is the case when $\kappa \to \infty$. But if labor policy is extremely inflexible, i.e. that workers *cannot* move between sectors, my estimation procedure would estimate $\hat{\kappa}$ close 1.[24] On the other hand, consider the case where workers are extremely varied in their levels of comparative advantage, such as the specific factors model. Even if labor market policy is extremely flexible, workers do not move between sectors. In this case, I would still estimate the value of $\hat{\kappa}$ to be 1.[25] It must be that estimates of κ capture components of both skill heterogeneity and labor

[24]Or that there would be no variation to identify in the limit.

[25]In this case, factors cannot produce in the other sector and therefore earn no income in that sector. Any labor reallocation moves one-to-one with group income.

Table 1.5: Estimates for κ, Before and After Hartz I-IV

	1992-2002		2005-2012	
Measurement of IV uses:	Emp. Share	Earn. Share	Emp. Share	Earn. Share
$\hat{\kappa}$	1.595***	1.377***	4.499***	4.614***
	(0.184)	(0.187)	(0.175)	(0.185)
First Stage F-Statistic	81.36	57.07	105.70	96.52
N	210	210	210	210
R^2	0.1739	0.1258	0.2679	0.2694

Notes: The independent variable for this regression is the instrument described in Equation 5.3 for $\hat{\pi}_{igs} = \frac{\hat{L}_{igs}}{L_{ig}}$ and $\hat{\pi}_{igs} = \frac{\hat{Y}_{igs}}{\hat{Y}_{ig}}$, respectively. The dependent variable is $\hat{y}_{ig}$. A group is the set of full-time employees for a particular local-labor-market-skill pair. The dichotomous skill variable measures "unskilled" full-time employees vs. all others. *** indicates significance at the 1% level.

flexibility.

With workers moving between sectors, it is unsurprising to find an estimate of $\kappa > 1$ in the previous exercise. After 2003-2005, however, the Hartz Reforms reduced labor frictions as described in Section 2, i.e. the reforms increased the flexibility of labor to move across sectors. For a given level of worker heterogeneity, an increase in flexibility would raise my estimate for the value of κ. Re-estimating κ between 2005-2012 answers whether the Hartz Reforms had a meaningful impact on the degree to which German workers were able to maximize the value from their comparative advantage amidst changes in wages due to trade.

Table 1.5 presents the results from the estimation exercise described in the previous section for 2005-2012. For ease of comparison, the results from 1992-2002 are repeated. Using employment (earnings) shares, my estimate of $\hat{\kappa}$ rises from 1.595 (1.377) to 4.449 (4.614) when estimated over the 2005-2012 horizon (even though the period is shorter!). I interpret the rise in the parameter estimate as evidence for the effect of the Hartz Reforms on labor mobility. As previously argued, I do not suggest that the reforms increase the heterogeneity of ability in German workers, but rather they ease the transition of workers between sectors, an effect that the model would be unable to otherwise distinguish.

I acknowledge that *all* of the change I measure in κ between the two time periods may not be due to the Hartz Reforms, but I do contend that it is a good approximation. The labor market reforms in Germany were unprecedented, and the social welfare system did not see another systematic overhaul before the end of the period. The Global Financial Crisis is apparent in the data, but it does not appear to be driving the results.[26] The substantial movement out of the manufacturing sector after German reunification in 1992 should bias my estimate for κ upward during the first decade, which would mute rather than enforce my measurement for the effect of the Hartz Reforms on κ. I perform additional robustness checks in Appendix 6 to address possible concerns about the starting year and the inclusion of Eastern European trade.

6 Simulation Exercise and Welfare Analysis

Armed with my pre- and post-Hartz estimates of κ, I simulate the general equilibrium model in the post-Hartz period using the pre-Hartz parameter value. This section answers the question, "How would the gains from trade with China between 2005-2012 have been distributed in the absence of the Hartz Reforms?" I use the embedded gravity equation of the model to back out the shock in terms of exogenous changes in trade costs, then insert that shock into the structural model to run counterfactual exercies. I use the model's system of equilibrium labor conditions in order to solve for the the matrix of equilibrium wage changes, $\hat{\boldsymbol{w}}_{is}$, which I use to characterize the aggregate and group-level welfare effects.

6.1 Estimating the China Shock

In order to answer how changes in labor mobility may have affected welfare outcomes, I need a theory-consistent shock to trade costs and/or technology in order to induce the change in wages that drive the welfare results. In this section, I show how to use the gravity side of this model in order to calculate changes in trade costs, an approach that is orthogonal to

[26]Indeed, Germany has been credited for its mild response to the crisis.

the value of κ.[27]

Suppose trade costs are symmetric, i.e. that $\tau_{ijs} = \tau_{jis}\ \forall\{i,j,s\}$, and that there are no technology shocks, $\hat{T}_{is} = 1\ \forall\{i,s\}$. Then using Equation 3.9, I can back out the implied change in Germany-China trade costs from the empirical change in trade shares between any two years. Specifically, the gravity equation is given by

$$\hat{\tau}_{ijs} = \hat{\tau}_{jis} = \left(\frac{\hat{\lambda}_{ijs}\hat{\lambda}_{jis}}{\hat{\lambda}_{iis}\hat{\lambda}_{jjs}}\right)^{-\frac{1}{2\theta_s}}. \tag{6.1}$$

I measure the empirical changes in trade shares for the period between 2005 and 2011,[28] and use the θ_s values estimated in Caliendo & Parro (2015).[29] In order to isolate the Germany-China channel, I set $\hat{\tau}_{ijs} = 1$ for all pairs excluding Germany-China. Note that this assumption will tend to reduce the magnitude of my results at the group level. By shutting down all other country-pair trade cost channels, I significantly reduce the scope for relative wages to change from China's opening to the rest of the world. Recall that all of the group-specific variation in welfare relies on the change in real income coming exclusively from changes in wages (for group $\{i,g\}$ in sectors $s \in S$). However, by looking exclusively at the Germany-China channel I can be more direct about the labor market institution effects vs. trade effects.

Table 1.6 presents the results for each sector. Shocks are particularly strong in the clothing sectors and in transportation equipment, consistent with findings on the growth in the Chinese textile sector and relative robustness of the German auto industry.

[27] GRY calibrate changes in Chinese technology to match the change in trade shares between the U.S. and China. Doing so requires taking a stance on the value of κ in the baseline calibration. For reasons of comparability, they use $\kappa = 2$ for the baseline calibration and then analyze changes in κ in their counterfactuals. While they find their results are not sensitive to changes in the baseline calibration, my approach does not rely on the value of κ in order to back out the trade shock.

[28] The WIOD's last year of data is in 2011, so I choose the closest possible year to the 2012 end date.

[29] Anderson & Van Wincoop (2004) summarize existing evidence on the estimated trade elasticities across sectors, finding θ_s between 4 and 9 (σ_s between 5 and 10). As would be expected given the form of Equation 3.12, higher values of θ_s reduce the magnitude of the effects through the Arkolakis et al. (2012) portion of the equation. See Figure A.1 for the values of the individual θ_s.

Table 1.6: Gravity Model Estimates for $\hat{\tau}_{CHN,DEU,s}$

Sector	Estimated Shock
Food, Beverages, and Tobacco	0.8910
Textiles and Textile Products	0.8778
Leather and Footwear	0.8352
Wood and Products of Wood and Cork	0.9955
Pulp, Paper, Printing, and Publishing	1.0123
Coke, Refined Petroleum, and Nuclear Fuel	0.9764
Chemicals and Chemical Products	0.8886
Rubber and Plastics	0.9067
Other Non-Metallic Mineral	0.9256
Basic Metals and Fabricated Metal	0.9826
Machinery, Nec	0.9009
Electrical and Optical Equipment	0.9275
Transport Equipment	0.8581
Manufacturing, Nec; Recycling	0.9673
Aggregated Non-manufacturing Sector	0.8765

Notes: Changes in symmetric CHN-DEU trade costs as calculated in Equation 6.1.

6.2 Results

I plug the estimated changes in trade costs into the system of equations given by Equation 3.7 and solve for the counterfactual change in equilibrium wages in each sector-country pair. From the $\hat{\boldsymbol{w}}_{\boldsymbol{is}}$ matrix, I compute the model-implied $\hat{\lambda}_{iis}$ and $\hat{\pi}_{igs}$ for Germany and insert these values into Equations 3.12 and 3.13 to calculate changes in welfare for individual groups and in the aggregate, respectively.

Table 1.7 presents the results for my two estimated values for κ from Section 5 as well as results for the theoretical limits, $\kappa \to 1$ and $\kappa \to \infty$. Turning first to the overall impact of the China shock during the 2000s, in all cases the aggregate welfare implications for Germany are positive, ranging from 0.144% to 0.223% (Column 2). Despite a different approach, this finding is in the same neighborhood as Levchenko & Zhang (2012), who calculate welfare gains of 0.226% for Germany from the opening of Eastern Europe.[30] The aggregate welfare gains fall as κ rises, as discussed in Section 3.4.

[30] In their baseline using $\kappa = 2$, GRY find $\hat{W}_{US} = 0.25\%$ for $\theta_s = 5$ during a different time span.

Table 1.7: Welfare Effects of China Shock

κ	Total $\hat{W}_{DEU}$	$\prod_s \hat{\lambda}_{iis}^{-\beta_{is}/\theta_s}$	Mean$\hat{W}_{ig}$	Min$\hat{W}_{ig}$	Max$\hat{W}_{ig}$
$\to 1$	0.223	0.181	0.217	0.037	0.720
1.377	0.212	0.177	0.205	0.046	0.615
4.614	0.176	0.161	0.172	0.098	0.337
$\to \infty$	0.144	0.144	0.144	0.144	0.144

Notes: The first column displays the value of κ used for the simulation. The second column presents the total change in German welfare $100(\hat{W}_{DEU} - 1)$ as in Equation 3.13. The third columns presents the Arkolakis et al. (2012) component of the welfare change $100\left(\prod_s \hat{\lambda}_{iis}^{-\beta_{is}/\theta_s} - 1\right)$ for Germany. The third, fourth, and fifth columns present the mean $100\left(\frac{1}{G}\sum_g \hat{W}_{ig} - 1\right)$, minimum $min\ 100\left(\hat{W}_{ig} - 1\right)$, and maximum $max\ 100\left(\hat{W}_{ig} - 1\right)$ group welfare changes, respectively.

Columns 4, 5, and 6 give the mean, minimum, and maximum group welfare changes. Total labor immobility, as is the case when $\kappa \to 1$, causes groups with relatively high manufacturing production to be hit harder, with the worst-off group gaining only 0.037%. At the other extreme, when $\kappa \to \infty$ (workers are both identical and freely mobile), the mean, minimum, and maximum collapse to the same value, as would be the case in EK or Costinot et al. (2012). In this special case, the welfare changes are identical to those presented in Arkolakis et al. (2012) (Column 3).[31]

Table 1.7 also answers the original question: How would the gains from trade with China between 2005-2012 have been distributed in the absence of the Hartz Reforms? Using the pre-Hartz estimate for κ between 2005-2012 predicts larger aggregate welfare gains at the cost of greater between-group inequality (the range between the minimum and maximum group welfare gains). In particular, the worst-off group would have gained 0.046% rather than 0.098%, and the best-off would have gained 0.615% rather 0.337%. This doubling in spread would have come at the benefit of higher aggregate welfare changes, improving from 0.176% to 0.212%.

Intuitively, this result is driven by the pattern of worker selection in Germany following greater competition in manufacturing from China. Cheaper Chinese goods lowered the wages for German workers in manufacturing, leading to the least productive workers in each sector

[31]Note that κ indirectly affects the multi-sector ACR term, $\prod_s \hat{\lambda}_{iis}^{-\beta_{is}/\theta_s}$, even though the shock is constant. This is because the value of κ affects the entire matrix of country-sector wages and thereby also the expenditure shares, $\hat{\lambda}_{iis}$.

to select into their next-best sector of comparative advantage. This selection induces greater competition in the non-manufacturing sector, which lowers wages in that sector as well. In the case where frictions induce total factor immobility, wage losses are concentrated in the manufacturing sectors and workers in the non-manufacturing sector gain from lower prices. As the labor market becomes more elastic, workers can more easily reallocate from impacted sectors and therefore narrow the distribution of welfare changes. In the case of an infinitely elastic supply, the model predicts that welfare changes for all workers would be equal (as in the model of EK).

These findings are not incosistent with the result that wage inequality increased during the Hartz Reforms as in [18]. My finding is that the growing wage inequality between 2005-2012 is lower *than it would have been* without the Hartz Reforms. This result has important implications for policy responses to the increase in global trade over the last few decades. While the Hartz Reforms cannot be perfectly recreated outside of Germany, my finding suggests that labor market policy targeting intersectoral labor mobility frictions has the capacity to mitigate the losses to impacted areas.

7 Conclusion

This paper has presented a structural model with a simple mechanism through which labor market liberalization policies can affect the distribution of welfare changes stemming from trade by reducing frictions in the labor market. I use the model to evaluate how a set of labor market policies between 2003-2005 in Germany known as the Hartz Reforms affected the response of the German economy to rising manufacturing import pressure from China. Using establishment-level data from the German Federal Employment Agency, I show how the intersectoral mobility of workers rose in the period following these reforms. I use this result to motivate a counterfactual exercise where, in absence of the Hartz Reforms, labor supply curves are steeper and hinder the degree to which workers can reallocate away from falling wages in import-competing sectors. By complementing my data with trade flows from the World Input-Output Database (WIOD) and simulating the counterfactual world using the structural model, I find that the reforms shrank the counterfactual gap in welfare gains between the worst-off and best-off labor markets by more than 50%.

Chapter II: Real Exchange Rates, Income Per Capita, and Sectoral Input Shares

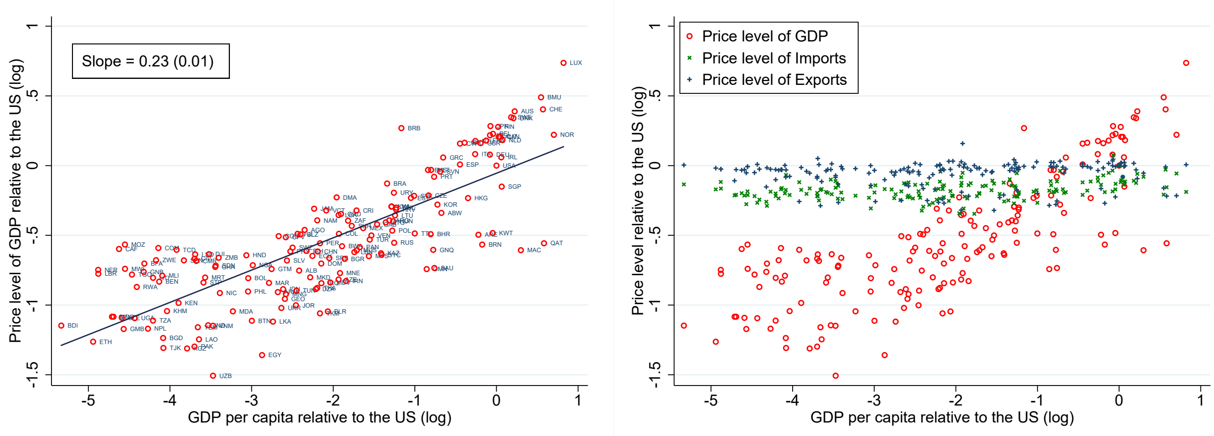
1 Introduction

Aggregate price levels are positively related to income per capita across countries, as illustrated in Figure 2.1a.[1] The leading explanation for this observation is the Balassa-Samuelson hypothesis, which postulates that productivity in tradable relative to non-tradable sectors increases with income. According to this theory, the price level is determined by the price of non-tradables, and high productivity in tradables leads to high wages and high non-tradable prices. Indeed, Figure 2.1b shows a strong correlation between GDP per capita and the aggregate price level, but not between GDP per capita and tradable prices.

[1]See Rogoff (1996) or Feenstra et al. (2015). The positive relation between relative prices and GDP per capita is often referred to as the 'Penn Effect', after Summers & Heston (1991).

Figure 2.1: Real exchange rates and GDP per capita

(a) Price level of GDP (b) Tradables and non-tradable prices



Notes: Price data is from the Penn World Table 9.0. GDP per capita at market prices is from the World Development Indicators.

In spite of its popularity, empirical evidence supporting the Balassa-Samuelson hypothesis is scarce. An important limitation is that, since sectoral productivities are rarely measured in levels, the model's predictions for relative price levels (i.e. real exchange rate levels) are hard to confront with data.[2] As a result, most of the empirical literature has focused on studying the model's predictions for the growth of the real exchange rate using proxies for sectoral productivity growth, often with mixed results.[3]

This paper evaluates an alternative mechanism linking real exchange rates to GDP per capita that relies on sectoral differences in input intensities rather than on cross-country differences in sectoral productivities, and hence can be easily quantified using data on sectoral input shares. The mechanism was first noted by Bhagwati (1984), who argued that if the tradable sector is capital intensive, the relative price of non-tradables should be higher in rich, capital-abundant countries where capital is relatively cheap. Our main contribution is to extend this idea to incorporate sectoral differences in intermediate input shares, which

[2]Sectoral productivity measures are typically available in index form only.

[3]In particular, a large literature finds that the Balassa-Samuelson model does not do well in explaining real exchange rates except in the very long run. See for example De Gregorio et al. (1994), Rogoff (1996), Tica (2006), Lothian & Taylor (2008), and Chong et al. (2012).

we show are much larger in tradable than in non-tradable sectors. The extended theory indicates that, if the cost of labor relative to the cost of intermediate inputs is higher in rich countries, so should be the relative price of non-tradables and the aggregate price level.

We quantify this mechanism by incorporating differences in input intensities across tradable and non-tradable sectors into a textbook open economy model.[4] In the model, goods and factor markets are competitive, and the price of tradables is equalized across countries. Differences in GDP per capita across countries may arise either from differences in aggregate or sector-specific productivity. The relationship between real exchange rate levels and GDP per capita is shaped by three mechanisms. First, real exchange rates are shaped by sectoral differences in intermediate input shares coupled with cross country differences in real wages, as explained above. Second, real exchange rates depend on differences in capital shares across sectors and cross-country differences in the stock of capital per capita, as proposed by Bhagwati. Crucially, since these two mechanisms depend only on sectoral factor and input intensities, and not on the relative levels of sectoral productivity, they can be quantified directly using publicly available data. Finally, real exchange rates are also shaped by cross-country differences in sectoral technology, as in the standard Balassa-Samuelson model. As highlighted above, this effect cannot be quantified directly without data on sectoral productivity levels in each country.[5]

We show that the observed differences in input shares across sectors account for about half of the elasticity of the aggregate price level with respect to GDP per capita. In particular, we write the real exchange rate of each country relative to the US as the sum of three terms that capture the mechanisms described above. Differences in intermediate input shares across tradable and non-tradable sectors imply an elasticity of the real exchange rate to GDP per capita of 0.16, more than two-thirds of the 0.23 elasticity measured in Figure

[4] See for example Obstfeld & Rogoff (1996).

[5] In turn, measures of sectoral productivity levels can only be constructed as a residual using data on sectoral relative price levels, as done by Inklaar & Timmer (2014). In contrast, our mechanism can be quantified independently of the sectoral price data.

2.1a.[6] The elasticity implied by sectoral differences in capital shares is -0.05. Contrary to Bhagwati's hypothesis, the share of capital in gross output is actually larger in non-tradable than in tradable sectors.[7] Together, the sectoral differences in input intensities generate an elasticity of 0.11, almost half the elasticity in the data. The residual component of the slope coefficient (0.12) can be attributed to differences in sectoral technologies, as in the Balassa-Samuelson model. We note, however, that this residual could be capturing other factors driving real exchange rates not included in the model, such as differences in the price of tradables across countries.[8] Our main focus is to assess how much of the observed slope between the aggregate price level and income per capita can be accounted for by the observed differences in input shares, rather than on measuring the Balassa-Samuelson effect (which is captured in our residual, potentially along with other factors).

Our proposed mechanism has strong implications for the behavior of industry-level real exchange rates. It implies that, as income increases, industry-level prices should increase relative to the aggregate price of non-tradables for industries where the share of intermediate inputs is lower than for the non-tradable sector as a whole. We find strong support for this prediction using detailed industry-level price data from the International Comparison Program (ICP). We also calibrate the model to the industry-level data and show that industry-level variation in input shares accounts for a significant fraction of the observed industry-level real exchange rates. While the Balassa-Samuelson model can rationalize these industry-level predictions, it can only do so through specific assumptions on how industry-level productivities change with income. Instead, our mechanism delivers these predictions from observed intermediate input coefficients for different industries.

We note that in our model, even under the assumption that there are no differences in sectoral technologies across countries, differences in sectoral value-added productivity across

[6]Feenstra et al. (2015) obtain similar estimates of this elasticity using data from the PWT 8.0.

[7]In contrast, the share of capital in value-added is indeed slightly larger in tradable sectors. We note, however, that real exchange rates are computed using prices of final expenditures, rather than 'value-added' prices.

