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What Determines State Heterogeneity in Response to US Tariff Changes?*

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Abstract

We develop a structural framework to identify the sources of cross-state heterogeneity in response to US tariff changes. We quantify the effects of unilaterally increasing US tariffs by 25 percentage points across sectors. Welfare changes range from −0.8 percent in Oregon to 2.1 percent in Montana. States gain more when their sectoral comparative advantage covaries negatively with that of the aggregate US. Consequently, "preferred" changes in tariffs vary systematically across states, indicating the importance of transfers in aligning state preferences over trade policy. Foreign retaliation substantially reduces the gains across states while perpetuating the cross-state variation.

Keywords: Interstate trade, Gains from trade, Customs union

JEL Classifications: F11, F62

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1 Introduction

One defining characteristic of the United States is that it is a customs union with 50 member states, meaning that interstate trade occurs duty-free and all states face common external tariffs. However, heterogeneous characteristics among states, including geography, productivity and endowments, generate winners and losers in response to common tariff changes. Even if the union benefits as a whole, cross-state transfers might be necessary to align state preferences over policy changes. Different from other customs unions, such as the European Union, the United States is also a fiscal union, so in principle such transfers are feasible. As such, it is essential to understand how cross-state heterogeneity influences the impact of trade policy in order to know the magnitudes of the transfers needed in conjunction with trade policy proposals.

We develop a general equilibrium model of international and interstate trade where comparative advantage is governed by Ricardian and Heckscher-Ohlin forces. The model is calibrated to identify the sources of cross-state heterogeneity in response to an increase in US import tariffs. We find that states gain (lose) when their sectoral productivity correlates negatively (positively) with that of the union. Protection favors *sectors* in which the United States has comparative disadvantage vis-à-vis foreign countries, and *states* that have comparative advantage vis-à-vis other states in these sectors reap most of those gains. Hence, states have different preferences over the common external tariffs. Retaliatory tariffs imposed by foreign countries substantially reduce welfare in most states, while perpetuating the cross-state variation in welfare changes. Our framework permits us to design cross-state transfers of tariff revenue so as to balance the welfare impacts.

The model features a multi-location, multi-sector Eaton-Kortum model of trade. Endowed with skilled and unskilled labor, each location differs in sectoral productivity and faces asymmetric physical trade costs and tariffs. Competitive firms produce output using location- and sector-specific labor, as well as tradable intermediate inputs from all sectors. Households in each location earn factor income from both types of workers across all sectors and receive lump-sum rebates of tariff revenue. A subset of locations (the US states) belong to a customs union where they trade duty-free with each other and face common external tariffs with non-US locations. The United States is also a fiscal union wielding the power to transfer tariff revenue across states. In our baseline analysis, US tariff revenue is rebated equally across states on a per-capita basis allowing us to focus on changes in factor income.

We calibrate the model to 50 US states, 8 foreign locations and a rest-of-world aggregate using 14 goods sectors and 2 services sectors for 2012. Following Levchenko and Zhang (2016), we infer bilateral trade costs and productivity for these sectors and locations from observed trade flows using a gravity approach. One challenge that we face is the lack of state-to-state trade data in agriculture, mining, and services, as well as state-to-country trade data in services. We construct sensible estimates for these missing trade flows using a gravity specification that links observed bilateral trade flows with observables, including production at the location-sector level, various measures of distance barriers, as well as sector, origin, and destination fixed effects. Finally, we scale these imputed trade flows to be consistent with state-sector production data and US-sector bilateral trade data with foreign countries.

Our calibration unveils patterns of comparative advantage across all locations. Relative to foreign countries, US *external* comparative advantage, determined by both Ricardian and Heckscher-Ohlin forces, lies in sectors like Computers and electronics and in Chemicals. Sectors with external comparative advantage are either those with high median productivity across states relative to foreign countries or those with high skill-labor intensity, since the US is relatively abundant in skilled labor. The United States has a comparative disadvantage in Mining and in Textiles. Within the United States, *internal* comparative advantage of each state reflects Ricardian forces due to sectoral productivity differences; Heckscher-Ohlin forces do not play a quantitatively important role. For example, Wyoming has a strong internal comparative advantage in Mining, and Oregon in Computers and electronics.