[8]We extend the baseline model to allow for differentiated tradable goods in Section 5.3.4.

countries arise endogenously from sectoral differences in intermediate input shares coupled with cross-country differences in aggregate productivity. This distinction between gross-output and value-added productivity does not arise in the textbook Balassa-Samuelson model without intermediate inputs. However, given value-added productivities in each country and each sector, the two models have the same predictions for the level of the real exchange rate. We highlight two advantages of starting from gross-output, rather than from value-added production functions. First, differences in sectoral value-added productivities arise endogenously from observed intermediate input shares, so they can be quantified directly from aggregate data. Second, while sectoral differences in intermediate inputs intensities have been ignored in the literature, real exchange rate measures are typically based on data on final prices. Since final prices reflect the costs of all the inputs used in production (and not just the value added costs), incorporating intermediate inputs in the analysis makes the prices in the theory consistent with the price data.[9]

Our paper contributes to the long literature that studies the relationship between real exchange rates and GDP per capita.[10] Most of the empirical literature has looked at the relationship between productivity and real exchange rate growth, but in most cases has only found evidence of a long-run relationship such as cointegration.[11] In a recent series of papers, [?] and [?] use newly-constructed data on Price Level Indices for countries in the Euro area to show evidence supporting the Balassa-Samuelson model. Our paper complements these studies by proposing a mechanism through which differences in sectoral value-added productivities arise endogenously from the differences in input intensities across sectors, in the spirit of Jones (2011). Since the mechanism does not require data on the level of sectoral productivity, we can quantify it both in growth rates and levels for a broad set of countries.

[9] Alternatively, one can start from value-added production functions, and work with 'value-added' price data. Herrendorf et al. (2013) and Bems & Johnson (forthcoming) are two recent examples that compute 'value-added' prices.

[10] See Rogoff (1996) for a summary of the early literature on this topic, and Inklaar & Timmer (2014) for recent evidence based on the new ICP data. Bergin et al. (2006) explain why the observed relation between real exchange rate levels and GDP per capita may have changed through time.

[11] See for example Asea & Mendoza (1994), De Gregorio et al. (1994), Canzoneri et al. (1999) and Lee & Tang (2007).

Another related strand of literature uses microdata to study deviations from the law of one price for detailed goods. Boivin et al. (2012) show that violations of the law of one price arise even for reset prices using data from three online book sellers in Canada and the US. Cavallo et al. (2014) study deviations of the law of one price for online prices of identical goods sold by four large global retailers, and show that the law of one price holds very well within currency unions. Crucini and Yilmazkuday (2014) document that trade costs and good-specific markups are an important source of deviations from the law of one price for detailed tradable goods, and that these deviations tend to average out at the aggregate level. In contrast to this literature, our focus is on understanding the correlation between the aggregate price level and income per capita. To do so, we mostly abstract from deviations of the LOOP for tradable goods at the micro level, which wash out in the aggregate as noted by Crucini and Yilmazkuday (2014).[12] We instead concentrate on the relative price of non-tradable goods since its relation with income per capita is much stronger than for the purely tradable component of prices, a view supported by Berka & Devereux (2013) and Feenstra et al. (2015) among others, and by the PWT data in Figure 2.1b.

The rest of the paper is organized as follows. Section 2 uses a simple model to illustrate our main mechanisms relating real exchange rate levels to GDP per capita. Section 3 describes a more detailed model incorporating capital as a factor of production and a richer input-output structure and that will be used for our quantification. Section 4 describes the data. Section 5 presents the quantitative results, and Section 6 concludes.

2 Intermediate input shares and sectoral relative prices

This section develops a simple model to show how sectoral differences in intermediate input shares can shape the relation between real exchange rates and GDP per capita. Consider a small open economy that produces two goods, tradables and non-tradables, using labor

[12] Section 5.3.4 shows how to extend our baseline framework to allow for LOOP deviations for tradable goods.

and intermediate inputs. For the moment, assume that production does not use intermediate inputs that are produced in other sectors.[13] The price of tradables is equalized across countries and set as the numeraire, $P^T = 1$. The production function for good j is given by:

$$Y^j = Z\bar{A}^j L^{j\theta^j} M^{j1-\theta^j},$$

where L^j and M^j denote labor and intermediate inputs used in sector j, θ^j is the share of value added in gross output, and $Z \times A^j$ is a productivity term that has an aggregate and a sector-specific component. All markets are perfectly competitive, so the price of good j equals

$$P^j = \left[ZA^j\right]^{\frac{-1}{\theta^j}} W, \qquad (2.1)$$

where $A^j \equiv \bar{A}^j \theta^{j\theta^j} \left[1 - \theta^j\right]^{1-\theta^j}$. We can write the relative price of non-tradables in terms of tradables as a function of the wage as:

$$P^N = \left[A^T W^{\theta^N - \theta^T}\right]^{\frac{1}{\theta^N}},$$

where we normalized $A^N = 1$ without loss of generality.[14]

Let $P \equiv \left[P^N\right]^{\omega}$ denote the aggregate price level of GDP in terms of the tradable good, where ω is the share of non-tradables in GDP. In addition, let the lower case of a variable denote the log of the variable, with $\Delta x \equiv x - x_w$ denoting the log of a variable relative to the rest of the world. Noting that GDP per capita in this economy is given by the wage, we can write the log of the price level relative to the rest of the world, $q \equiv \Delta p$, as:

$$q = \frac{\omega}{\theta^N} \left[\Delta a^T + \left[\theta^N - \theta^T\right] \Delta gdp\right], \qquad (2.2)$$

[13]That is, non-tradables are not used in the production of tradables, and vice-versa.
[14]This equation follows from solving for Z and substituting back using equation (2.1).

where we used the equality $\Delta w = \Delta gdp$.

Equation (2.2) relates relative price levels to cross-country differences in relative sectoral productivities and cross-country differences in GDP per capita.[15] It postulates that the price level should be higher in countries that are relatively more productive in the tradable sector (high a^T). In the Balassa-Samuelson model, it is assumed that a^T is relatively high in rich countries, which leads to a positive correlation between the relative price level and GDP per capita. The equation also shows that, if the share of value-added is larger in non-tradable sectors, $\theta^N > \theta^T$, prices should be higher in countries with a high level of GDP per capita, even if there are no cross-country differences in sectoral productivity $\Delta a^T = 0$.

Of course, cross country differences in GDP per capita are endogenous, and in this model may arise from either cross-country differences in aggregate or in sectoral productivity, Z or A^j. In particular, using equation (2.1) for tradables to and substituting in (2.2) we can write:

$$q = \frac{\omega}{\theta^N}\left[\left[\theta^N - \theta^T\right]\underbrace{\left[\Delta a^T + \Delta z\right]/\theta^T}_{\Delta gdp} + \Delta a^T\right], \tag{2.3}$$

where the difference in GDP across countries is given by the term in curly brackets. Given data on Δgdp, and irrespective of whether it arises from Δa^T or Δz, we can implement equation (2.4) and ask what is the difference in price levels arising from the difference input shares. The observed differences in input shares alone imply that a log point difference in GDP per capita should result in a $\omega\left[\theta^N - \theta^T\right]/\theta^N$ log point difference in the price level. Clearly, the overall elasticity of q with respect to Δgdp will be larger if the differences in GDP per capita arise from Δa^T. The focus of this paper is to quantify the part of the elasticity

[15] The relation between relative price levels and GDP evaluated at world prices (that is, PPP adjusted GDP), $gdp^{ppp} \equiv gdp - q$, is:

$$q = \frac{\omega}{\bar{\theta}}\left[\Delta a^T + \left[\theta^N - \theta^T\right]\Delta gdp^{ppp}\right],$$

where $\bar{\theta} \equiv \omega\theta^T + \theta^N\left[1 - \omega\right]$. We evaluate this relation in our robustness exercises.

that we can directly measure using aggregate data on input intensities (i.e., the part arising from differences in input shares), rather than to estimate the elasticity of the price level arising from Δa^T vs. Δz.

Value-added production functions and mapping to the Balassa-Samuelson model

We can write the production functions in this model in value-added terms, rather than in gross-output terms. Substituting intermediate input demands into the value-added production functions, $V^j \equiv \theta^j Y^j$, we obtain

$$V^j = B^j L^j, \tag{2.4}$$

where $B^j \equiv [ZA^j]^{\frac{1}{\theta^j}}$.[16] The equation shows that even if there are no differences in gross-output productivity across sectors, $A^j = 1$, sectoral differences in value-added productivity, B^j, can arise endogenously from differences in the share of intermediate inputs in production, θ^j. The intuition for this result is that, as noted by Jones (2011), intermediate inputs deliver a multiplier similar to the multiplier associated with capital in the neoclassical growth model. If the multiplier is greater in the tradable sector, $\theta^T < \theta^N$, this implies that a given increase in aggregate productivity Z has a larger impact in tradable than in non-tradable output.

This observation makes clear that the theoretical predictions of the model for the real exchange rate are isomorphic to a Balassa-Samuelson model with production functions given by equation (2.4). We highlight two important advantages of incorporating sectoral differences in intermediate-input shares explicitly in the model. First, while sectoral differences in intermediate input intensities have been ignored in the literature, real exchange rate measures are typically based on data on final prices.[17] Since final prices reflect the costs of all the inputs used in production (and not just the costs of the value added that goes into production), incorporating intermediate inputs in the analysis makes the prices in the theory

[16]This follows from the input demands that minimize costs, $M^j = \left[\left[1 - \theta^j\right] Z\bar{A}^j \right]^{\frac{1}{\theta^j}} L^j$.

[17]An important exception is Bems & Johnson (forthcoming) who estimate of value-added real exchange rates.

consistent with the prices that we measure in the data. Second, while the Balassa-Samuelson model simply assumes how differences in sectoral productivities change with development (i.e. the model assumes a correlation between B^T/B^N and GDP per capita), these differences can also arise endogenously from differences in the intermediate input shares across sectors and differences in aggregate productivity Z across countries. Perhaps more importantly, differences in the relative level of productivity across sectors and countries are not measured by statistical agencies -i.e. neither A^T nor B^T is measured in levels- which makes it virtually impossible to directly quantify the Balassa-Samuelson hypothesis in levels. In contrast, differences in the share of intermediate inputs across sectors are easily quantifiable, so the input multiplier channel can be directly quantified. A back of the envelope calculation using equation (2.2) reveals that this channel is potentially large: using US values for $\theta^N = 0.61$, $\theta^T = 0.35$, and $\omega = 0.84$, indicates that, given relative sectoral productivities, the elasticity of the relative price level of GDP with respect to relative GDP per capita is 0.38 vs. 0.23 in the data in Figure 2.1a. The remainder of the paper measures the importance of this channel in a more detailed quantitative framework that incorporates capital as a factor of production, allows for multiple non-tradable sectors and a richer input-output structure, and allows for differences in factor shares across countries.

3 Quantitative framework

Production The production function for good j is given by:

$$Y_i^j = Z_i \bar{A}_i^j \left[L_i^{j^{1-\alpha_i^j}} K_i^{j^{\alpha_i^j}} \right]^{\theta_i^j} \left[\left[M_i^{T,j} \right]^{\sigma_i^{Tj}} \left[M_i^{N,j} \right]^{\sigma_i^{Nj}} \right]^{\left[1-\theta_i^j\right]}, \tag{3.1}$$

where Y_i^j, L_i^j and K_i^j denote gross output, employment, and capital in country i and sector j, $M_i^{T,j}$ is the quantity of tradable intermediate inputs used in the production of sector j, and $M_i^{N,j}$ is a composite of non-tradable goods used in the production of j. θ_i^j and α_i^j denote the share of value-added in gross output and the share of capital in value-added respectively.

Note that production in sector j can potentially use both tradable and non-tradable inputs. The share of tradable and non-tradable inputs used in sector j is given by $\sigma_i^{Tj} \times \left[1-\theta_i^j\right]$ and $\sigma_i^{Nj} \times \left[1-\theta_i^j\right]$ respectively, where $\sigma_i^{Tj} + \sigma_i^{Nj} = 1$. As in the previous section, $Z_i \times \bar{A}_i^j$ is a productivity term that has an aggregate and a sector-specific component.

Prices Perfect competition implies that the price of good j is given by:

$$P_i^j = \bar{\gamma}_i^j W_i^{\left[1-\alpha_i^j\right]\theta_i^j} R_i^{\alpha_i^j \theta_i^j} \left[\left[P_i^T\right]^{\sigma_i^{Tj}} \left[P_i^N\right]^{\sigma_i^{Nj}}\right]^{\left[1-\theta_i^j\right]} / \left[\bar{A}_i^j Z_i\right],$$

where W_i and R_i denote the wage and the rental rate of capital in country i in units of the tradable good and where $\bar{\gamma}_i^j$ is a constant.[18,19] Taking logs we can write the log-price of good j as:

$$p_i^j = log\bar{\gamma}_i^j - \bar{a}_i^j + \theta_i^j w_i + \alpha_i^j \theta_i^j \left[r_i - w_i\right] + \sigma_i^{Nj} p_i^N \left[1-\theta_i^j\right] - z_i, \qquad (3.2)$$

where p_i^j is the (log of the) price for good j, and $p_i^T = 0$ given the choice of the numeraire. Let ω_i^j denote the share of non-tradable good j in the non-tradable sector, so that $\sum_{j=1}^J \omega_i^j = 1$. We can write the log of the non-tradable price index as:

$$p_i^N \equiv \sum_{j=1}^{J} \omega_i^j p_i^j.$$

In combination with (3.2) this implies

$$p_i^N = \frac{\bar{\bar{a}}_i^T}{\bar{\theta}_i^N} + \frac{\theta_i^N - \theta_i^T}{\bar{\theta}_i^N} w_i + \frac{\alpha_i^N \theta_i^N - \alpha_i^T \theta_i^T}{\bar{\theta}_i^N}\left[r_i - w_i\right], \qquad (3.3)$$

[18]Note that we have assumed that the price of capital R_i is country specific. We evaluate the implications of assuming that capital is internationally mobile (and its price is equalized across countries) in Section 5.3.5.

[19]The constant is given by $\left[\bar{\gamma}_i^j\right]^{-1} \equiv \left[\left[1-\alpha_i^j\right]^{1-\alpha_i^j} \alpha_i^{j\,\alpha_i^j}\right]^{\theta_i^j} \theta_i^{j\,\theta_i^j} \left[1-\theta_i^j\right]^{1-\theta_i^j} \left[\prod_{j'} \sigma_i^{j'j\,\sigma_i^{j'j}}\right]^{\left[1-\theta_i^j\right]}$.

where $\bar{\bar{a}}_i^T \equiv log\left[\bar{\gamma}_i^N/\bar{\gamma}_i^T\right] + \bar{a}_i^T - \bar{a}_i^N$ and $\bar{\theta}_i^N \equiv \theta_i^N + \sigma_i^{TN}\left[1-\theta_i^N\right] + \sigma_i^{NT}\left[1-\theta_i^T\right]$.[20]

Relative prices and GDP per capita We are interested in understanding the relation between the aggregate price level and GDP per capita. Let $1-\bar{\alpha}_i \equiv W_i L_i/GDP_i$ and $\bar{\alpha}_i \equiv R_i K_i/GDP_i$ denote the aggregate labor share and capital share in country i, where $L_i = \sum_j L_i^j$ and $K_i = \sum_j K_i^j$ are the aggregate labor supply and the aggregate capital stock. Factor prices are related to factor supplies by:

$$\frac{R_i}{W_i} = \frac{\bar{\alpha}_i}{1-\bar{\alpha}_i}\frac{L_i}{K_i}.$$

We can then write the (log) price of non-tradables in terms of tradables as:

$$p_i^N = \frac{\theta_i^N - \theta_i^T}{\bar{\theta}_i^N} gdp_i + \frac{\alpha_i^T\theta_i^T - \alpha_i^N\theta_i^N}{\bar{\theta}_i^N} k_i + \frac{\bar{\bar{\bar{a}}}_i^T}{\bar{\theta}_i^N}, \tag{3.4}$$

where gdp_i is the log of GDP per capita measured in units of the tradable good, k_i is the log of the capital-labor ratio in the economy, and $\bar{\bar{\bar{a}}}_i^T$ captures country-specific productivity differences across the two sectors.[21] Equation (3.4) links the price of non-tradables to GDP per capita and the capital-labor ratio in the economy. The equation shows that, if the share of intermediate inputs in gross output is relatively high in the tradable sector, $\theta_i^N > \theta_i^T$, the price of non-tradables increases with GDP per capita. Intuitively, as productivity grows, labor gets more expensive relative to intermediate inputs, which increases the price in sectors that use labor more intensively. In addition, if the non-tradable sector uses capital more intensively, $\alpha_i^N\theta_i^N > \alpha_i^T\theta_i^T$, the price of non-tradables decreases with the capital-labor ratio in the economy, k_i.

[20]Note that, in contrast to the simple model from Section 2, the elasticity of p_i^N with respect to w_i now depends on the input-output coefficients σ_i^{TN} and σ_i^{TN}.

[21]That is, $k_i \equiv log\frac{K_i}{L_i}$, $gdp_i \equiv log\frac{GDP_i}{L_i}$, and $\bar{\bar{\bar{a}}}_i^T \equiv \bar{\bar{a}}_i^T + log\left[\bar{\alpha}_i^{\alpha_i^N\theta_i^N - \alpha_i^T\theta_i^T}\left[1-\bar{\alpha}_i\right]^{\theta_i^N\left[1-\alpha_i^N\right]-\left[1-\alpha_i^T\right]\theta_i^T}\right]$.

Decomposing real exchange rates We now decompose the determinants of bilateral real exchange rates in the model. To facilitate comparisons with the data in Figure 2.1a we define the real exchange rate as the price level of GDP in each country relative to the US. The log of the price level of GDP in country i is defined as $p_i = \omega_i^N p_i^N$, where ω_i^N denotes the share of non-tradables in country i's GDP. Letting $\Delta x_i \equiv x_i - x_{us}$ denote the log difference of a variable relative to the US, we can write the log-price of GDP in country i relative to the US, $q_i \equiv \omega_i^N \Delta p_i^N$, as:[22]

$$q_i = \underbrace{\omega_i^N \frac{\theta_i^N - \theta_i^T}{\bar{\theta}_i^N} \Delta gdp_i}_{\text{'Intermediate Inputs'}} + \underbrace{\omega_i^N \frac{\alpha_i^T \theta_i^T - \alpha_i^N \theta_i^N}{\bar{\theta}_i^N} \Delta k_i}_{\text{'Capital-Deepening'}} + \underbrace{\omega_i^N \Delta a_i^T}_{\text{'Residual'}}, \tag{3.5}$$

where

$$\Delta a_i^T \equiv \frac{\bar{\bar{\bar{a}}}_i^T}{\bar{\theta}_i^N} - \frac{\bar{\bar{\bar{a}}}_{us}^T}{\bar{\theta}_{us}^N} + \left[\frac{\alpha_i^T \theta_i^T - \alpha_i^N \theta_i^N}{\bar{\theta}_i^N} - \frac{\alpha_{us}^T \theta_{us}^T - \alpha_{us}^N \theta_{us}^N}{\bar{\theta}_{us}^N} \right] k_{us} + \left[\frac{\theta_i^N - \theta_i^T}{\bar{\theta}_i^N} - \frac{\theta_{us}^N - \theta_{us}^T}{\bar{\theta}_{us}^N} \right] gdp_{us}.$$

Equation (3.5) decomposes cross-country differences in the price level into three terms. The first term, labeled 'Intermediate Inputs', captures the differences in aggregate price levels that arise from sectoral differences in intermediate input shares coupled with differences in GDP per capita across countries. It states that, if the share of intermediate inputs is larger in the tradable sector, $\theta_i^N > \theta_i^T$, countries with higher GDP per capita should have a higher price level. This effect is the main focus of this paper and is measured in the quantitative section below.

The second term, labeled 'Capital-Deepening', captures how cross-country differences in the capital-labor ratio affect relative price levels, and states that the relative price level should increase with the capital-labor ratio if the production of tradables is more intensive in capital $\alpha_i^T \theta_i^T > \alpha_i^N \theta_i^N$. This mechanism was first highlighted by Bhagwati (1984). Note that

[22] Note that, in line with the price level index estimates of the ICP, our relative price level focuses on weighted averages of relative price differences ($\sum_j \omega_i^j \left[p_i^j - p_{us}^j \right]$) as opposed to differences in the weighted average or price levels ($\sum_j \omega_i^j p_i^j - \sum_j \omega_{us}^j p_{us}^j$).

if the share of value-added in the tradable sector is low enough, the price level can actually decrease with the capital-labor ratio even if the capital share in value-added is higher in the tradable sector $\alpha_i^T > \alpha_i^N$. Indeed, in contrast to what is postulated in Bhagwati (1984), $\alpha_i^T \theta_i^T < \alpha_i^N \theta_i^N$ for the vast majority of countries for which input-output data are available.[23]

Finally, the 'Residual' captures differences in the price level that arise from cross-country differences in sectoral technology, which encompass both cross-country differences in the relative level of sectoral productivity $\bar{A}_i^T$, as in the Balassa-Samuelson model, and cross-country differences in sectoral factor shares α_i^j, θ_i^j, and $\bar{\theta}_i^N$. These terms cannot be measured directly from national accounts data, as it requires not only data on the relative level of sectoral productivity, $\bar{A}_i^T$, but also data on the level of US GDP measured in units of tradables (which requires taking a stand on the level of the dollar price of tradable goods).[24] Note that the residual also captures differences in the aggregate capital share in the economy $\bar{\alpha}_i$. These differences may arise even if the sectoral capital shares are identical across countries, $\alpha_i^j = \alpha^j$, when there are differences in capital intensities across sectors and cross-country differences in the sectoral composition of the economy.[25]

[23]Note that the production function in equation (3.1) does not separate land from other forms of capital. If the price of land is higher in rich countries, and land is used more intensively in the production of non-tradable goods, this would be an additional channel through which sectoral differences in input shares generate a positive relation between price levels and income per-capita, reinforcing the mechanisms in this paper. We do not to include land as a separate input of production since sectoral land shares and prices for multiple countries are hard to come by. Valentinyi & Herrendorf (2008) estimate sectoral factor shares for the US, and find that in the share of land is about 0.04 for tradable vs. 0.05 for non-tradable sectors, which suggest that the quantitative effects of this mechanism may be limited. Note that separating land from the other forms of capital would not affect the measurement of the 'intermediate inputs' channel in equation (3.5) (since separating land from other forms of capital would not affect our estimates of the value added shares θ_i^j).

[24]In addition, as mentioned above and highlighted again in Section 5.3.4, the composition of the residual depends on how the model is closed on the demand side.

[25]If factors are sector-specific and preferences are not homothetic, the price of nontraded goods may rise with GDP if the demand for nontraded goods rises with income. This 'Linder' mechanism was studied by Bergstrand (1991), and is reflected here in the fact that the aggregate labor share $1 - \bar{\alpha}^i$ may increase with income if higher income countries consume more non-tradables and the labor share is higher in the non-tradable sector. Such mechanism would also be part of our residual. While quantifying this mechanism its outside the scope of this paper, Appendix Figure E.1 shows no systematic relation between the aggregate labor share and GDP per capita in the PWT data (see also Gollin (2002)).

Real exchange rates and productivity differences: Equation (3.5) expresses cross-country differences in price levels in terms of differences in observable variables, Δgdp_i and Δk_i, and a residual term that captures unobserved differences in sectoral productivity levels, potentially along with other factors omitted from the model. Clearly, the differences Δgdp_i and Δk_i, are endogenous, and may arise from cross-country differences in aggregate or in sectoral productivities, Z or A^j. This subsection makes two additional assumptions that allow us to rewrite equation (3.5) in terms of productivity differences, like we did in Section 2. In particular, if input shares are common across countries, $\theta_i^j = \theta^j$ and $\sigma_i^j = \sigma^j$, and the share of capital in value added is common across countries and sectors, $\alpha_i^j = \alpha$, we can rewrite (3.5) as:[26]

$$q_i = \underbrace{\frac{\bar{\theta}^N}{\bar{\theta}}\Delta\bar{a}_i^T}_{\text{Balassa-Samuelson.}} + \frac{\omega^N}{\bar{\theta}^N}\left[\theta^N - \theta^T\right]\underbrace{\left[\underbrace{\frac{\bar{\theta}^N}{\bar{\theta}}\Delta z_i}_{\text{Aggregate}} + \underbrace{\frac{\bar{\theta}^N}{\bar{\theta}}\left[\theta^N + \sigma^{TN}\left[1-\theta^N\right]\right]\Delta\bar{a}_i^T}_{\text{Interaction}}\right]}_{\Delta[gdp_i - \alpha k_i]}. \tag{3.6}$$

Equation (3.6) writes cross-country differences in price levels in terms of three terms capturing: (i) cross-country differences in sectoral productivity levels (i.e. the Balassa Samuelson effect), (ii) differences in aggregate productivity, (labeled 'Aggregate'), and (iii) the indirect effect of sectoral productivity differences that arises from their interaction with sectoral differences in input shares, (labeled 'Interaction'). The input channel highlighted in this paper is given by from the sum of the last two terms, as the equation also shows that differences in 'value-added TFP', $\Delta\left[gdp_i - \alpha k_i\right]$, arise both from differences in aggregate and sectoral productivities, Δz_i and $\Delta\bar{a}_i^T$.

3.1 Industry-level real exchange rates

We now derive the model's implications for industry-level real exchange rates. From equations (3.2) and (3.4) we can write the price of any non-tradable good j as:

[26] See the Online Appendix for a derivation.

$$p_i^j = \beta_i^{gdp,j} gdp_i + \beta_i^{k,j} k_i + a_i^j,$$

with

$$\beta_i^{gdp,j} \equiv \left[\theta_i^j - \theta_i^N\right] \left[1 - \sigma_i^{NN} \frac{\theta_i^N - \theta_i^T}{\bar{\theta}_i^N}\right] - \left[\sigma_i^{NN} - \sigma_i^{Nj}\right] \left[1 - \theta_i^j\right] \frac{\theta_i^N - \theta_i^T}{\bar{\theta}_i^N} + \frac{\theta_i^N - \theta_i^T}{\bar{\theta}_i^N},$$

and

$$\beta_i^{k,j} \equiv \alpha_i^j \theta_i^j + \sigma_i^{Nj} \left[1 - \theta_i^j\right] \frac{\alpha_i^N \theta_i^N - \alpha_i^T \theta_i^T}{\bar{\theta}_i^N}.$$

The log price in industry j relative to the US (i.e. the industry-level real exchange rate) is:

$$q_i^j = \underbrace{\beta_i^{gdp,j} \Delta gdp_i}_{\text{'Intermediate Inputs'}} + \underbrace{\beta_i^{k,j} \Delta k_i}_{\text{'Capital-Deepening'}} + \underbrace{\Delta a_i^j}_{\text{'Residual'}} \tag{3.7}$$

Equation (3.7) states that the slope of the industry-level real exchange rate with respect to GDP should increase with the share of value-added in the industry θ_i^j; a prediction we verify in Section (5.2). Finally, we can write the price of non-tradable good j relative to the average price of non-tradables, relative to the US as:

$$\Delta \left[p_i^j - p_i^N\right] = \underbrace{\left[\beta_i^{gdp,j} - \beta_i^{gdp}\right] \Delta gdp_i}_{\text{'Intermediate Inputs'}} + \underbrace{\bar{\beta}_i^{k,j} \Delta k_i}_{\text{'Capital-Deepening'}} + \underbrace{\Delta a_i^j}_{\text{'Residual'}} \tag{3.8}$$

with $\bar{\beta}_i^{k,j} \equiv \frac{\theta_i^N - \theta_i^j}{\bar{\theta}_i^N} \left[\alpha_i^N \left[\sigma_i^{TN} + \sigma_i^{NT} \left[1 - \theta_i^T\right]\right] + \alpha_i^T \theta_i^T \sigma_i^{NN}\right]$. Equation (3.8) states that, as GDP per capita grows, all else equal, industry-level prices will rise relative to the price of non-tradables in industries where the share of intermediate inputs is relatively high, $\theta_i^j < \theta_i^N$.[27]

[27]Clearly, if $\sigma_i^{NN} = \sigma_i^{Nj}$, $\beta_i^{gdp,j} > \beta_i^{gdp}$ only if $\theta_i^j > \theta_i^N$. More generally this relation will also depend the degree to which industry-level inputs are non-tradable, σ_i^{Nj}.

4 Data

To evaluate the relation between relative prices and GDP per capita derived in equations (3.5), (3.7), and (3.8) we need data on relative price levels, GDP per capita, and the stock of capital per capita across countries. We also need to assign values to the share of value-added in gross output for each country and sector, θ_i^j, the labor share in each country and sector, $1-\alpha_i^j$, the intermediate inputs shares, $\sigma_i^{j'j}$, and the share of non-tradables in GDP, ω_i^N.

Relative price levels, GDP per capita, and capital-labor ratios: We take GDP per capita at market prices from the World Development Indicators Tables (WDI). Data on relative prices come from the Penn World Table 9.0 (PWT). Our baseline relative price measure is the price level index of GDP relative to the US, which is variable PL_GDP^o in the PWT.[28] We focus on a subsample of 168 countries for which we have data in both the PWT and WDI. We construct GDP per capita at PPP dollars from the PWT by taking the ratio of real GDP at constant 2011 national prices (variable $RDGP^{NA}$ in the PWT) to population. For the stock of capital per capita, we use the capital stock in PPP dollars (variable RK^{NA}). When looking at growth, we compute the growth rates of these per capita variables. We complement these data with the benchmark ICP 2011 data containing sector-specific price level indices and expenditure shares.[29]

Input shares and sectoral weights: Input-output coefficients come from the OECD Inter-Country Input-Output (ICIO) Tables, which provide input-output tables for 61 countries between 1995-2011. We classify sectors in the ICIO and the ICP into tradables and non-tradables following Crucini et al. (2005).[30] We compute θ_i^j as the ratio of value-added to gross output in each sector, and the parameters $\sigma_i^{j'j}$ as the ratio of the value of inputs

[28]See Feenstra et al. (2015) for a description of the new PWT.

[29]While the benchmark PLIs in the detailed ICP data are defined relative to the world, we divide by the US PLIs to work with price indices of consumption relative to the US.

[30]See Table E.1 in the Appendix.

from sector j' to the total value of inputs used in sector j. For the countries for which the ICIO data is not available, we assign the parameter values of the average ICIO country.

Unfortunately, the shares of labor compensation in value-added, $1-\alpha_i^j$, are not directly observable in the ICIO tables. In particular, I-O tables report the share of compensation to employees relative to value-added for each sector. It is well known that compensation to employees understates labor compensation as it does not include payments to self-employed workers.[31] The PWT adjusts the labor income of employees to account for the income of self-employed workers to obtain an aggregate measure of the labor share. We follow this approach and rescale the sectoral ratios of compensation to employees to value-added that we observe in the ICIO to match the aggregate labor shares reported in the PWT. In particular, for each country in the ICIO we compute

$$1-\alpha_i^j = \frac{\text{Comp. to employees}_i^j}{\text{Value added}_i^j} \times \frac{\text{Labor comp.}_i/\text{Value added}_i}{\text{Comp. to employees}_i/\text{Value added}_i}, \tag{4.1}$$

where the sectoral and aggregate ratios of compensation to employees to value-added come from the ICIO, and the aggregate ratio of labor compensation to value-added is obtained from the PWT. For countries not available in the ICIO tables, we impute the cross-country average of the observed θ_i^j, $\sigma_i^{j'j}$ and compensation-to-employees-to-value-added ratio, and use equation (4.1) to obtain sectoral measures of the labor share that are consistent with the PWT. In all cases, we use the shares as measured in 2011. The industries in ICIO are mapped to the industries in the ICP program with the concordance in Appendix Table E.1.

Appendix Table E.2 reports the share of value-added in gross output, θ_i^j, for the countries in our sample. Appendix Table E.4 shows the share of tradable intermediate inputs relative to total intermediate inputs used in each sector. Non-tradable sectors are significatively more labor intensive than tradable sectors for every country in the sample. They also use relatively fewer tradable intermediate inputs than the tradable sectors. For the average country, the share of value-added in gross output in tradable sectors is about half than in

[31] See Gollin (2002) and Feenstra et al. (2015).

the non-tradable sectors (0.33 vs 0.54). This is consistent with the finding of Johnson & Noguera (2017), who show that the value added content of trade has been falling dramatically, especially in manufacturing sectors.

Finally, we compute the share of tradables in GDP, $1-\omega_i^N$, as the ratio of value-added in the tradable sectors to total value-added. We use value-added data evaluated at *producer's prices* from the ICIO Tables. As discussed in Appendix E.5, by evaluating output at producer prices, we do not include distribution margins into the price of tradable, and prevent overstating the true share of tradable on the price index. Appendix Table E.5 reports the division of the ICIO industries into tradables and non-tradable sectors. Within the non-tradable sector, industry-specific ω_i^j's are computed as the ratio value-added between industry j to total value-added in the non-tradable sector.

5 Quantitative results

This section uses the framework in Section 3 to disentangle the sources of the cross-country relation between real exchange rate levels and GDP per capita. First, we use equation (3.5) to evaluate how much of the observed differences in price levels across countries can be accounted for by sectoral differences in input shares coupled with cross-country differences in GDP per capita. Second, we use equations (3.7) and (3.8) to test the industry-level predictions of this mechanism. Third, we show that the results of this section are unchanged if we instead focus on the relation between price levels and GDP per capita measured at PPP prices, the relation between the growth of the price level and real GDP per capita across countries, in a version of the model where tradable goods are differentiated across countries, or if we assume that capital is fully mobile across countries.

5.1 Price levels and GDP per capita

We first decompose the relation between aggregate price levels and GDP per capita following the decomposition in Section 3. In particular, for each country i, we compute the terms labeled 'Intermediate Inputs' and 'Capital-Deepening' in equation (3.5), given by $\omega_i^N \left[\theta_i^N - \theta_i^T\right] / \bar{\theta}_i^N \Delta gdp_i$ and $\omega_i^N \left[\alpha_i^T \theta_i^T - \alpha_i^N \theta_i^N\right] / \bar{\theta}_i^N \Delta k_i$ respectively. Subtracting these two terms from the observed relative price levels we can obtain the residual.

Figure 2.2 shows the results of this decomposition by plotting the 'Intermediate Inputs' and 'Capital-Deepening' terms along with the relative price levels observed in the data.[32] The relation between aggregate price levels and GDP per capita can be mostly attributed to sectoral differences in intermediate inputs shares, captured by the term labeled 'Intermediate Inputs'. This term gives an elasticity of the relative price level with respect to GDP per capita of 0.16, more than two thirds of the 0.23 aggregate elasticity observed in the data. In contrast, sectoral differences in the share of capital in gross output, captured by the 'Capital-Deepening' term, generate a small but negative elasticity of the price to GDP per capita of -0.05. This is due to the fact that, in contrast to the postulate of Bhagwati (1984), in the data the share of capital in gross output is higher in non-tradable sectors, that is, $\alpha_i^T \theta_i^T < \alpha_i^N \theta_i^N$, even though $\alpha_i^T > \alpha_i^N$. Together, these two terms generate a slope of 0.11, about half of the elasticity observed in the data. Appendix Figure E.2 plots the residual, which among other factors captures country specific differences in sectoral productivity as in the 'Balassa-Samuelson' model. This term gives an elasticity of the price level to GDP per capita of 0.12.[33]

In our model, differences in price levels across countries arise from cross-country differences in the price of non-tradable goods. In the Online Appendix we show that decomposition in terms of non-tradables is similar to our main decomposition: differences in input intensi-

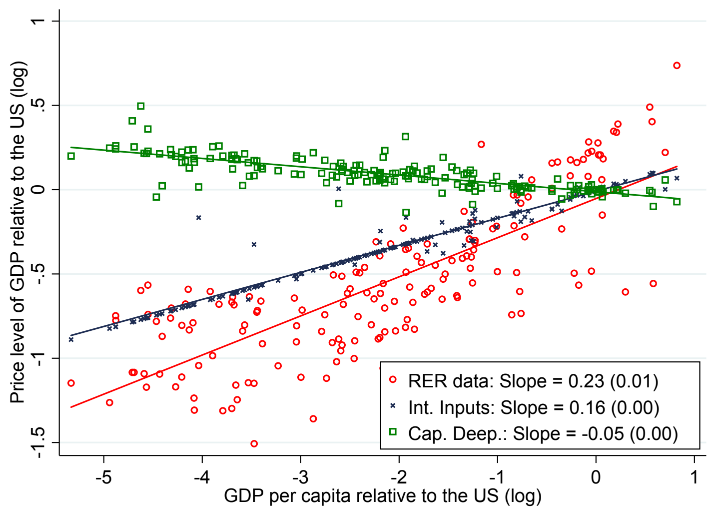
[32] To prevent cluttering the figure, the residual term is plotted separately in Appendix Figure E.2.

[33] Note that while the 'Intermediate Input' term produces a relation between the price level and GDP per capita, the relation between prices and GDP per capita in the data is not perfect, indicating that there are other factors unrelated to differences in GDP per capita that can drive differences in price levels.

ties (i.e. the combination of the 'Intermediates' and 'Capital' slopes) account for about half of the slope of the relation between non-tradable prices and GDP per capita.

How much of the observed variation in our decomposition arises from by cross-country differences in input and factor shares? In the Online Appendix we show that there is little correlation between the coefficients θ^N, θ^T, and $\bar{\theta}^N$ and GDP per capita. We also show that the relation between the 'Intermediate Inputs' and 'Capital-Deepening' terms and GDP per capita is barely affected if we instead recompute the terms in our decomposition from equation (3.5) under the assumption that all input and factor shares are common across countries, and equal in value to that of the median country.

Figure 2.2: Real exchange rate decomposition



Notes: This figure plots the relation between the log of the price level of each country relative to the US and the log of GDP per capita relative to the US. 'RER data' refers to the relative price of GDP relative to the US obtained from the PWT 9.0, already depicted in Figure 2.1a. 'Int. Inputs' and 'Cap. Deep.' are the relative prices implied by the terms labeled 'Intermediate Inputs' and 'Capital-Deepening' in equation (3.5).

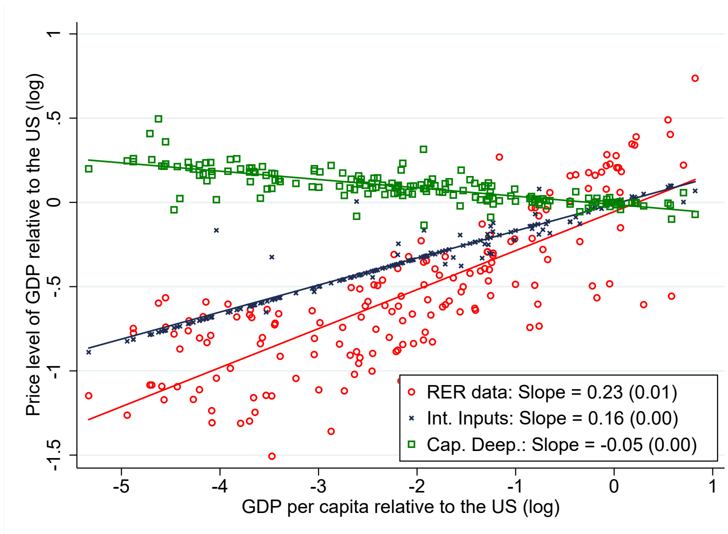
5.1.1 Price levels and relative productivities

As noted throughout the paper, the advantage of the decomposition in (3.5) vs. that in (3.6) is that cross-country differences in GDP per capita and capital per worker are observable, whereas differences in sectoral productivity levels are not. In fact, cross-country differences in sectoral productivity levels can only be computed using the data on cross-country relative price levels that we are trying to explain. This section uses the stronger assumptions imposed for deriving equation (3.6) to gauge the importance of cross-country differences in sectoral vs. aggregate productivities for aggregate price levels. As noted above, these stronger assumptions do not substantially alter the results of our main decomposition.

We calibrate the aggregate and sectoral productivities under two alternative exercises. In the first exercise, we back out cross-country differences in sectoral productivities from data on relative prices. In particular, we calibrate $\Delta\bar{a}_i^{T1}$ and Δz_i^1 to exactly match data on value added TFP and real exchange rate levels using equations (3.6) and $\Delta\left[gdp_i - \alpha k_i\right] = \frac{\bar{\theta}^N}{\bar{\theta}}\Delta z_i^1 + \frac{\left[\theta^N + \sigma^{TN}\left[1-\theta^N\right]\right]}{\bar{\theta}}\Delta\bar{a}_i^{T1}$. By construction, plugging these values of $\Delta\bar{a}_i^{T1}$ and Δz_i^1 back into equation (3.6) will exactly reproduce the differences in price levels observed in the data. The goal of this exercise is to decompose these differences into the different terms that compose equation (3.6).

For our second exercise, we assume that there are no differences in sectoral productivities across countries, $\Delta a_i^{T2} = 0$, and calibrate cross-country differences in aggregate productivity to match the observed differences in value added TFP, $\Delta z_i^2 \equiv \frac{\bar{\theta}}{\bar{\theta}^N}\Delta\left[gdp_i - \alpha k_i\right]$. We then evaluate (3.6) under Δz_i^2 and $\Delta a_i^{T2} = 0$. This exercise answers: how much of the observed relation between prices and GDP per capita can be accounted for in a model where sectors only differ in their input shares, and countries only differ in their aggregate productivities?

Figure 2.3: Real exchange rate and productivity differences



Notes: This figure plots the relation between the log of the price level of each country relative to the US and the log of GDP per capita relative to the US. 'RER data' refers to the relative price of GDP relative to the US obtained from the PWT 9.0, already depicted in Figure 2.1a. "Exercise 1: Aggregate" and "Exercise 1: Interaction" report the values of the terms labeled 'Aggregate' and 'Interaction' in equation (3.6) when evaluated at Δz_i^1 and $\Delta a_i^{T_1}$. "Exercise 2: Aggregate+Interaction" reports the value of (3.6) evaluated at Δz_i^2 and $\Delta a_i^{T_2}$.

Figure 2.3 plots the results of these two exercises. The first exercise shows that roughly half of the intermediate input channel highlighted in this paper comes from the interaction between aggregate productivity differences and sectoral differences in intermediate input shares (i.e. the term labeled 'Aggregate', which generates a slope of 0.043), while the other half comes from the interaction between sectoral productivity differences and intermediate input shares (i.e. the term labeled 'Interaction', which generates a slope of 0.053). The residual in this exercise is fully attributed to the direct effect of sectoral productivity differences (i.e. the Balassa-Samuelson effect).

The second exercise underscores that a model where sectors only differ in their input shares and countries only differ in their aggregate productivities can account for almost half of the slope between relative prices and relative GDP per capita, provided that the aggregate productivity differences are calibrated to match the observed differences on value added TFP. Note that by construction, the price differences generated in this exercise are exactly equal to those generated by adding up the 'Aggregate' and 'Interaction' terms from exercise 1, as both exercises all calibrated to match the data on $\Delta\left[gdp_i - \alpha k_i\right]$. This highlights that, given data on the differences Δgdp_i and Δk_i, specifying the source of these differences is inconsequential for the measurement of the intermediate input channel in this paper.

5.2 Industry-level real exchange rates

The mechanism highlighted in this paper makes sharp predictions for the behavior of industry-level relative prices. There is wide variation in the share of intermediate inputs across non-tradable industries. Appendix Table E.2 shows the share of value added in gross output for the countries in ICIO for 7 non-tradable sub-sectors for which the ICP reports detailed price indexes.[34] The share of intermediate inputs in Education, Health, and Recreation is lower than for the non-tradable sector as a whole, and is higher in Transport, Communication, and Restaurants. An implication that can be gleaned from equation (3.7) is that the slope of the price level of an industry with respect to GDP per capita should be larger the higher is the share of value-added in the industry (i.e. the higher is θ_i^j).

We first evaluate this prediction by running a regression of industry-level real-exchange rates on relative GDP per capita and an interaction of GDP per capita with the value-added share of the sector θ_i^j.[35] We expect the coefficient on the interaction term to be positive: the slope of the of the industry-level real exchange rate should be higher in industries for which the share of value-added is high (and the share of intermediate inputs is low). Table 2.1 supports this result. The first column shows a significant positive relation between the industry-level real exchange rates and GDP per capita, similar in magnitude to the

[34]See Table E.1 for our concordance. Appendix Table E.2 also reports these shares for each country in our sample.

[35]More precisely, in our baseline regression in Column 2 of Table 2.1 we estimate:

$$q_i^j = \alpha + \beta_1 \Delta gdp_i + \beta_2 \left[\theta_i^j \times \Delta gdp_i\right] + \beta_3 \theta_i^j + \varepsilon_i^j.$$

where we obtain the industry specific value-added shares θ_i^j by matching the expenditure categories in the ICP data from which the q_i^j's are obtained to the industries in the Input-Output Tables manually, as described in Appendix Table E.1.

Table 2.1: Industry level relative prices and sectoral input shares

Dep var: q_i^j	(1)	(2)	(3)	(4)
Δgdp_i	0.235***	0.241***		0.419***
	(0.0163)	(0.0163)		(0.0237)
$\theta_i^j \times \Delta gdp_i$		0.676***	0.667***	0.429***
		(0.0694)	(0.0643)	(0.0859)
θ_i^j		-0.906***	-0.974***	0.615**
		(0.171)	(0.152)	(0.297)
R-squared	0.266	0.476	0.630	0.775
Observations	1,127	1,127	1,127	399
CTY FE	No	No	Yes	No
IND FE	No	No	No	Yes

Notes: Robust standard errors clustered at the country level in parentheses. ***: significant at 1%; **: significant at 5%; *: significant at 10%.

aggregate slope in Figure 2.1a. The second column adds the interaction of GDP per capita and the sectoral value-added share. The coefficient on the interaction term is positive and strongly statistically significant, in line with the predictions of our mechanisms. Moreover, the R-squared of the regression increases from 0.266 to 0.476 once we add the interaction term, indicating that sectoral input shares are important for understanding the variation in industry-level prices. Column 3 adds country-level fixed effects, so that the interaction term is identified from the variation in value-added shares across industries within countries, and shows that the interaction terms is very similar under this specification. Finally, the last column includes industry-level fixed effects.[36] We continue to find a positive and significant coefficient in this specification. We conclude that the reduced form evidence supports the notion that sectoral differences in intermediate input shares shape the relation between real exchange rates and GDP per capita.

An obvious challenge with our estimates in Table 2.1 is that we cannot control for industry-level productivity differences across non-tradable sectors. This issue could be problematic if the industries with the higher use of intermediate inputs (lower θ_i^j) happen to be

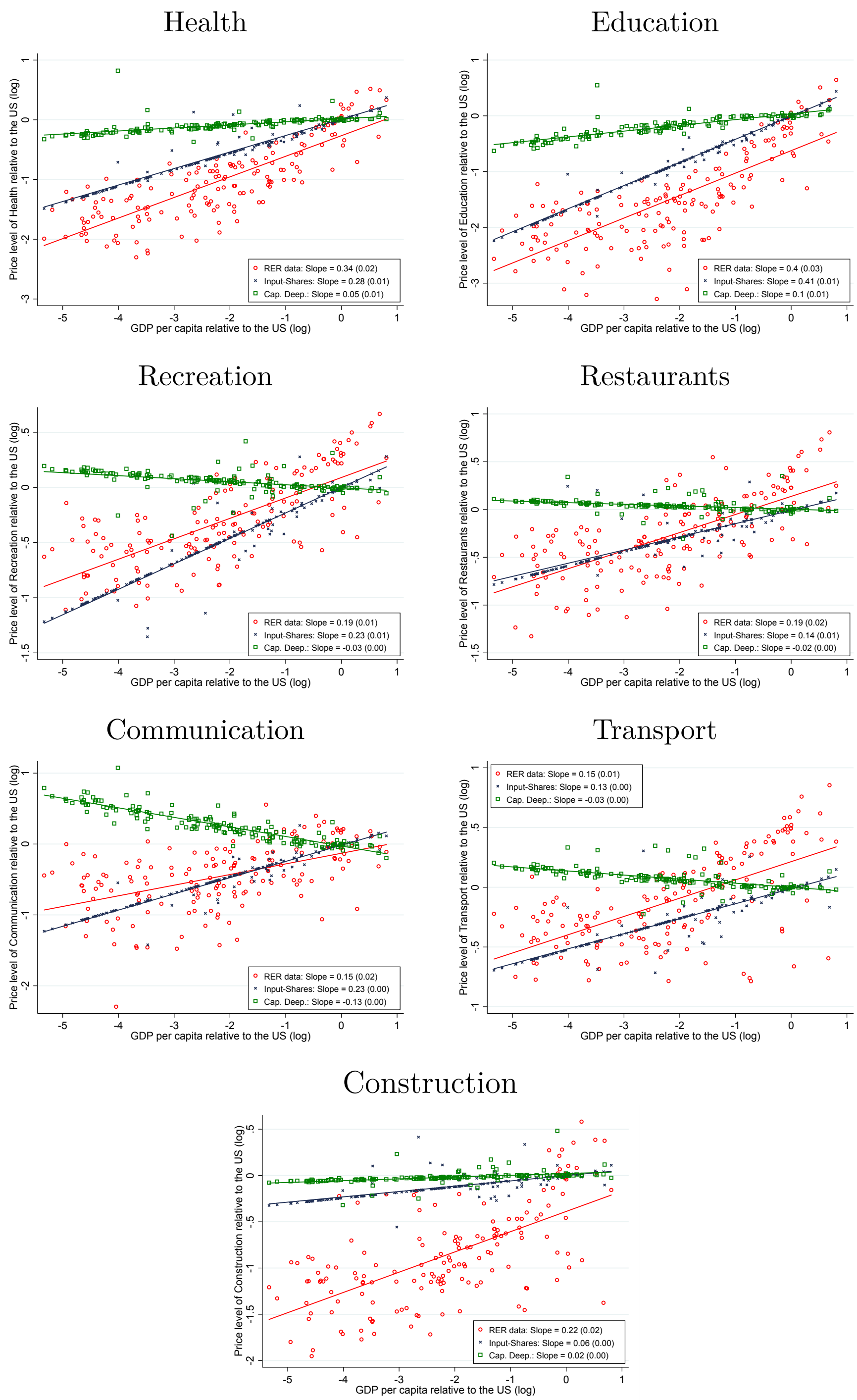
[36] For this specification, we exclude the countries for which we impute θ_i^j, and only include the set of countries for which we can directly observe θ_i^j from the ICIO data.

the ones for which the productivity gap between rich and poor countries is the largest. With this in mind, we go back to our model and ask what is the relation between industry-level prices and GDP per capita that is implied solely by the observed differences in input shares.

Figure 2.4 computes the terms labeled 'Intermediate Inputs' and 'Capital-Deepening' in equation (3.7) for seven expenditure categories for which the ICP reports price data. It shows that industry-level differences in intermediate input shares account for a significant fraction of the relation between industry-level real exchange rates and GDP per capita. This shows that the mechanism is quantitatively important in accounting for the real exchange rates industry-by-industry.

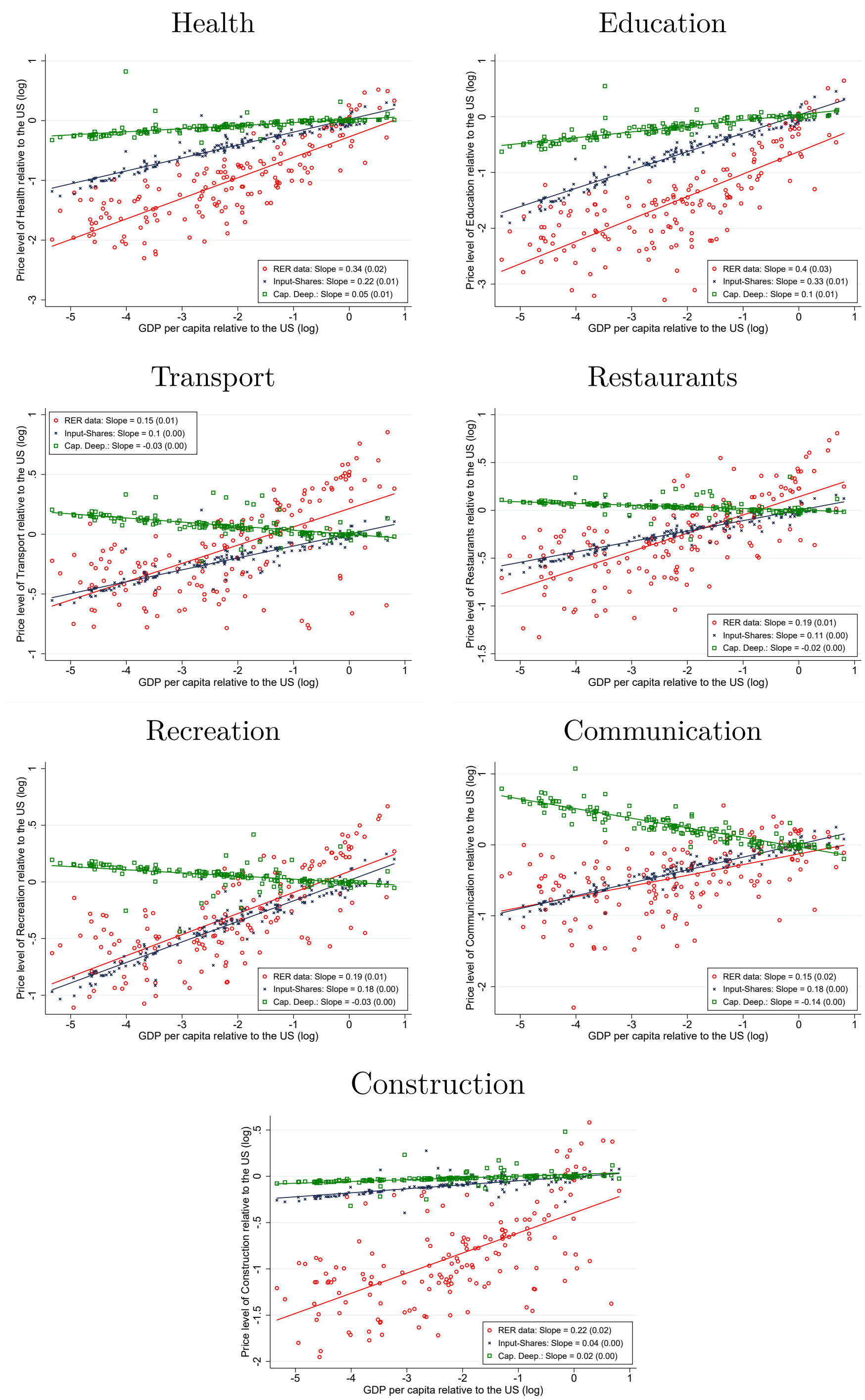
Finally, equation (3.8) implies that as GDP per capita grows, non-tradable industry-level prices should not only increase, but they should increase faster than the aggregate price of non-tradables in industries where the share of intermediate inputs is lower than for the non-tradable sector as a whole, $\theta^j > \theta^N$. Figure 2.5 evaluates this prediction. It shows the price of each industry relative to the aggregate price of non-tradables in the data vs in the observable terms in the model. In particular, we compare data on relative prices to the sum of first two terms in equation (3.8), ignoring the 'Residual' term. Despite the fact that the mapping between the industry categories in the ICIO and the expenditure categories in the ICP data is imperfect, the figure shows that the price of each industry relative to the aggregate non-tradable price index in the data is positively correlated to that in the model for the Health, Education, Transport, Restaurants, Communication and Construction industries, although for Construction this relation is not statistically significant. In contrast, the industry-level differences in input shares do not generate much variation across countries in the prices of Recreation relative to the price of non-tradables. Overall, the mechanism is successful in matching the relation of the relative industry level prices and GDP per capita.

Figure 2.4: Industry-level real exchange rate decomposition



Notes: 'RER data' refers to the relative price of the industry relative to the US obtained from the ICP data. 'Int. Inputs' and 'Cap. Deep.' are the relative price implied by the terms labeled 'Intermediate Inputs' and the 'Capital-Deepening' terms in equation (3.7).

Figure 2.5: Industry-level relative prices: Data vs. model with common sectoral technologies across countries



Notes: This figure plots the price of each industry relative to the price of non-tradables, relative to that relative price in the US from the ICP data (y-axis) and from adding the 'Intermediate Inputs' and 'Capital-Deepening' terms in equation (3.8) in the model.

5.3 Robustness

5.3.1 Relative prices and GDP per capita evaluated at PPP prices

This section shows that our quantitative results do not change if we focus on the relation between the real exchange rate and GDP measured in PPP dollars. With this in mind, we write differences in the relative price level as a function of the difference in GDP per capita evaluated as US prices, $gdp_i^{ppp} \equiv gdp_i - q_i$:

$$q_i = \underbrace{\beta_i^{gdp^{ppp}} \Delta gdp_i^{ppp}}_{\text{'Intermediate Inputs'}} + \underbrace{\beta_i^k \Delta k_i}_{\text{'Capital-Deepening'}} + \underbrace{\Delta \bar{\bar{a}}_i}_{\text{'Residual'}} , \tag{5.1}$$

where the elasticities are given by:

$$\beta_i^{gdp^{ppp}} = \frac{\omega_i^N \left[\theta_i^N - \theta_i^T\right]}{\bar{\theta}_i^N - \omega_i^N \left[\theta_i^N - \theta_i^T\right]},$$

and

$$\beta_i^k = \frac{\omega_i^N \left[\alpha_i^T \theta_i^T - \alpha_i^N \theta_i^N\right]}{\bar{\theta}_i^N - \omega_i^N \left[\theta_i^N - \theta_i^T\right]}.$$

In the Online Appendix (Figure OA.4.), we evaluate the terms in this decomposition and show that the sectoral differences in input shares account for about half of the elasticity between the real exchange rate and PPP adjusted GDP per capita seen in the data (0.12 vs. 0.24).

5.3.2 Real exchange rates and GDP growth

We now evaluate the model's prediction for the growth of the real exchange rate. Taking differences across time in equation (5.1) and using hats to denote log-changes across time, we obtain an expression for the change in the real exchange rate:

$$\hat{q}_i = \underbrace{\beta_i^{gdp^{ppp}} \Delta \widehat{gdp}_i^{ppp}}_{\text{'Intermediate Inputs'}} + \underbrace{\beta_i^k \Delta \hat{k}_i}_{\text{'Capital-Deepening'}} + \underbrace{\Delta \hat{\hat{a}}_i}_{\text{'Residual'}} \tag{5.2}$$

Equation (5.2) establishes that, if $\theta_i^N > \theta_i^T$, fast growing countries should appreciate. In the Online Appendix (Figure OA.5.) we compare the terms in equation (5.2) to the growth of the real exchange rate observed in the data, and show that sectoral differences in input shares account for about half of the elasticity of the growth of the real exchange rate to the growth of real GDP over the 1997-2014 period.

5.3.3 Alternative classifications of the tradable sector

This section re-evaluates the results of Section 5.1 under an alternative classification of industries into tradables and non-tradables. In particular, we follow the macro-economic database of the European Commission's Directorate General for Economic and Financial Affairs (AMECO) and classify the Wholesale and Retail Trade, Hotels, Restaurants, Transport, Utility, and Storage industries as tradables. In the Online Appendix, we plots the decomposition of equation (3.5) using this classification (Figure OA.6.), and show that differences in intermediate input shares still account for about half the slope of the relation between the real exchange rate and GDP per capita using this alternative classification.

5.3.4 Differentiated tradable goods and deviations from the law of one price

We now show how to extend our baseline model to allow for differentiated tradable goods and deviations from the law of one price. In particular, assume that tradable goods are differentiated by country of origin. We continue to assume the production functions from Section 3, but assume that trade between countries i and n is costly and subject to iceberg trade costs $\tau_{in} > 0$ for $i \neq n$, and $\tau_{ii} = 1$. t

Final good producers in each country i aggregate tradable intermediates from different source countries according to the aggregator

$$G_i^T = \left[\sum_{n=1}^{N} \omega_{ni}^{\frac{1}{\rho}} {Y_{ni}^T}^{\frac{\rho-1}{\rho}}\right]^{\frac{\rho}{\rho-1}}, \tag{5.3}$$

where Y_{ni}^T denotes country $i's$ absorption of tradable good from country n, ρ is the elasticity of substitution across tradable goods from different source countries, and the parameters ω_{ni} control the share of goods from country n in total absorption of tradables by country i. The price of the tradable bundle consumed in country i is then given by:

$$P_i^T = \left[\sum_{n=1}^{N} \omega_{ni} \left[\varphi_{ni}^T\right]^{1-\rho}\right]^{\frac{1}{1-\rho}}, \tag{5.4}$$

where φ_{ni}^T denotes the price of the tradable product produced in country n and consumed in country i, and the parameter ω_{ni} controls the trade shares. Note that, because of the iceberg trade costs, this price varies across destinations, so that the law of one price does not hold. Sales from country n into country i are given by:

$$\varphi_i^T Y_{ni}^T = \omega_{ni} \left[\frac{\varphi_{ni}^T}{P_i^T}\right]^{1-\rho} P_i^T G_i^T. \tag{5.5}$$

The Online Appendix fully describes this version of the model, characterizes the equilibrium, and shows that in this case the real exchange rate can be written as:

$$q_i = \underbrace{\beta_i^{gdp} \Delta gdp_i}_{\text{'Intermediate Inputs'}} + \underbrace{\beta_i^{k} \Delta k_i}_{\text{'Capital-Deepening'}} + \underbrace{\beta_i^{p} \Delta p_i^T + \beta_i^{\varphi} \Delta log \varphi_{ii}^T + \Delta a_i}_{\text{'Residual'}}, \tag{5.6}$$

with $\beta_i^{gdp} \equiv \omega \frac{\theta_i^N - \theta_i^T}{\theta_i^N}$, $\beta_i^k \equiv \omega \frac{\alpha_i^T \theta_i^T - \alpha_i^N \theta_i^N}{\theta_i^N}$, $\beta_i^p \equiv 1 - \omega \frac{1-\left[\theta_i^T - \theta_i^N\right]}{\theta_i^N}$, $\beta_i^{\varphi} \equiv \frac{\omega}{\theta_i^N}$, and $\Delta a_i \equiv \frac{\gamma}{\theta_i^N} \Delta log \left[\frac{\bar{\gamma}_i^N \bar{A}_i^T}{\bar{\gamma}_i^T \bar{A}_i^N}\right]$. Equation (5.6) states that, in addition to the 'Intermediate Inputs,' 'Capital-Deepening,' and Δa terms already present in equation (3.5), the residual now includes differences in the price of tradable across countries, $\Delta p_i^T$and $\Delta log \varphi_{ii}^T$. Note, however, that the coefficients β_i^{gdp} and β_i^k, have not changed. That is, the part of the elasticity between GDP per capita and the aggregate price level that can be attributed to sectoral differences in input shares in this model would be the same that would be attributed in our baseline model of Section 3. Incorporating differentiated tradable inputs does affect the interpretation of the residual.

5.3.5 Tradable capital

Finally, we evaluate the model's prediction under the alternative assumption that capital is mobile across countries, as in Obstfeld & Rogoff (1996). In this case, Equation (3.3) can be written as:

$$p_i^N = \frac{\bar{a}_i^T}{\bar{\theta}_i^N} + \frac{\theta_i^N\left[1-\alpha_i^N\right]-\theta_i^T\left[1-\alpha_i^T\right]}{\bar{\theta}_i^N} w_i + \frac{\alpha_i^N\theta_i^N-\alpha_i^T\theta_i^T}{\bar{\theta}_i^N} r^*,$$

where r^* is the international rate of return to capital. Following the steps from Section 3, we can write the price level in country i relative to the US as

$$q_i = \underbrace{\omega_i^N \frac{\left[1-\alpha_i^N\right]\theta_i^N - \left[1-\alpha_i^T\right]\theta_i^T}{\bar{\theta}_i^N} \Delta gdp_i}_{'\text{Input shares}'} + \underbrace{\omega_i^N \Delta\bar{a}_i^{rT}}_{'\text{Residual}'}, \tag{5.7}$$

where

$$\begin{aligned}\Delta\bar{a}_i^{rT} \equiv{}& \frac{a_i^T}{\bar{\theta}_i^N} - \frac{a_{us}^T}{\bar{\theta}_{us}^N} + \left[\frac{\alpha_i^T\theta_i^T-\alpha_i^N\theta_i^N}{\bar{\theta}_i^N} - \frac{\alpha_{us}^T\theta_{us}^T-\alpha_{us}^N\theta_{us}^N}{\bar{\theta}_{us}^N}\right] r^* \\ &+ \left[\frac{\theta_i^N\left[1-\alpha_i^N\right]-\theta_i^T\left[1-\alpha_i^T\right]}{\bar{\theta}_i^N} - \frac{\theta_{us}^N\left[1-\alpha_{us}^N\right]-\theta_i^T\left[1-\alpha_{us}^T\right]}{\bar{\theta}_{us}^N}\right] gdp_{us}.\end{aligned}$$

Note that in this case, the coefficient on Δgdp_i depends on the sectoral differences in the labor share in gross-output, $\left[1-\alpha_i^N\right]\theta_i^N - \left[1-\alpha_i^T\right]\theta_i^T$, rather than on the sectoral differences in intermediate input shares, $\theta_i^N - \theta_i^T$. We note that in the data, however, sectoral differences in the share of labor in gross output arise primarily from sectoral differences in the share of value added in gross output, θ_i^j, rather than from sectoral differences in the labor share in value added, $\left[1-\alpha_i^j\right]$.

In the Online Appendix (Figure OA.7.), we compare the term labeled 'Input shares' to the real exchange rate observed in the data, and show that sectoral differences in input shares account for almost half of the elasticity of the real exchange rate to GDP per capita.

6 Conclusion

This paper proposes a mechanism to account for the relation between real exchange rates and GDP per capita. If the share of intermediate inputs in the production of tradables is relatively high and the price of tradables is equalized across countries, the price of non-tradables should increase with GDP per capita. The intuition is that the input multiplier will be larger for tradables in this case. Since this mechanism acts independently of the differences in the level of productivities across sectors, it can be easily evaluated using input-output data. We show that differences in input shares across tradable and non-tradable sectors can account for about a half of the elasticity of real exchange rates to income per capita.

Chapter III: Services Trade and Internet Connectivity

1 Introduction

Long records in the exchange of goods across countries have led much of the trade literature to focus on trade in goods, rather than services. But as services play a larger and larger role in modern economies - and data become increasingly available - it is a reality that trade models must account for the change in composition. The share of services in trade volumes has been rising over the last three decades, and policy makers view the service sector as a key to economic growth, export competitiveness, and poverty reduction (World Bank, 2010). At the same time, the advent of the Internet in the late 1980s has connected people all around the globe, making it easier to communicate and exchange digital data.

Anecdotally, the connection between Internet accessibility and the exchange of services is already prevalent. Call centers in India manage US tech problems from thousands of miles away, Airbnb makes traveling abroad cheaper and easier, insurance policies are traded across borders by firms halfway across the globe, and Netflix brings international entertainment at the click of a button. But capturing the effect of the Internet in economic data can prove difficult, especially when thinking internationally. Using historical data on the advent of the Internet and its international spread helps relate connectivity to the growth in bilateral service exports.

This paper explains the growth in international services trade through rising Internect connectivity in a standard gravity setting. The novelty of my approach is in creating a database of the system of underwater fiber-optic cables (Figure E.3) to measure the degree of country interconnectivity. These cables make the transfer of data in large quantities between countries possible; 99% of international data traffic between countries travels through the underwater system. By analyzing the growth in the cable system, I answer the question, "Can bilateral Internet connectivity explain the growth in services trade in recent decades?" Using data on the capacity[1] of these fiber-optic cables, I find that a one percentage point increase in connectivity correlates to a 0.25-2.25 percentage point increase bilateral exports in data-intensive services.

The value of my approach is twofold. The first is that the growth in the fiber-optic cable map provides some sense of *bilateral* connectivity. Though it will take a careful explanation of how international data flow works, the result is that my exercise returns an estimated coefficient for the strength of the connection between countries X and Y rather than more top-down approaches based on the number of Internet users or registered domain names. To clarify, consider the case of US connectivity with India and Japan. Large parts of India have low Internet access (18.0/100 persons in 2014), but Japan is very well-connected (90.6/100). Using this top-down approach, one might guess that Japanese services exports to the U.S. dwarf Indian services exports to the U.S. by 5-to-1. But the true ratio was 3-to-1 by 2008 and has continued to shrink. The reason why is that Electronic City in Bangalore is almost universally connected to the Internet (even if the rest of the country is not), and it has a high-capacity connection to the US through the submarine cable network.

The second benefit is that my point estimate provides a coefficient for the growth in trade that is targetable by policy and infrastructure. With more abstract approaches to international connectivity, the policy lever to encourage services trade is less clear. In my exercise, the answer is to build more capacity. To establish causality, I perform a sepa-

[1]While full detail will come in Section 2, "capacity" gives a sense how much data can be transferred between two points.

rate exercise, wherein I apply the “routing” identification strategy of Chandra & Thompson (2000), Michaels (2008), and Fajgelbaum & Redding (2014). Whereas my above-mentioned results tie together bilateral connectivity and services trade growth, there is an obvious endogeneity problem: countries build submarine cables between one another with the intention of increasing capacity, possibly for trade in services. I seek to show an effect where cable connectivity is *unexpected*. The “routing” idea is as follows: suppose Country A wants to connect to some Country C, and vice versa. To do so, they have to pass through Country B. Though Country B has made no plans of its own to connect to Country A and Country C, it now has access to the cable system. I then measure whether B’s service trade with A and C grows.

While cables between North America and Europe and between East Asia and North America came online very quickly, Western Europe was without the reliability of a high-capacity fiber-optic undersea cable to Eastern Asia until recently. Building such a cable, such as the FLAG Europe-Asia cable in 1997, necessitates stopping points in Egypt and along the southeast Asian coast. I find that increasing cable capacity by 1 percentage point yields a 2.25 percentage point increase in data-intensive services exports along the cable line in the case of Egypt, or a 1.82 percentage point increase in a broader set of countries along the cable lines.

My research is consistent with previous papers providing evidence on the association between Internet connectivity and trade in services. Freund & Weinhold (2002, 2004) present evidence that Internet connectivity is related to growth in services trade, in terms of both exports and imports, where their connectivity measure is the number of web hosts attributed to each country. A more recent paper by Bojnec & Fertőo (2010) relates Internet connectivity to manufacturing trade, where the relevant variable is number of Internet users per country. Their results show that Internet access is related to better access to information, an increase in competition, and a reduction of trade costs. Guerrieri & Meliciani (2005) also address the relationship between communications technologies and producer services. A recent paper by Eichengreen et al. (2016) relates cable connectivity and electronic currency trading, but their focus is on the foreign exchange market.

My work also contributes to the research on the relationship between information and trade of Steinwender (2014). She shows that the establishment of the transatlantic telegraph in 1866 allowed for price information to move from the UK to the US nearly instantaneously, a huge improvement from waiting for the next ship to make the journey across the Atlantic and deliver new price information. Average trade flows increased after the telegraph transmitted data on demand shocks more quickly. It is my goal to extend this type of analysis into the Information Age.

Lastly, my work adds to the "gravity" literature of international trade. I augment the empirical approach by providing a time-dependent, bilateral measure of connectivity for services exports. My results are consistent with one where submarine cables reduce trade costs between countries. In this view, bilateral connectivity makes certain services cheaper to export and incentivizes growth in industries with relatively high data requirements. My modeling will also be consistent with the emerging literature on the econometric issues with zeros in trade data, e.g. Silva & Tenreyro (2006), that I will address in robustness checks.

The map of the discussion is as follows. Section 2 details the workings of the Internet and data transfer, catalogs the history of submarine cables, and explains the importance of modern day fiber-optic cables. Section 3 explains the data. Section 4 explains my estimation strategy and presents results. Section 5 suggests some extensions of my work. Section 6 concludes.

2 The Internet and Cable History

Before presenting the model, it will aid the reader to have a fuller understanding of the relevant history of long-distance data transfer and how the Internet works.[2]

[2] What will be presented here is still a simplification. For a more thorough explanation, I would suggest Rus Schuler's White Paper on the Internet (https://web.stanford.edu/class/msande91si/www-

First, a few words of terminology will help. A *bit* is a zero or a one. All data are made up of bits: 8 bits are a byte, 1,024 bytes are a kilobyte, 1,024 kilobytes are a Megabyte (MB), 1,024 MB are a Gigabyte (GB), and 1,024 GB are a Terabyte (TB). An email is on the order of a handful of kilobytes, whereas a PDF of this paper is a few MBs. A present-day laptop's disk holds around 1TB or more. A *bit-rate* is a measurement of bits-per-time, which is the data equivalent of measuring miles-per-hour – X bits moving at Y bits-per-second tells you how long it takes to get those bits between two locations. *Bandwidth* refers to the maximum bit-rate of available or consumed information capacity. Bandwidth is also rate – the bit-rate of a given medium is capped by the available bandwidth. The rate of successful delivery over a communication channel, such as a cable, depends on the limitations of this underlying medium (copper cables versus fiber-optic ones), the available processing power of the system components (how good your computer is), and end-user behavior. Sending an email doesn't require much bandwidth, but a Skype call does.

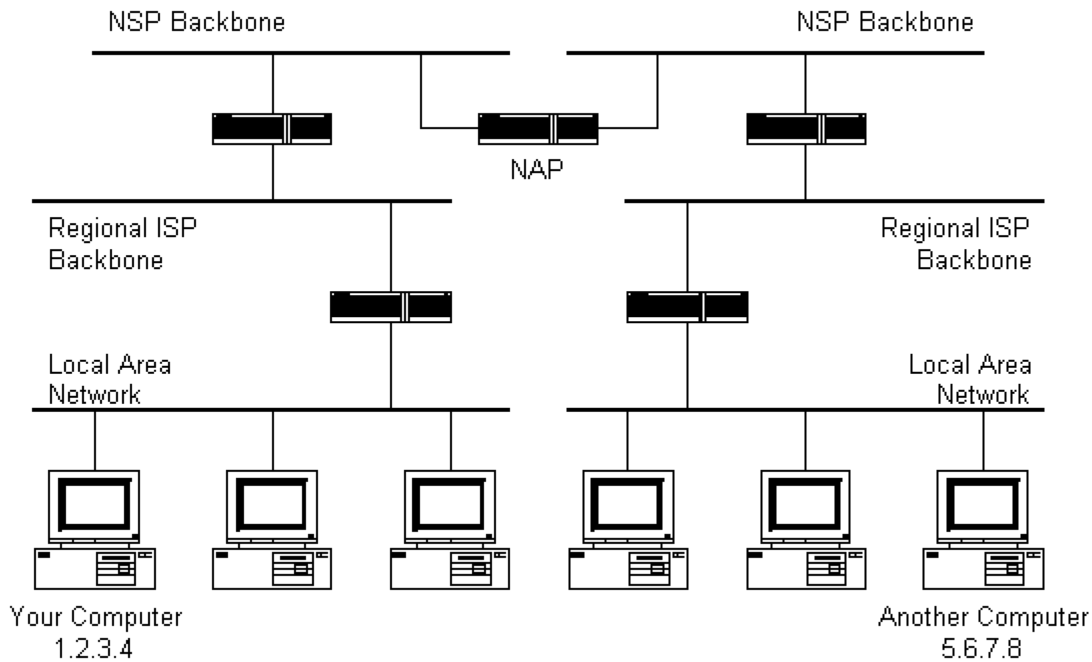
If two computers want to "talk" to each other, say via email, there must be some connection between them.[3] Each computer has an Internet Protocol Address (IP Address) and sends messages through a series of interconnected routers to another computer. In Figure 3.1, a computer at IP address 1.2.3.4 can transfer data to the computer at IP address 5.6.7.8 through a Network Access Point. In my international case, think of Network Access Points connected to each other through the undersea cable network. No matter the hardware at either end of the connection, the underlying medium (the cable) will dictate the bandwidth that is available between two end users. I'm interested in measuring the value of (and the growth in) the bandwidth of these cables, which I will refer to throughout the paper as the cable's "capacity."

The last bit of subtlety about bandwidth is in how it's measured: bits per second from point A to point B. You could put a bunch of hard drives in a jet and transfer a lot of bits per second from France to Egypt, but if you're swapping messages a conversation could only

spr04/readings/week1/InternetWhitepaper.htm).

[3]Satellites account for less than 1% of international data flow and are often used for very remote locations.

Figure 3.1: Organization of Data Transfer



ISP stands for Internet Service Provider, NSP stands for Network Service Provider, and NAP stands for Network Access Point. NAPs are also known as Internet Exchange Points (IXPs).
Source: https://web.stanford.edu/class/msande91si/www-spr04/readings/week1/InternetWhitepaper.htm

progress after each time the jet landed. Cables, on the other hand, can transmit very quickly but in smaller quantities. But therein lies the value of modern fiber-optic cables: high speeds *and* high bandwidth.

While countries have been connected via telegraph and coaxial telephone cables since the first transatlantic cable in 1866, the advent of fiber-optic cables allowed for high enough bandwidth in order to make some services trade viable. The first copper wires could transfer 10-12 words per minute; now businesses thousands of miles apart can interact over Skype. Fiber-optic cables use lasers in a glass tube that permit higher signal speeds ($\sim$200,000 km/s) at higher capacities than their predecessors. TAT-8, the first submarine fiber-optic cable, connected France, Britain, and the US in late 1988 with a capacity of 40,000 telephone channels, an order of magnitude increase in capacity over contemporary coaxial cables.

The new fiber-optic cables were still not without problems, however. Initial fiber-optic cables were attacked by sharks due to a lack of electrical shielding. Fishing trawlers and anchors would still regularly break cables. To adapt, cables were woven in self-healing fiber rings to increase redundancy (and thus reliability). Cables began being buried in the seabed floors to avoid human destruction. PTAT-1 and cables that followed it were fitted with shielding to avoid becoming fish food. Around the same time, the development of submarine branching units allowed multiple destinations to be served by a single cable. The world was more and more becoming connected by reliable, high-capacity cables that far outstripped the previously laid coaxial cables.

The submarine fiber-optic cable system laid mostly after 1990 represents a discontinuous jump in speed and capacity from its coaxial and telegraphic predecessors. Cables are still occasionally broken by anchors and natural disasters, but the incidence of submarine cable faults is very low (0.44 faults per 1000km per year after 1985 vs. a 1991 report of 2.13 for conventional buried cables). As a result, the construction of fiber-optic cables between two countries provides a reliable, high-capacity avenue for data transfer. In the empirical section, I will show that the country linkages provided by these cables is correlated with increased exports of data-intensive services.

3 Data

Data on the undersea fiber-optic cables come from several sources. My primary source is TeleGeography's Global Bandwidth research, a telecommunications market research and consulting firm whose primary research areas include international Internet networks, undersea cables, capacity, and long-distance traffic. They provide information on active and planned submarine cable systems with a maximum upgradeable capacity of at least 5 Gb/s, including ready-for-service date, length, owners, and landing point. As of the writing of this paper, there are data on 347 extant and planned cables, beginning in 1989.

These data are supplemented by the Submarine Cable Almanac, put together by the Submarine Telecoms Forum. Remaining possible gaps in cable lines and cable capacities were scraped from http://www.cablemap.info/ and cable-specific websites.[4] I end up with a final sample of 254 cables that are relevant to my study (I exclude future planned cables, cables only connecting small island chains outside of my study, etc.). Wherever available, I include data on the capacity of each cable. In general, I am able to find the capacities of all large and major cables, though data on older and smaller cables often lack reliable measures of capacity. As a result, my usable sample for capacity comprises 138 cables with measures of available bandwidth.

To measure connectivity, I use the cable data in two different ways. The first is to use the broadest set of information available, namely the raw number of cables and the countries they connect. In this case, there will be higher connectivity between countries for which there are a more cables: this measure is an integer value. The second measure uses all the available capacity data. Since cables range in capacity by two orders of magnitude, a more accurate measure of connectivity would be to use the sum of these capacities for any country pair. For further detail on these two measures, see Appendix 6.

The services trade data come from the World Integrated Trade Solution (WITS), which is a collaborative effort between the World Bank, United Nations Conference on Trade and Development, United Nations Statistical Division, and World Trade Organization. These data comprise bilateral exports/imports between country-pairs on trade partners around the globe by BOP disaggregation. I perform my analysis at the 2-digit and 3-digit levels and find similar results. While data at the 3-digit level are more precise, the drawback is that many countries do not report trade flows at this level of specificity. As such, I use the 2-digit in all cases when describing my results. See Table E.6 for a full list of countries and Table E.8 for a list of sectors.

Ex ante one might expect that Internet access has different effects for different service industries; Skype doesn't make it easier to give an intercontinental haircut. To capture this idea, I separate services into two groups: data-intensive services (DIS) and all else (non-DIS).

[4]E.g. http://www.smw3.com/ for SEA-ME-WE 3.

To determine which sectors are "data-intensive," I use the World Input-Output Database (WIOD) to measure the input ratio of telecommunications in each sector. I find that financial services, computer & information, and other business services are the most data dependent.[5] My estimation strategy will use a dummy for DIS interacted with connectivity to test if there is a different effect for these sectors.

The goods trade information comes from the World Trade Flows data compiled by Robert Feenstra of the Center for International Data. These data similarly comprise bilateral exports, though I lack the sector break-out that is available for our services data.

4 Estimation

As mentioned above, one can view the change in cable connections and capacity to be akin to a time-varying change in the distance variable in a traditional gravity model. I rely on the source-destination-year variation in the cable network in order to estimate the correlation between inter-country service exports and connectivity. In order to soak up the variation due to country size, cultural similarities, geography, and other covariates, I include fixed effects at the source-sector-year level, the destination-sector-year level, and the source-destination-sector level.

Recall that the goal is to measure the effect of the variability in fiber-optic connections between countries. This variance occurs over time, t, between a source country, i, and a destination country, n, for all sectors, s, in a given pair. I therefore prefer an estimating equation taking the stochastic form

$$X_{inst} = \beta_0 \; cables_{int}^{\alpha} \; e^{\theta_{ins} d_{ins} + \theta_{ist} d_{ist} + \theta_{nst} d_{nst}} e^{\eta_{inst}}, \tag{4.1}$$

[5] In particular, I find Financial Intermediation, Other Business Activities (which includes Computer and Related Services), and Air Transport to have the largest inputs from the telecommunication sector. The relevance of Air Transport is driven almost entirely by the United States in the WIOD sample, so I exclude it.

or, taking logs,

$$ln(X_{inst}) = ln(\beta_0) + \alpha \; cables_{int} + \theta_{ins}d_{ins} + \theta_{ist}d_{ist} + \theta_{nst}d_{nst} + \eta_{inst}, \tag{4.2}$$

where X_{inst} represents exports from i into n in esctor s at year t, $cables_{int}$ represents a measure of cable connectivity between a country pair in time t, d_{ins} is a source-destination-sector fixed effect, d_{ist} is a source-sector-time fixed effect, and d_{nst} is a destination-sector-time fixed effect. As described in Section 3, my measure of $cables_{int}$ will take two forms: 1) The raw number of cables, i.e. the coefficient will be a semi-elasticity between cable number and log point increase in exports; and 2) The logged capacity (GB/s) of all cables between two countries, i.e. the coefficient is an elasticity between the log point addition in cable capacity and the log point increase in exports.

Since I allow for a difference in the effect of cables on my two groups of services sectors, my main estimation equation will take the form

$$\begin{aligned} ln(X_{inst}) = & ln(\beta_0) + \gamma_1 \mathbb{I}\{DIS \; sector\} \times cables_{int} \\ & + \gamma_2 \mathbb{I}\{non - DIS \; sector\} \times cables_{int} \\ & + \gamma_3 \mathbb{I}\{goods \; sector\} \times cables_{int} \\ & + \theta_{ins}d_{ins} + \theta_{ist}d_{ist} + \theta_{nst}d_{nst} + \eta_{inst}, \end{aligned} \tag{4.3}$$

where γ_1 and γ_2 are the parameters of interest.

Table E.9 presents the results for the full sample using all available data. All standard errors are clustered at the source-destination level. Exports in services increase across the board, but the coefficients for DIS are nearly double those of other services. The measure using cable capacity delivers more precise estimates than that using only raw cable number. As not all cables are created equal, this result supports the idea that growth in services trade is correlated with growth in capacity. These results are robust to several additional considerations. See Section 4.2 for full detail.

I readily admit that, when considering the full sample, these results tell only a correlative story. There is clear endogeneity in the regressors as infrastructure projects are not exogenous. In the following section, I discuss an identification strategy that establishes two possible cases where connections to cables could be exogenous.

4.1 Identification

I follow the "routing" identification strategy of Chandra & Thompson (2000), Michaels (2008), and Fajgelbaum & Redding (2014). The obvious endogeneity is that cables will be built where there is a desire for them. Then the construction of cables will be correlated with higher services trade due to projected growth rather than admitting any sort of causal story; providing reliable capacity to a country would not promote service trade, rather the desire for a cable is only indicative of underlying services growth. The main idea behind "routing" is that while the infrastructure assignment is non-random, locations can be treated with cable infrastructure for a reason aside from characteristics unobserved to the econometrician: these places happen to lie along the route between two other important locations. In the case of the fiber-optic cables between Western Europe and East Asia, the funding for the construction came mostly from the telecom companies at either end rather than countries in between. I consider two possible stories: 1) All countries not in Western Europe or East Asia[6] received cable connections due to routing; 2) Egypt – due to the presence of the Gulf of Suez, the Red Sea, and the Gulf of Aden – is routed through only because it provides the shortest possible land route between the two bodies of water abutting Europe and East Asia. In particular, there exist four such cables (Figures E.4, E.5, E.6, E.7) that have landing points in between the Europe-East Asia route. In this empirical exercise, I consider the effect that connectivity with these cables increases services trade between the connected countries, but not other nearby countries.

Tables E.10 and E.11 present the results for regression equation 4.3.[7] In this case, only

[6] A list of these countries is presented in Table E.7.

[7] For the exercise with Egypt as the only source country, the destination-sector-time and source-sector-time

the coefficient on exports for data-intensive services is positive. Other services remain flat or even decline. The magnitudes are much larger than those of the previous exercise, suggesting that these individual countries tend to expand their DIS exports faster than the countries who are responsible for routing the cables. As it remains unclear why other services would decline with the expansion of Internet connectivity, these results push me again to favor my measurement using cable capacities.

4.2 Robustness

I provide robustness checks to three anticipated concerns: 1) Only the first cable connection matters; 2) The importance of cable connectivity is nonlinear; and 3) The dropped zeros in the gravity equation are driving the results.

4.2.1 Single Cable

Consideration of my results and identification strategy might lead one to suspect that only the first connection to a fiber-optic cable is important. Table E.12 presents my estimates for coding a cable variable with a maximum value of 1: any additional cable connections are seen as redundant. The weak precision in these estimates suggests that a single cable's connection does not do a very good job at capturing the full effect. As previous results suggested that the capacity measurements do a relatively better job, it is not surprising that the single-cable results do not tell the full story.

4.2.2 Quadratic Term

It may be the case that the relationship between connectivity and service trade is nonlinear. To test this hypothesis, I rerun all of the capacity regressions with a quadratic term included. Table E.13 presents the results. Here, the coefficients are consistent with a story of only higher connections mattering: the quadratic is positive while the linear coefficient is negative.

fixed effects are replaced with year dummies to identify the effects.

This result pairs nicely with my findings on single cable connections, as the first cable is likely to have the least capacity.

4.2.3 Zeros

Research into the zeros in trade data neccessitates the consideration of other estimation procedures that can account for them. In particular, Santos Silva & Tenreyro address the bias in estimates of the gravity model under heteroskedasticity. They advise use of a Poisson pseudo-maximum likelihood estimatation (PML) that performs significantly better in the presence of heteroskedasticity. However, due to the high dimensionality in the fixed effects I use for estimation, I can only present results here for a smaller sample. Table E.14 presents the results for the case of Egypt. The results for DIS remain consistently positive, but the PML procedure yields strongly negative coefficients for other services. As this latter result is a bit puzzling, I leave it as an area for future research.

5 Extensions

The use of this new source of data, the undersea fiber-optic cable network, raises many questions that I am not able to answer in my current analysis. I address a few of them here as avenues for further research.

My analysis has mainly focused on bilateral connections as measured by landing sites for the various cables. This measure precludes landlocked countries in the data from receiving any effect from cable connectivity. In practice, this is not quite right. While Switzerland's access to the United States will be gated by any existing under*ground* cables connecting it to a coastal country, it may certainly make use of a France-to-U.S. undersea fiber-optic cable once data make it to the Atlantic. With more data on land routes for communications infrastructure, one would be able to estimate the effect of coastal cables on inland countries who will have less control over cable placement, giving a sound identification structure.

If cable connectivity is as good an indicator of service sector export growth as I have measured (for specific service sectors), one could use the cables as an IV for the effect of service growth on total country growth. The World Bank's position is that the service sector is vital to overall domestic welfare, so any expansion thereof should have substantial welfare implications.

Lastly, this research question could also speak to the idea of "blueprint" transfer in FDI as in Keller (2001). A branch of future research could use the Internet connectivity measure as a clearer mechanism for the transfer of ideas via FDI; transfer of inventions is likely higher through the Internet than embodied in goods trade.

6 Conclusion

By creating a dataset of the undersea fiber-optic cable network, I find that improving bilateral Internet connections promotes bilateral service trade in data-intensive sectors. I argue that this effect is true both in the aggregate world economy and in particular for a smaller subset of countries for whom I argue the cable connections to be exogenous. Service sectors in finance, computers and information, and other business services tend to have the greatest effects.

APPENDICES

Appendix A: Data Summary and Simulation Procedure

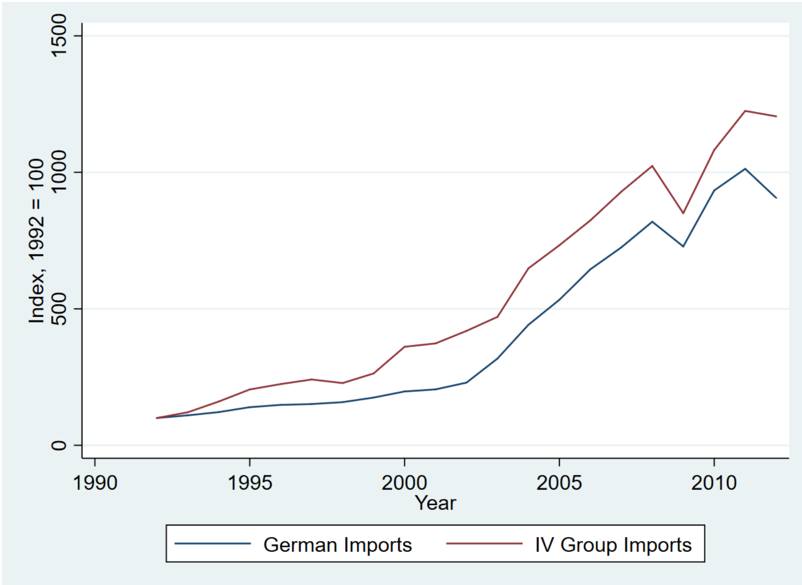
In this section, I detail the creation of the main variables I use in my estimation procedure for κ, and provide more information on my simulation procedure.

Trade Data

My trade data come from two different sources as each has different advantages. I use COMTRADE data for the creation of my instrument detailed in Section 5.1. The United Nations Commodity Trade Statistics Database contains detailed imports and exports statistics reported by statistical authorities of close to 200 countries or areas. It concerns annual trade data from 1962 to the most recent year. I use a subsample of two decades beginning in 1992 (for robustness, I also consider 1993 as a base year).

I translate the SITC Rev. 3 product codes from COMTRADE to ISIC Rev. 3 to NACE Rev. 1 at the two-digit level via the correspondence tables provided by the UNSD and Eurostat RAMON. I do so in order to match the categorization of the trade data and German employment data. I translate first to the ISIC Rev. 3 nomenclature as it matches fairly easily to NACE Rev. 1. The SITC Rev. 3 to ISIC Rev 3. match is less straightforward. For all cases where (e.g.) a SITC industry maps to two or more ISIC industries, I evenly divide the flow value into each ISIC bin. As an example, SITC 5226 is the code for Inorganic Bases and Metallic Oxies, Hydroxides, and Peroxides, N.E.S., which maps to both Chemicals

Figure A.1: German and IV Group Manufacturing Imports from China



Notes: Data on trade flows come from COMTRADE.

and Chemical Products (ISIC 24) and Other Non-Metallic Minerals (ISIC 26). Therefore, I divide the value for SITC 5226 in half and assign it to each of the two ISIC categories.

I apply this method to all annual manufacturing imports from China reported by Germany and the IV Group countries. Figure A.1 displays an index for manufacturing imports from China for both Germany and the IV Group. As expected, imports from China grow steadily during the entire sample period, and the IV Group does a good job imitating German import movements.

I use the WIOD for my simulation exercise.[8] This database has the added benefit of non-manufacturing sectoral output and imports, but it lacks the full range of years of the COMTRADE database. The industry specificity is also less granular, but much easier to match as can be seen in Table A.1. I use data between 2005-2011 to perform simulations and welfare calculations for the individual κ values.

[8]Specifically, I use the 2013 Release tables. While this set of tables lacks data for 2012, the matches between ISIC Rev. 3 and the German NACE categories are clearer.

Table A.1: Sector Definitions and Elasticities

Industry	Manufacturing	WIOD	NACE	Caliendo & Parro θ_s
Food, Beverages and Tobacco	Y	15-16	15-16	2.55
Textiles and Textile Products	Y	17-18	17	5.56
Leather, Leather and Footwear	Y	19	18-19	5.56
Wood and Products of Wood and Cork	Y	20	20	10.83
Pulp, Paper, Paper , Printing and Publishing	Y	21-22	21-22	9.07
Coke, Refined Petroleum and Nuclear Fuel	Y	23	23	51.08
Chemicals and Chemical Products	Y	24	24	4.75
Rubber and Plastics	Y	25	25	1.66
Other Non-Metallic Mineral	Y	26	26	2.76
Basic Metals and Fabricated Metal	Y	27-28	27-28	7.99
Machinery, Nec	Y	29	29	1.52
Electrical and Optical Equipment	Y	30-33	30-33	10.60
Transport Equipment	Y	34-35	34-35	0.69^{α}
Manufacturing, Nec; Recycling	Y	36-37	36	5.00
Aggregated Non-manufacturing Sector	N	All else	All else	4.55^{β}

Notes: Closest sector-to-sector matches between the WIOD and NACE Rev. 1. $^{\alpha}$As I combine autos and other transport in my estimation procedure, I take the average of [21]'s findings in these two sectors. $^{\beta}$4.55 is the aggregate elasticity value found by same.

Group-level variables

In order to solve for the proportional change in sector-specific wages, I need: 1) Data on group-level income levels (Y_{ig}), trade imbalances (D_i), trade shares (λ_{ijs}), expenditure shares (β_{is}), labor allocation shares (π_{igs}), and labor endowments (L_{ig}).

The German labor market data (Y_{ig}, L_{ig}, π_{igs}) at the local sector level come from the IAB Establishment History Panel (BHP; see Spengler (2008) for more information) which includes the universe of all German establishments with at least one employee subject to social security. This data set consists of an annual panel with approximately 2.7 million yearly observations on establishments aggregated from mandatory notifications to social security starting in 1975 (1992 for East Germany). Due to the administrative origin, the data are restricted to information relevant for social security (structure of workforce with regard to age, sex, nationality, qualification, occupation, wage) but at the same time are highly reliable and available on a highly disaggregated level. Detailed data for regional sectoral employment is available from 1978 onwards. I define groups by skill level and local labor market. My skill groups are given by "share of unskilled full-time employment" and the remaining full-time employed. Labor allocation shares π_{igs} are computed as the employment share $\pi_{igs} = \frac{L_{igs}}{L_{ig}}$ and earnings share $\pi_{igs} = \frac{Y_{igs}}{Y_{ig}}$.

The trade data (D_i, λ_{ijs}, β_{is}) at the country-sector level come from the World Input-Output Database (see Timmer et al. (2015)). In order to ensure that the sum of the Y_{ig} add up to the Y_i from the WIOD, data from the BHP are rescaled according to the formula, $Y_{ig}^{WIOD} \equiv \frac{Y_{ig}^{BHP}}{Y_i^{BHP}} Y_i^{WIOD}$, where BHP and WIOD give the source of each variable.

Simulation Steps

In this section, I provide detail to the simulation procedure performed in Section 6. To solve for the proportional change in sector-specific wages, $\hat{\boldsymbol{w}}_{\boldsymbol{is}}$, I use the system of equations given by 3.7. To that end, I first collect : 1) Data on group-level income levels (Y_{ig}), trade imbalances (D_j), trade shares (λ_{ijs}), expenditure shares (β_{is}), labor allocation shares (π_{igs}), and labor endowments (L_{ig}) as detailed above; 2) Parameter values for the shape parameters on sectoral technologies (θ_s) and group efficiencies/flexibilities (κ_{ig}), given by Table A.1 and $\kappa_{ig} = \hat{\kappa}$ as presented in Table 1.5; and 3) A measure of the shocks to trade costs ($\hat{\tau}_{ijs}$) from the gravity model as described in Section 6. Using Equations 3.9 and 3.10, I can then use the $\hat{\boldsymbol{w}}_{\boldsymbol{is}}$ to solve for the proportional changes in trade shares and sector employment shares.

The algorithm works as follows:

1. Choose a value for κ.

2. Formulate guess for the NxS (number of countries by number of sectors, 41x15) matrix of $\hat{\boldsymbol{w}}_{\boldsymbol{is}}$.

3. Given $\hat{\boldsymbol{w}}_{\boldsymbol{is}}$, compute $\hat{Y}_{ig}$, $\hat{\lambda}_{igs}$, and $\hat{\pi}_{igs}$ for all country-group-sector triads as given in Equations 3.8, 3.9, and 3.10, respectively.

4. Plug in values for the NxS equations for excess labor demand given by

$$\sum_j \hat{\lambda}_{ijs}\lambda_{ijs}\beta_{js}\left(\sum_{g\in G_j}\hat{Y}_{jg}Y_{jg}+D_j\right)=\sum_{g\in G_i}\hat{\pi}_{igs}\hat{Y}_{ig}\pi_{igs}Y_{ig}.$$

5. Update guess for $\hat{\boldsymbol{w}}_{\boldsymbol{is}}$ to minimize excess labor demand.

6. Go back to Step 3 and repeat until converged.

With the solution for the counterfactual change in country-sector wages, I can calculate the change in welfare according to Equations 3.12 and 3.13. I repeat this process for each value of $\hat{\kappa}$ given in Table 1.7.

Appendix B: Robustness Exercises

Alternate Base Years

Eastern European Trade Shock

In this exercise, I follow DFS in their focus on the effects of trade with China (the "far" east) and Eastern Europe[9] (the "near" east) in manufacturing. The fall in the Iron Curtain led to increased demand for German manufacturing goods (e.g. autos), while the rise of China led to strong foreign competition in some sectors (e.g. clothing). To define how groups of

[9]In line with DFS, I consider Eastern Europe to comprise the countries Bulgaria, Czech Republic, Hungary, Poland, Romania, Slovakia, Slovenia, and the former USSR or its succession states Russian Federation, Belarus, Estonia, Latvia, Lithuania, Moldova, Ukraine, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan.

Table B.1: Estimates for κ, Before and After Hartz I-IV

	1993-2003		2002-2012		2003-2013	
IV uses:	Emp. Share	Earn. Share	Emp. Share	Earn. Share	Emp. Share	Earn. Share
$\hat{\kappa}$	2.235***	2.023***	4.739***	4.844***	4.718***	4.873***
	(0.212)	(0.233)	(0.170)	(0.187)	(0.162)	(0.171)
First Stage F-Stat	51.04	33.31	100.27	96.82	115.15	107.16
N	210	210	210	210	210	210
R^2	0.2088	0.1814	0.3423	0.3412	0.2594	0.2627

Notes: The independent variable for this regression is the instrument described in Equation 5.3. The dependent variable is is given by $\hat{\pi}_{igs} = \frac{\hat{L}_{igs}}{L_{ig}}$ and $\hat{\pi}_{igs} = \frac{\hat{Y}_{igs}}{\hat{Y}_{ig}}$, respectively. A group is the set of full-time employees for a particular local-labor-market-skill pair. The dichotomous skill variable measures "unskilled" full-time employees vs. all others. *** indicates significance at the 1% level.

Table B.2: Estimates for κ, Before and After Hartz I-IV

	1992-2002		2005-2012	
Measurement of IV uses:	Emp. Share	Earn. Share	Emp. Share	Earn. Share
$\hat{\kappa}$	1.227***	1.131***	4.563***	4.708***
	(0.149)	(0.148)	(0.168)	(0.176)
First Stage F-Statistic	49.94	37.02	61.95	58.69
N	210	210	210	210
R^2	0.1124	0.0064	0.2688	0.2703

Notes: The independent variable for this regression is the instrument described in Equation 5.3. The dependent variable is is given by $\hat{\pi}_{igs} = \frac{\hat{L}_{igs}}{L_{ig}}$ and $\hat{\pi}_{igs} = \frac{\hat{Y}_{igs}}{\hat{Y}_{ig}}$, respectively. A group is the set of full-time employees for a particular local-labor-market-skill pair. The dichotomous skill variable measures "unskilled" full-time employees vs. all others. *** indicates significance at the 1% level.

individuals are potentially affected by the rise of the East during the time periods of interest, I construct an analogous measure of trade export exposure at the sector level, given by

$$\Delta\,[\text{export exposure}]^{\text{EE}}_{st} \equiv \frac{\Delta \text{EX}^{\text{DEU}\to\text{EE}}_{st}}{L_{st}}, \tag{.1}$$

where 'EE' represents Eastern Europe.

As in Section 5.1, denote the IV Group countries by 'OTHER ' with $\Delta \text{EX}^{\text{OTHER}\to\text{EE}}_{st}$ defined as above, with the exception that the trade flows are out of these 'OTHER' countries rather than Germany. I use these trade flows to construct the instrument as

$$\Delta\,[\text{IV export exposure}]^{\text{EE}}_{st} \equiv \frac{\Delta \text{EX}^{\text{OTHER}\to\text{EE}}_{st}}{L_{st}}. \tag{.2}$$

Table B.2 presents the results for estimating κ using Equation 5.5 for the periods 1992-2002 and 2005-2012. While the coefficients are in the same range as those in Table 1.5, the weaker F-statistics and R^2 cause me to favor the results without Eastern Europe.

Appendix C: Full Derivation of Model

Here I present a full derivation of the model.

Demand side

Technology. Suppose there are N countries indexed by i, j and S sectors indexed by s. Labor is the only factor of production. There are constant returns to scale in the production of each sector. Labor is mobile across sectors and immobile across countries.[10] Denote the number of workers in country i by L_i and the country-sector-specific efficiency wage as w_{is}. Goods in each sector s may come in an infinite number of varieties indexed by $\omega \in \Omega$, where $\Omega \equiv [1, 2, ..., \infty]$. Denote by $z_{is}(\omega)$ the number of units of a variety ω in sector s that can be produced by one unit of labor in country i. Assume, for all countries, sectors, and their varieties, that $z_{is}(\omega)$ is independently drawn from an $\{i, s\}$-specific Fréchet distribution such that

$$F_{is}(z) = \exp[-T_{is} z^{-\theta_s}], \qquad \forall z \geq 0,$$

where $z_{is} > 0$ and $\theta_s > 1$.

[10] Labor is also immobile across "groups" as defined above, but the derivation is the same regardless of modeling groups in each country.

Each sector s aggregates varieties ω unique to sector s using a CES production function

$$Y_{is} = \left[\int_{\Omega} Q_{is}(\omega)^{(\nu-1)/\nu} d\omega\right]^{\nu/(\nu-1)},$$

where ν denotes the elasticity of substitution across varieties, $Q_{is}(\omega)$ gives the amount of variety ω that is produced, and Y_{is} is the total output of country i in sector s.

Trade costs. I make the "iceberg" trade cost assumption. For each unit of a good in sector s shipped from country i to country j, only $1/\tau_{ijs}$ units arrive. I normalize $\tau_{iis} = 1\ \forall i, s$,[11] and assume the trade cost of traveling through any additional country between i and j is greater than or equal to the cost of traveling between i and j.

Market structure. Markets are assumed to be perfectly competitive. Since production has constant returns to scale in each sector, and goods and factor markets are perfectly competitive, the price at which country i supplies a good in sector s to j is

$$P_{ijs}(\omega) = \frac{\tau_{ijs} w_{is}}{z_{is}(\omega)}.$$

Buyers of each good in sector s in country j will pay the minimum possible cost amongst countries. Thus, the actual price they pay is

$$P_{js}(\omega) = \min_{1 \le i \le N} \left\{ \frac{\tau_{ijs} w_{is}}{z_{is}(\omega)} \right\}.$$

Preferences. In each country, there exists a representative consumer with a two-level utility function. The "upper" tier utility function is Cobb-Douglas with shares $\sum \beta_{js} = 1$, while the "lower" tier utility function is one with constant elasticity of substitution:

$$U_j = \prod_s X_{js}^{\beta_{js}},$$

with budget constraint $X_j = Y_j + D_j$. Then total expenditure of variety ω of a good in sector

[11] I do not have data on trade between groups in Germany.

s is given by

$$X_{js}(\omega) = [P_{js}(\omega)/P_{js}]^{1-\sigma_s} \cdot \beta_{js} X_j,$$

where $0 \leq \beta_{js} \leq 1$ and $P_{js} \equiv [\sum_\omega p_{js}(\omega)^{1-\sigma_s}]^{1/1-\sigma_s}$. Denote the total value of exports from country i to country j in sector s by

$$X_{js} \equiv \sum_{\omega}^{\Omega_{ijs}} X_{js}(\omega),$$

where $\Omega_{ijs} \equiv \{\omega \in \Omega | c_{ijs}(\omega) = \min_{1 \leq i \leq N} c_{ijs}(\omega)\}$ is the set of varieties in sector s that country i exports to country j. Denote the share of exports from country i to country j in sector s by

$$\lambda_{ijs} \equiv \frac{X_{ijs}}{\sum_i X_{ijs}}.$$

I do not make the balanced trade assumption in Costinot et al. (2012). I do require, however, that world trade is balanced, namely $\sum_i D_i = 0$.

Equilibrium. The competitive equilibrium of this model world economy consists of a set of prices, allocation rules, and trade shares such that: (i) Given the prices, all firms' labor inputs satisfy the first-order conditions, and their output is given by the production function; (ii) Given the prices, the consumers' demand satisfies the first-order conditions; (iii) The prices ensure the market clearing conditions for labor and goods; (iv) Trade shares ensure trade is balanced globally. The prices are the wage rate, sectoral prices, and aggregate price levels. The allocation rules include the allocation labor across sectors and consumption demand for each sector.

Following EK, define

$$\Phi_{js} = \sum_{i=1}^{N} T_{is}(\tau_{ijs} w_{is})^{-\theta_s}.$$

Substituting the expression for sectoral-level prices into the productivity CDF above, the Fréchet distribution gives a convenient form for the distribution of prices: the price of a good in sector s in country j is simply

$$P_{js} = \Gamma\left[1 + \frac{1-\sigma_s}{\theta_s}\right]^{1/(1-\sigma_s)} \cdot (\Phi_{js})^{-1/\theta_s},$$

where Γ is the gamma function. This is the result given by Equation 3.3. This EK structure in each sector s also delivers the result that the probability of importing good ω from country i is equal to the share of total spending on goods coming from country i. Namely,

$$\lambda_{ijs} \equiv \frac{X_{ijs}}{\sum_i X_{ijs}} = \frac{T_{is}(\tau_{ijs}w_{is})^{-\theta_s}}{\sum_i T_{is}(\tau_{ijs}w_{is})^{-\theta_s}},$$

as in Equation 3.2. Using this notation, it follows that the demand for efficiency units in $\{i, s\}$ is given by

$$\frac{1}{w_{is}} \sum_j \lambda_{ijs}\beta_{js}X_j,$$

mirroring the result in Equation 3.1.

Supply side

Technology. Suppose there are G_i groups in country i who provide labor in sectors s as characterized above. Denote by ϵ_{igs} the number of units in sector s that can be produced by one unit of labor in country-group ig.[12] Assume, for all countries, groups, and sectors, that ϵ_{igs} is independently drawn from an $\{i, g, s\}$-specific Fréchet distribution such that

$$F_{igs}(\epsilon) = \exp[-A_{igs}\epsilon^{-\kappa_{ig}}], \qquad \forall \epsilon \geq 0,$$

where $\epsilon_{igs} > 0$ and $\kappa_{ig} > 1$.

Occupational choice. Workers choose the sector in which they earn their highest in-

[12]There is a slight abuse in notation here. In the main text (as in Equation 3.4), I use z rather than ϵ. So as not to confuse the reader by using z for both the demand and supply side distributions, I use ϵ in this appendix.

come, and their choice of sector determines labor supply. More formally, define a set of productivities $\boldsymbol{\epsilon} = (\epsilon_{ig,1}, \epsilon_{ig,2}, ..., \epsilon_{ig,S})$ and let $\Omega_{ig} \equiv \{\boldsymbol{\epsilon} \text{ s.t. } \epsilon_{igs} w_{is} \geq \epsilon_{igr} w_{ir} \ \forall r \in S\}$. Any worker with productivity vector $\boldsymbol{\epsilon}$ will choose to work in sector s if and only if $\boldsymbol{\epsilon} \in \Omega_{ig}$. Said differently, the probability that the worker in ig chooses to work in sector s is the probability that $\epsilon_{igs} w_{is}$ yields the greatest income. As in Section 6, given that the productivity draws are iid Fréchet, the greatest income (highest utility) can also be characterized by a Fréchet distribution. Accordingly, the probability that a given worker in $\{i, g\}$ (and therefore proportion of the workers in L_{ig}) to select into sector s can be given by

$$\pi_{igs} \equiv \int_{\Omega_{ig}} dF_{igs}(\epsilon) = \frac{A_{igs} w_{is}^{\kappa_{ig}}}{\sum_s A_{igs} w_{is}^{\kappa_{ig}}},$$

which is the result in Equation 3.4. For a given group, the average productivity in each sector is

$$E[\epsilon_{igs}] = \eta_{ig} \left(\frac{A_{igs}}{\pi_{igs}} \right)^{1/\kappa_{ig}},$$

where $\eta_{ig} \equiv \Gamma\left[1 - \frac{1}{\kappa_{ig}}\right]$. Then the supply of efficiency units in $\{i, g, s\}$can be given by

$$E_{igs} \equiv L_{ig} \int_{\Omega_{is}} \epsilon_s dF_{ig}(\epsilon)$$

$$\begin{aligned}
L_{ig} \int_{\Omega_{is}} \epsilon_s dF_{ig}(\epsilon) &= E[\epsilon_{igs}] \pi_{igs} L_{ig} \\
&= \eta_{ig} \left(\frac{A_{igs}}{\frac{A_{igs} w_{is}^{\kappa_{ig}}}{\sum_s A_{igs} w_{is}^{\kappa_{ig}}}} \right)^{1/\kappa_{ig}} \pi_{igs} L_{ig} \\
&= \eta_{ig} \frac{1}{w_{is}} \left(\sum_s A_{igs} w_{is}^{\kappa_{ig}} \right)^{1/\kappa_{ig}} \pi_{igs} L_{ig} \\
&= \eta_{ig} \frac{\Phi_{ig}}{w_{is}} \pi_{igs} L_{ig}
\end{aligned}$$

where $\Phi_{ig}^{\kappa_{ig}} = \sum_s A_{igs} w_{is}^{\kappa_{ig}}$, providing the result in Equation 3.5.

Appendix D: Cable Network Data

When constructing the cable network dataset, I am forced to make a decision on how to quantify a bilateral pair's connectivity. One approach would be to create a dichotomous variable that takes a value of one whenever at lease one cable links two countries (as is the case in Table E.12). In this interpretation, the relevant factor is whether two countries are connected through a submarine cable at all. To better replicate the nature of data transfer, however, I would like to use a more nuanced measure of the capacity of connectivity between two points.

With the data available to me, I can make two possible refinements. I can include a cummulative total of the connecting cables between two countries, or I can measure the available bandwidth between those two countries. As more cables increase the available bandwidth between two endpoints, these two measures are highly correlated. They are not identical, however, as each cable is not identical in the bandwidth it provides. The capacities of cables have grown over time, and there is also significant variation within a given year. This latter form of variation is often due to geographical anomalies requiring low-capacity cables to service small islands. As an example, the 2011 Europe-India Gateway is a high-capacity cable connecting two continents whereas the 2011 Energinet Laeso-Varberg cable connects the Danish island of Laeso to Varberg, Sweden. Without taking capacity into account, these connections would be face neutral.

From a technological perspective, using the capacity measurement would be a better solution over the cable count. Unfortunately, some of the smaller cables do not publically list their capacities. As a result, I use both measures in my estimation and analysis. The gravity regression results tell similar stories between the two measurements. I prefer the capacity results over the raw cable count as the coefficient is more interpretable – log points of capacity translate to log points of services exports rather than translating an integer of cables to log points of services exports.

Appendix E: Supplementary Tables and Figures

Table E.1: ICP-ICIO Concordance

ICP	ICIO	ICIO	Tradable
Health	Health & Social Work	85	N
Transport	Transport & Storage	60t63	N
Communication	Post & Telecommunications	64	N
Recreation & Culture	Other community, Social & Personal Services	90t93	N
Education	Education	80	N
Restaurants & Hotels	Hotels & Restaurants	55	N
Food & Non-Alcohol	Food Products, Beverages & Tobacco	15t16	Y
Alcohol, Tobacco, & Narcotics	Food Products, Beverages & Tobacco	15t16	Y
Clothing & Footwear	Textiles, Textile Products, Leather & Footwear	17t19	Y

Table E.2: Value added share in gross output by sector

Country	Trad.	Non-trad.	ω^N	Health	Trans.	Comm.	Rec.	Educ.	Rest.	Cons.
AUS	0.40	0.52	0.80	0.67	0.44	0.49	0.59	0.75	0.46	0.31
AUT	0.32	0.53	0.79	0.62	0.40	0.44	0.56	0.83	0.61	0.40
BEL	0.21	0.50	0.85	0.60	0.33	0.53	0.41	0.88	0.38	0.28
BGR	0.26	0.47	0.72	0.57	0.31	0.56	0.44	0.78	0.58	0.26
BRA	0.30	0.61	0.76	0.56	0.47	0.50	0.51	0.71	0.42	0.52
BRN	0.77	0.59	0.30	0.66	0.72	0.80	0.52	0.86	0.43	0.21
CAN	0.40	0.60	0.78	0.82	0.56	0.63	0.58	0.78	0.50	0.43
CHE	0.36	0.57	0.79	0.68	0.35	0.52	0.45	0.73	0.51	0.47
CHL	0.42	0.55	0.69	0.61	0.34	0.48	0.69	0.81	0.45	0.53
CHN	0.24	0.43	0.53	0.41	0.47	0.60	0.45	0.58	0.40	0.25
COL	0.48	0.60	0.67	0.40	0.44	0.55	0.57	0.79	0.46	0.50
CRI	0.33	0.60	0.77	0.69	0.48	0.51	0.65	0.85	0.47	0.42
CYP	0.33	0.61	0.91	0.65	0.54	0.63	0.58	0.87	0.49	0.37
CZE	0.23	0.43	0.72	0.59	0.37	0.54	0.40	0.75	0.41	0.29
DEU	0.31	0.57	0.75	0.70	0.36	0.42	0.60	0.77	0.50	0.43
DNK	0.34	0.52	0.83	0.70	0.26	0.43	0.52	0.73	0.38	0.37
ESP	0.30	0.60	0.83	0.64	0.42	0.48	0.55	0.85	0.63	0.50
EST	0.27	0.46	0.77	0.61	0.28	0.42	0.43	0.70	0.34	0.32
FIN	0.26	0.53	0.79	0.65	0.39	0.47	0.53	0.70	0.41	0.35
FRA	0.25	0.58	0.87	0.75	0.46	0.44	0.53	0.82	0.47	0.45
GBR	0.35	0.53	0.85	0.51	0.42	0.52	0.54	0.70	0.47	0.41
GRC	0.33	0.65	0.86	0.70	0.44	0.79	0.57	0.91	0.73	0.29
HKG	0.16	0.56	0.98	0.71	0.40	0.28	0.51	0.74	0.53	0.51
HRV	0.35	0.53	0.76	0.67	0.47	0.55	0.47	0.79	0.57	0.33
HUN	0.23	0.53	0.73	0.58	0.41	0.60	0.51	0.76	0.36	0.41
IDN	0.51	0.51	0.50	0.46	0.40	0.78	0.50	0.60	0.45	0.35
IND	0.35	0.63	0.66	0.60	0.44	0.58	0.74	0.90	0.27	0.35
IRL	0.31	0.46	0.71	0.56	0.31	0.42	0.41	0.76	0.46	0.26
ISL	0.33	0.48	0.78	0.54	0.25	0.35	0.48	0.56	0.38	0.34
ISR	0.34	0.59	0.83	0.49	0.43	0.62	0.48	0.75	0.44	0.46
ITA	0.28	0.54	0.81	0.63	0.39	0.50	0.49	0.85	0.47	0.43
JPN	0.31	0.63	0.80	0.60	0.58	0.56	0.67	0.80	0.45	0.49

Table E.3: Value added share in gross output by sector

Country	Trad.	Non-trad.	ω^N	Health	Trans.	Comm.	Rec.	Educ.	Rest.	Cons.
KHM	0.45	0.53	0.46	0.62	0.47	0.56	0.70	0.70	0.38	0.48
KOR	0.21	0.51	0.66	0.55	0.33	0.39	0.50	0.76	0.33	0.35
LTU	0.30	0.65	0.75	0.63	0.65	0.66	0.61	0.80	0.72	0.53
LUX	0.28	0.34	0.93	0.75	0.45	0.40	0.62	0.83	0.49	0.40
LVA	0.28	0.43	0.80	0.61	0.36	0.40	0.49	0.74	0.39	0.21
MEX	0.43	0.72	0.69	0.75	0.73	0.61	0.64	0.90	0.74	0.50
MLT	0.34	0.41	0.84	0.68	0.30	0.48	0.26	0.83	0.37	0.35
MYS	0.26	0.46	0.53	0.34	0.27	0.49	0.33	0.64	0.38	0.25
NLD	0.28	0.53	0.81	0.73	0.40	0.47	0.44	0.78	0.51	0.36
NOR	0.53	0.53	0.64	0.78	0.28	0.39	0.52	0.78	0.49	0.38
NZL	0.31	0.51	0.79	0.63	0.42	0.50	0.51	0.71	0.46	0.30
PHL	0.36	0.60	0.66	0.52	0.44	0.61	0.49	0.68	0.37	0.55
POL	0.27	0.52	0.75	0.60	0.38	0.53	0.54	0.81	0.53	0.34
PRT	0.26	0.54	0.83	0.56	0.41	0.49	0.50	0.85	0.49	0.34
ROU	0.39	0.46	0.67	0.53	0.40	0.53	0.53	0.81	0.46	0.35
SAU	0.77	0.58	0.40	0.54	0.52	0.52	0.49	0.80	0.46	0.39
SGP	0.22	0.43	0.79	0.54	0.34	0.44	0.49	0.69	0.46	0.23
SVK	0.23	0.48	0.74	0.57	0.34	0.53	0.62	0.75	0.52	0.39
SVN	0.29	0.51	0.76	0.63	0.34	0.47	0.45	0.76	0.48	0.31
SWE	0.31	0.53	0.80	0.72	0.32	0.41	0.50	0.67	0.37	0.44
THA	0.29	0.52	0.56	0.46	0.33	0.59	0.29	0.78	0.34	0.22
TUN	0.37	0.64	0.67	0.68	0.64	0.77	0.86	0.90	0.58	0.30
TUR	0.26	0.58	0.71	0.51	0.49	0.55	0.53	0.78	0.44	0.43
TWN	0.20	0.60	0.72	0.61	0.35	0.56	0.52	0.80	0.51	0.29
USA	0.35	0.61	0.84	0.61	0.51	0.55	0.61	0.74	0.53	0.53
VNM	0.32	0.49	0.47	0.61	0.49	0.71	0.68	0.68	0.52	0.26
ZAF	0.32	0.54	0.75	0.46	0.53	0.41	0.70	0.51	0.45	0.30
Mean	**0.33**	**0.54**	**0.73**	**0.61**	**0.42**	**0.53**	**0.53**	**0.76**	**0.47**	**0.37**

Table E.4: Share of tradable intermediate inputs by sector

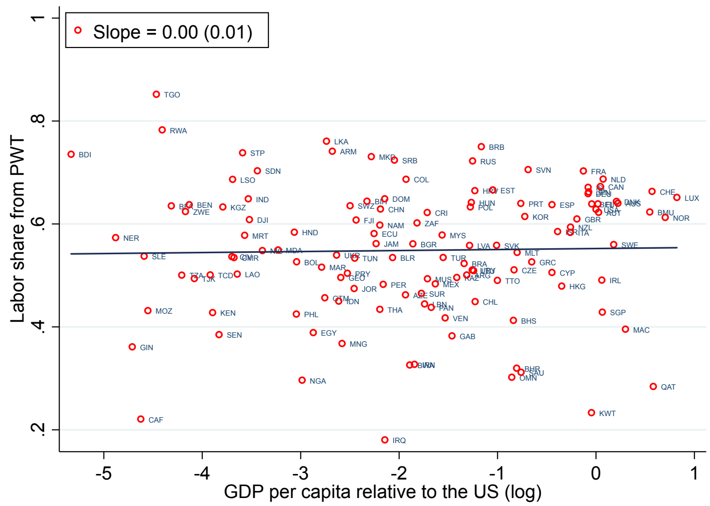
Country	Trad.	Non-trad.	Country	Trad.	Non-trad.
AUS	0.52	0.19	KHM	0.80	0.57
AUT	0.60	0.19	KOR	0.81	0.44
BEL	0.60	0.17	LTU	0.56	0.33
BGR	0.60	0.34	LUX	0.61	0.08
BRA	0.65	0.26	LVA	0.58	0.21
BRN	0.86	0.32	MEX	0.71	0.35
CAN	0.63	0.25	MLT	0.68	0.19
CHE	0.52	0.22	MYS	0.79	0.41
CHL	0.63	0.27	NLD	0.63	0.19
CHN	0.80	0.54	NOR	0.60	0.24
COL	0.68	0.34	NZL	0.57	0.20
CRI	0.59	0.30	PHL	0.76	0.42
CYP	0.61	0.30	POL	0.63	0.31
CZE	0.71	0.22	PRT	0.62	0.23
DEU	0.62	0.21	ROU	0.60	0.33
DNK	0.48	0.26	SAU	0.68	0.22
ESP	0.60	0.26	SGP	0.62	0.18
EST	0.63	0.24	SVK	0.69	0.25
FIN	0.57	0.28	SVN	0.61	0.24
FRA	0.57	0.19	SWE	0.55	0.19
GBR	0.58	0.18	THA	0.75	0.45
GRC	0.60	0.24	TUN	0.75	0.53
HKG	0.43	0.13	TUR	0.73	0.34
HRV	0.57	0.35	TWN	0.75	0.41
HUN	0.67	0.27	USA	0.67	0.23
IDN	0.75	0.53	VNM	0.80	0.54
IND	0.69	0.46	ZAF	0.55	0.26
IRL	0.59	0.17	**Mean**	0.64	0.29
ISL	0.59	0.19			
ISR	0.62	0.20			
ITA	0.57	0.23			
JPN	0.68	0.33			

Table E.5: Industry Tradability

Sector	Code	Feenstra	AMECO
C01T05	Agriculture, hunting, forestry and fishing	T	T
C10T14	Mining and quarrying	T	T
C15T16	Food products, beverages and tobacco	T	T
C17T19	Textiles, textile products, leather and footwear	T	T
C20	Wood and products of wood and cork	T	T
C21T22	Pulp, paper, paper products, printing and publishing	T	T
C23	Coke, refined petroleum products and nuclear fuel	T	T
C24	Chemicals and chemical products	T	T
C25	Rubber and plastics products	T	T
C26	Other non-metallic mineral products	T	T
C27	Basic metals	T	T
C28	Fabricated metal products	T	T
C29	Machinery and equipment, nec	T	T
C30T33X	Computer, Electronic and optical equipment	T	T
C31	Electrical machinery and apparatus, nec	T	T
C34	Motor vehicles, trailers and semi-trailers	T	T
C35	Other transport equipment	T	T
C36T37	Manufacturing nec; recycling	T	T
C40T41	Electricity, gas and water supply	N	N
C45	Construction	N	N
C50T52	Wholesale and retail trade; repairs	N	T
C55	Hotels and restaurants	N	T
C60T63	Transport and storage	N	T
C64	Post and telecommunications	N	N
C65T67	Financial intermediation	N	N
C70	Real estate activities	N	N
C71	Renting of machinery and equipment	N	N
C72	Computer and related activities	N	N
C73T74	R&D and other business activities	N	N
C75	Public admin. and defense; compulsory social security	N	N
C80	Education	N	N
C85	Health and social work	N	N
C90T93	Other community, social and personal services	N	N

Notes: The Table reports the average and median sectoral labor shares for the countries in our sample Source: Authors calculations based on ICIO Tables and the PWT.

Figure E.1: Aggregate labor share and income per capita



Notes: This figure plots the relation between the aggregate labor share and income per capita. Source PWT and WDI indicators, data for 2011.

Figure E.2: Real exchange rates and sectoral differences in technologies

Notes: This figure plots the relation between the log of the price level of each country relative to the US and the log of GDP per capita relative to the US. 'RER data' refers to the relative price of GDP relative to the US obtained from the PWT 9.0. 'Residual' corresponds to the relative prices implied by the term labeled 'Residual' in equation (3.5).

Table E.6: List of Countries

Afghanistan	Costa Rica	Haiti	Moldova	Singapore
Albania	Cote d'Ivoire	Honduras	Mongolia	Slovakia
Algeria	Croatia	Hong Kong	Montenegro	Slovenia
American Samoa	Cuba	Hungary	Morocco	Somalia
Andorra	Cyprus	Iceland	Mozambique	South Africa
Angola	Czech Rep.	India	Myanmar	Spain
Argentina	Denmark	Indonesia	Namibia	Sri Lanka
Armenia	Djibouti	Iran	Nepal	Sudan
Australia	Dominican Republic	Iraq	Netherlands	Suriname
Austria	Ecuador	Ireland	New Zealand	Sweden
Azerbaijan	Egypt	Israel	Nicaragua	Switzerland
Bahamas	El Salvador	Italy	Niger	Syria
Bahrain	Equatorial Guinea	Jamaica	Nigeria	Taiwan
Bangladesh	Estonia	Japan	Norway	Tajikistan
Belarus	Ethiopia	Jordan	Oman	Tanzania
Belgium	Fiji	Kazakhstan	Pakistan	Thailand
Belize	Finland	Kenya	Palestine	Togo
Benin	France	Korea	Panama	Tonga
Bermuda	French Guiana	Kuwait	Papua New Guinea	Tunisia
Bhutan	French Polynesia	Kyrgyzstan	Paraguay	Turkey
Bolivia	Gabon	Latvia	Peru	USA
Bosnia & Herzegovina	Gambia	Lebanon	Philippines	Uganda
Brazil	Georgia	Liberia	Poland	Ukraine
Brunei	Germany	Libya	Portugal	United Arab Emirates
Bulgaria	Ghana	Lithuania	Puerto Rico	Uruguay
Cambodia	Gibraltar	Luxembourg	Qatar	Uzbekistan
Cameroon	Great Britain	Madagascar	Reunion	Venezuela
Canada	Greece	Malaysia	Romania	Viet Nam
Cayman Islands	Greenland	Maldives	Russia	Virgin Islands (Brit.)
Central African Republic	Grenada	Mali	Rwanda	Yemen
Chad	Guadeloupe	Malta	Samoa	Zambia
Chile	Guam	Mauritania	Saudi Arabia	Zimbabwe
China	Guatemala	Mauritius	Senegal	
Colombia	Guinea	Mayotte	Serbia	
Congo (Dem. Rep. of)	Guyana	Mexico	Seychelles	

Table E.7: Routing Subsample

Bangladesh	Jordan	Pakistan	Thailand
Djibouti	Lebanon	Philippines	Tunisia
Egypt	Malaysia	Saudi Arabia	United Arab Emirates
India	Morocco	South Africa	

Table E.8: List of Service Sectors

200 Total EBOPS Services	249 4 Construction services
205 1 Transportation	250 4.1 Construction abroad
206 1.1 Sea transport	251 4.2 Construction in the compiling economy
207 1.1.1 Passenger	253 5 Insurance services
208 1.1.2 Freight	254 5.1 Life insurance and pension funding
209 1.1.3 Other	255 5.2 Freight insurance
210 1.2 Air transport	256 5.3 Other direct insurance
211 1.2.1 Passenger	257 5.4 Reinsurance
212 1.2.2 Freight	258 5.5 Auxiliary services
213 1.2.3 Other	260 6 Financial services
214 1.3 Other transport	262 7 Computer and information services
215 1.3.1 Passenger	263 7.1 Computer services
216 1.3.2 Freight	264 7.2 Information services
217 1.3.3 Other	266 8 Royalties and license fees
218 1.4 Space transport	268 9 Other business services
219 1.5 Rail transport	269 9.1 Merchanting and other trade-related services
220 1.5.1 Passenger	270 9.1.1 Merchanting
221 1.5.2 Freight	271 9.1.2 Other trade-related services
222 1.5.3 Other	272 9.2 Operational leasing services
223 1.6 Road transport	273 9.3 Misc. business, professional, and technical serv.
224 1.6.1 Passenger	274 9.3.1 Legal, accounting, consulting, public relations
225 1.6.2 Freight	275 9.3.1.1 Legal services
226 1.6.3 Other	276 9.3.1.2 Accounting, auditing, bookkeeping, tax serv.
227 1.7 Inland waterway transport	277 9.3.1.3 Business and management
228 1.7.1 Passenger	278 9.3.2 Advertising, market research
229 1.7.2 Freight	279 9.3.3 Research and development
230 1.7.3 Other	280 9.3.4 Architectural, engineering, other technical serv.
231 1.8 Pipeline trans./elec. transmission	281 9.3.5 Agricultural, mining, on-site processing serv.
232 1.9 Oth. supp./aux. trans. services	282 9.3.5.1 Waste treatment and depollution
236 2 Travel	283 9.3.5.2 Agric., mining, other on-site processing serv.
237 2.1 Business travel	284 9.3.6 Other business services
238 2.1.1 Exp. by seasonal/border workers	285 9.3.7 Services between related enterprises, n.i.e.
239 2.1.2 Other	287 10 Personal, cultural, and recreational services
240 2.2 Personal travel	288 10.1 Audiovisual and related services
241 2.2.1 Health-related expenditures	289 10.2 Other personal, cultural, and recreational serv.
242 2.2.2 Education-related expenditures	291 11 Government services, n.i.e.
243 2.2.3 Other	292 11.1 Embassies and consulate
245 3 Communications services	293 11.2 Military units and agencies
246 3.1 Postal and courier services	294 11.3 Other government services
247 3.2 Telecommunications services	

Sectors in blue are considered data-intensive as measured by telecommunications input in WIOD.

Figure E.3: Cable Map

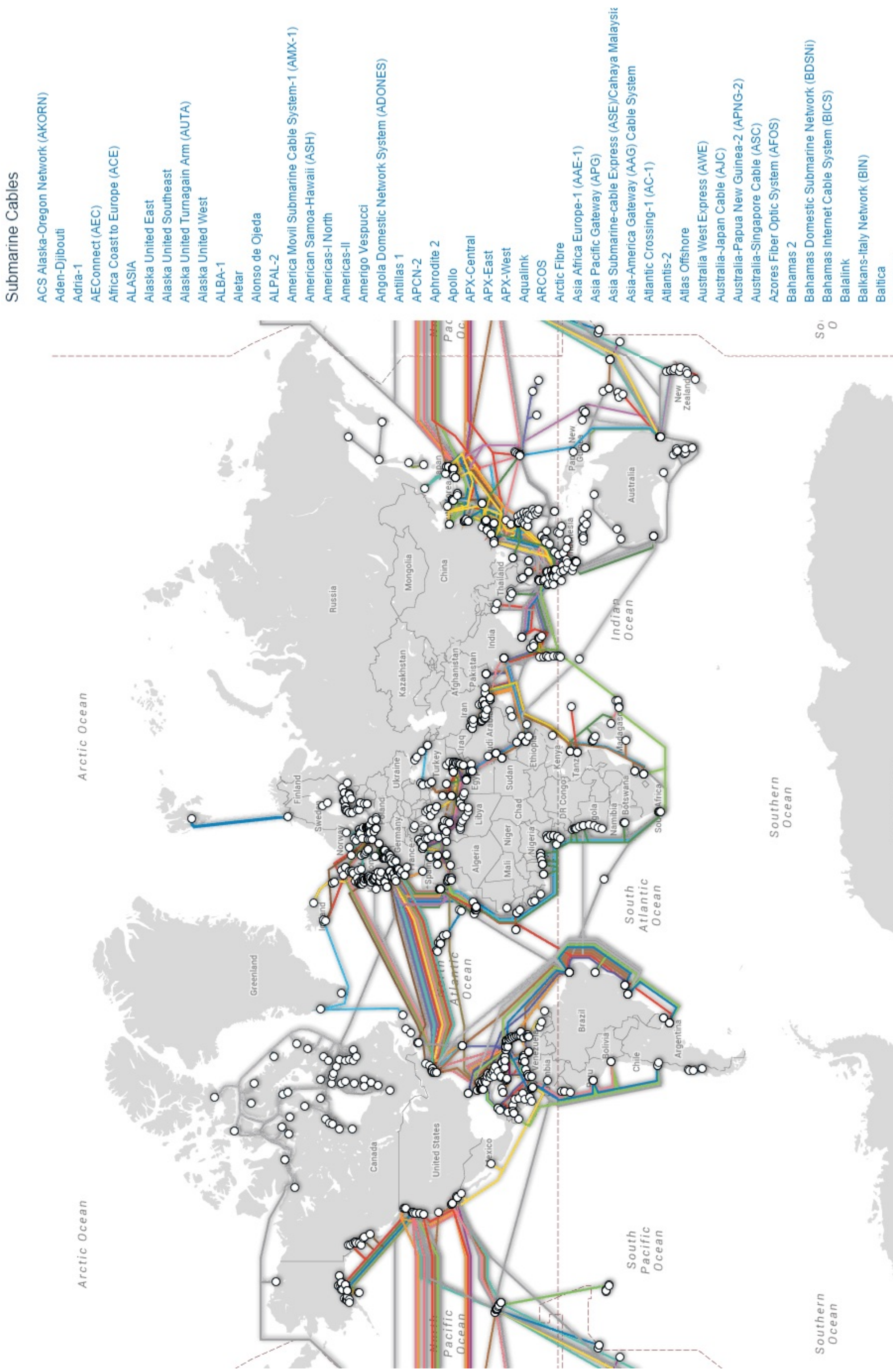


Figure E.4: FEA

Figure E.5: SEA-ME-WE 3

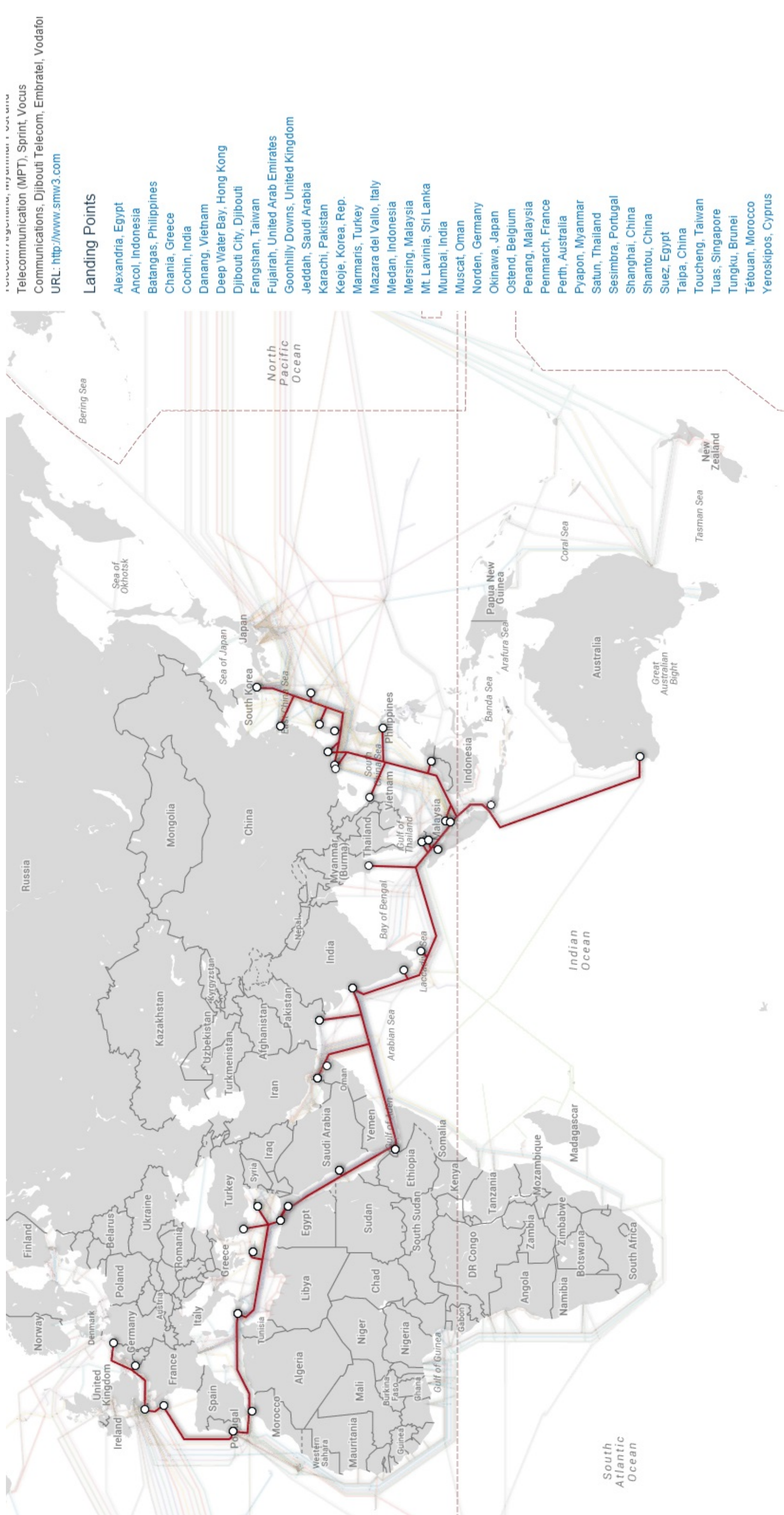


Figure E.6: SEA-ME-WE 4

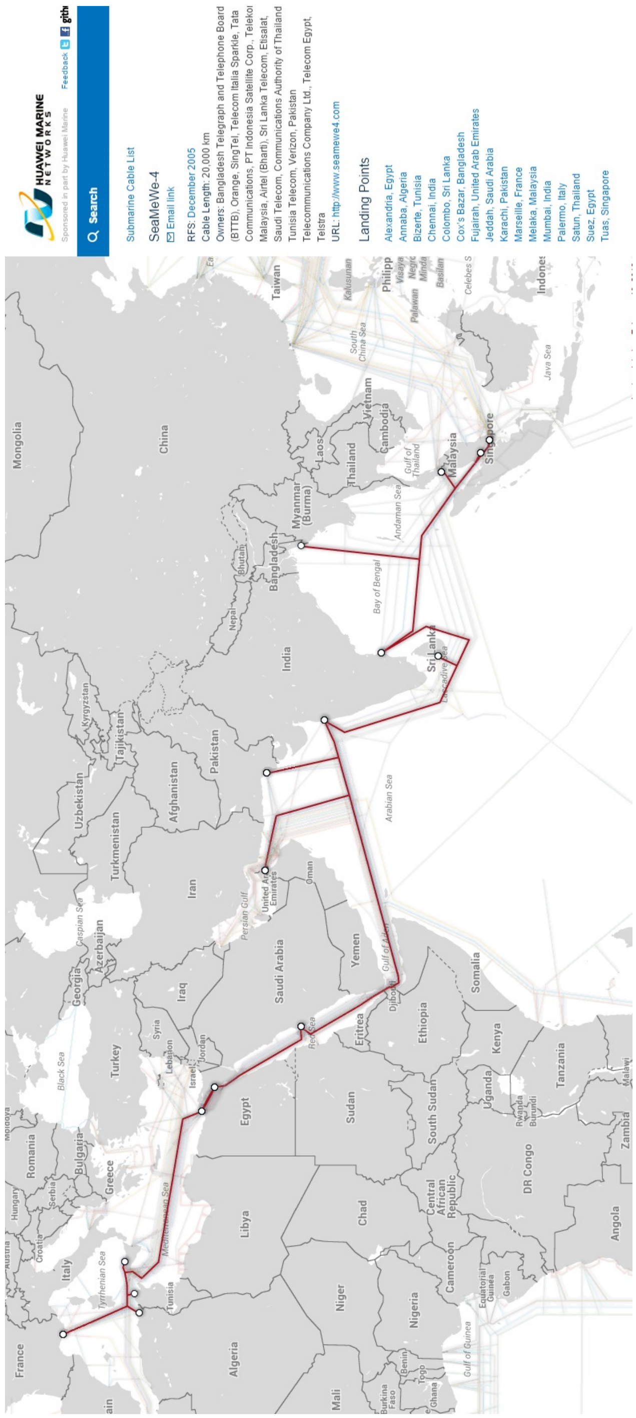


Figure E.7: IMEWE

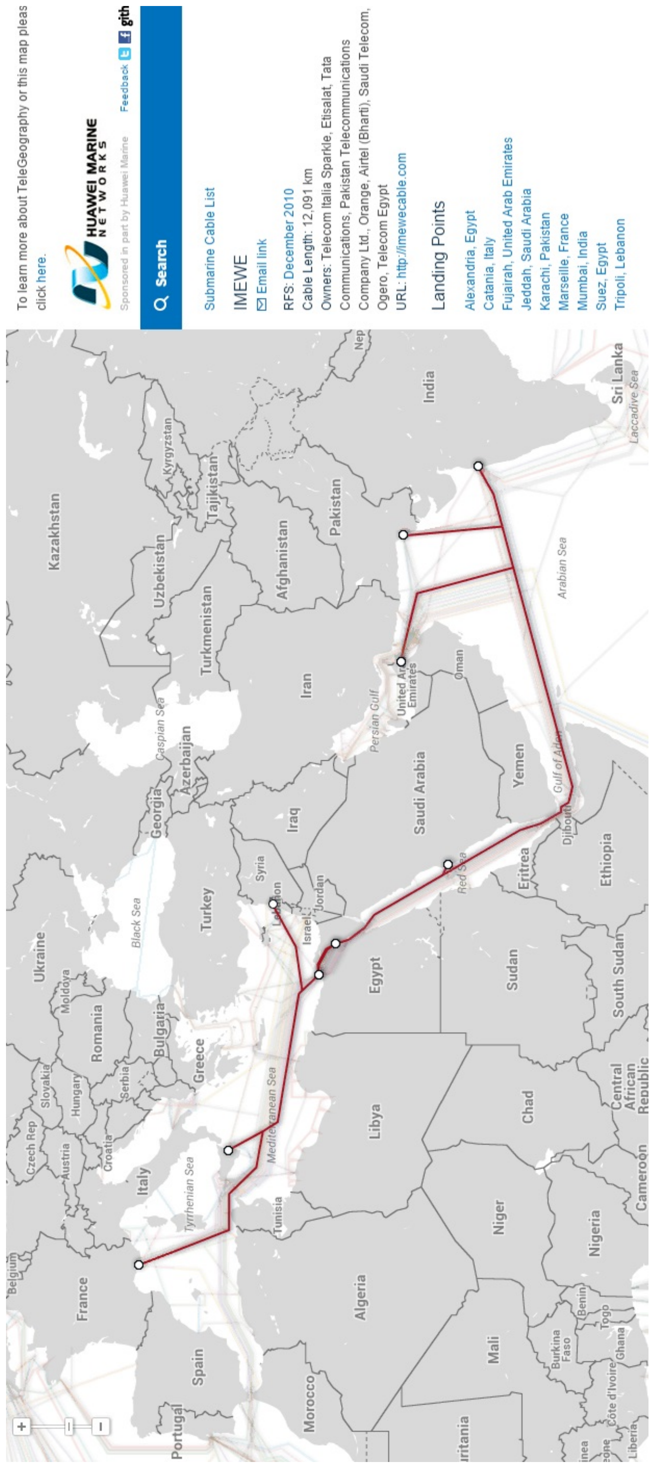


Table E.9: Full Sample

	Cables (2-digit)	Tb/s (2-digit)	Cables (3-digit)	Tb/s (3-digit)
Data-Intensive Services	0.066	0.258***	0.127***	0.338***
	(0.044)	(0.103)	(0.048)	(0.119)
Other Services	0.034	0.100**	0.146***	0.377***
	(0.025)	(0.050)	(0.055)	(0.115)
Destination-Source-Sector FE	Y	Y	Y	Y
Source-Sector-Year FE	Y	Y	Y	Y
Destination-Sector-Year FE	Y	Y	Y	Y
Observations	683,997	683,997	669,919	669,919
Groups	41,828	41,828	41,825	41,825
R^2	0.880	0.880	0.878	0.878

Standard errors are clustered at the Destination-Source level. Asterisks represent statistical significance at the 10% level (*), 5% level (**), and 1% level (***).

Table E.10: Restricted Sample

	Cables (2-digit)	Tb/s (2-digit)
Data-Intensive Services	0.414**	1.822***
	(0.208)	(0.653)
Other Services	-0.199	-0.289
	(0.151)	(0.708)
Destination-Source-Sector FE	Y	Y
Source-Sector-Year FE	Y	Y
Destination-Sector-Year FE	Y	Y
Observations	78,658	78,658
Groups	3,896	3,896
R^2	0.890	0.890

Standard errors are clustered at the Destination-Source level. Asterisks represent statistical significance at the 10% level (*), 5% level (**), and 1% level (***).

Table E.11: Egypt Sample

	Cables (2-digit)	Tb/s (2-digit)
Data-Intensive Services	0.919***	2.249**
	(0.304)	(1.110)
Other Services	-0.370***	-1.288
	(0.095)	(0.791)
Destination-Source-Sector FE	Y	Y
Year FE	Y	Y
Observations	4,633	4,633
Groups	214	214
R^2	0.842	0.842

Standard errors are clustered at the Destination-Source level. Asterisks represent statistical significance at the 10% level (*), 5% level (**), and 1% level (***).

Table E.12: Single Cable Connectivity

	Full Sample (2-digit)	Exo Sample (2-digit)	Egypt (2-digit)
Data-Intensive Services	0.174*	-0.076	0.628***
	(0.094)	(0.247)	(0.105)
Other Services	-0.053	0.136	-0.482**
	(0.053)	(0.284)	(0.195)
Destination-Source-Sector FE	Y	Y	Y
Source-Sector-Year FE	Y	Y	N
Destination-Sector-Year FE	Y	Y	N
Year FE	N	N	Y
Observations	683,997	78,658	4,633
Groups	41,828	3,896	214
R^2	0.880	0.890	0.842

Standard errors are clustered at the Destination-Source level. Asterisks represent statistical significance at the 10% level (*), 5% level (**), and 1% level (***).

Table E.13: Inclusion of Quadratic Term

	Full Sample (2-digit)	Exo Group (2-digit)	Egypt (2-digit)
Gb/s, Data-Intensive Services	0.232	-18.940**	-87.251**
	(0.932)	(9.140)	(39.676)
Gb/s^2, Data-Intensive Services	-0.088	9.589**	43.796**
	(0.464)	(4.601)	(19.874)
Gb/s, Other Services	-0.034	14.800**	2.181
	(0.053)	(7.262)	(7.279)
Gb/s^2, Other Services	0.022	-7.445**	-1.158
	(0.266)	(3.671)	(3.650)
Destination-Source-Sector FE	Y	Y	Y
Source-Sector-Year FE	Y	Y	N
Destination-Sector-Year FE	Y	Y	N
Year FE	N	N	Y
Observations	683,997	78,658	4,633
Groups	41,828	3,896	214
R^2	0.880	0.890	0.843

Standard errors are clustered at the Destination-Source level. Asterisks represent statistical significance at the 10% level (*), 5% level (**), and 1% level (***).

Table E.14: Poisson PML (Egypt)

	Cables (2-digit)	Tb/s (2-digit)
Data-Intensive Services	0.533***	1.157*
	(0.190)	(0.665)
Other Services	-0.271**	-0.834***
	(0.119)	(0.302)
Destination-Source-Sector FE	Y	Y
Year FE	Y	Y
Observations[a]	4,644	4,644
Groups[a]	217	217

Standard errors are clustered at the Destination-Source level. Asterisks represent statistical significance at the 10% level (*), 5% level (**), and 1% level (***).
[a]The glm command in Stata does not drop singleton observations. As such, there are 11 more observations and three more groups than in previous regressions with this sample.

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