We quantify the effects of increasing US import tariffs across all sectors by 25 percentage points. The change in welfare encompasses contributions from real factor income and from real tariff revenue. US population-weighted welfare increases by 0.55 percent. Real factor income contributes negatively to this welfare change by 1.04 percent because the increased tariffs distort the efficient spatial allocation of production and lead to lower real output. In contrast, tariff revenue contributes positively by 1.59 percent. Because the United States is a large customs union with initially low tariffs, moderately higher tariffs generate an increase in tariff revenue despite a decline in import demand. This creates a favorable shift in the terms of trade, whereby lower US import demand dampens foreign factor returns, subjugating pre-tariff import prices and transferring surplus from foreign countries to home.

The aggregate effects mask important variation across states: welfare changes range from -0.8 percent in Oregon to 2.1 percent in Montana. Most of this heterogeneity across states comes from the variation in factor income contributions since US tariff revenue is rebated across states equally on a per-capita basis. Specifically, most states experience negative factor income contributions that are highly correlated with the welfare changes, while all states experience positive tariff revenue contributions that are uncorrelated with the welfare changes.

What determines the impact of higher tariffs on a state's factor income? The answer hinges on how a state's internal comparative advantage co-varies with US external comparative advantage. When a state's sector of internal comparative advantage coincides with a sector of US external comparative disadvantage, the state experiences a large increase in labor income. Higher tariffs cause US states to redirect expenditures from foreign to domestic producers, especially in sectors that the United States has an external comparative disadvantage (e.g. Mining). States that benefit the most (e.g., Wyoming) are those with an internal comparative advantage and a large share of production in such sectors (e.g., Mining). In contrast, states that benefit the least (e.g., Oregon) are those whose internal comparative advantage lies in Computer and electronics, a sector of US external comparative advantage.

Heterogeneous impacts across states imply that states have considerably different preferences over tariffs. To illustrate this point, we trace out the welfare change for each state across uniform tariff increases, ranging from zero to a prohibitively high value, and identify the tariff increase that maximizes each state's welfare. States like Wyoming, whose internal comparative advantage negatively correlates with US external comparative advantage, favor prohibitively high tariff increases at the expense of other states. Even as tariffs become prohibitively high and tariff revenue dissipates to zero, Wyoming continues benefiting. The reason is because it continues gaining US market share in Mining and purchases goods in Computers and electronics from states like Oregon, whose factor prices are declining with higher tariffs.

We also examine a scenario in which foreign countries impose a tit-for-tat retaliation by increasing their tariffs on imports from the US by 25 percentage points across sectors. This substantially reduces US welfare as the terms of trade shift in favor of foreign countries. In this scenario, US welfare declines by 0.94 percent, in contrast to a welfare increase of 0.55 percent when there is no retaliation. Welfare in foreign countries falls by only 0.13 percent, compared with 0.26 percent with no retaliation. Foreign retaliation also perpetuates the cross-state variation in welfare gains. States whose internal comparative advantage coincides with that of the United States tend to be large exporters, and foreign retaliation hurts exporting states more.

Lastly, we explore sector-specific tariff increases and alternative transfers of tariff revenue across states. We find that a higher tariff in any one sector, rather than a uniform increase across all sectors, produces both winning and losing states. This implies that transfers across states are necessary to align states' preferences over tariff increases even when the policy targets a certain sector. In practice, such cross-state transfers likely need to be outlined in tariff revision proposals to garner majority support. Thus, it is important to understand the fundamentals determining winners and losers in any trade policy change so as to design such transfers.

We contribute to a recent literature that quantitatively integrates internal and international trade (e.g. Caliendo et al., 2018; Caliendo, Dvorkin, and Parro, 2019; Coşar and Fajgelbaum, 2016).[1] A common challenge in this literature is to estimate internal trade costs in spite of missing state-level trade data. We impute the missing trade flows using a reduced-form gravity approach with limited state-to-state and state-to-country trade data but complete country-country trade data, production and expenditure data, and geographic information. Rodríguez-Clare, Ulate, and Vasquez (2020) use a similar approach to estimate internal trade costs when studying the impact of trade shocks on unemployment across US local labor markets. Recent papers by Eckert et al. (2019) and Gervais and Jensen (2019) impute internal trade flows using the difference between a location's expenditure and revenue. Similar to Ramondo, Rodríguez-Clare, and Saborío-Rodríguez (2016), they impose symmetric trade costs, which has the advantage of requiring less data.

Recent research has explored the cross-state impacts of US trade policy changes. Caliendo and Parro (2022) quantify the impacts of the 2018 trade war and provide a thorough review of the trade policy literature. We complement their work by unpacking the cross-state heterogeneity in state-level fundamentals to characterize the determinants of the heterogeneous impacts of trade policy. Auer, Bonadio, and Levchenko (2020) quantify the impact of revoking NAFTA across US sectors and compute the welfare impact on each congressional district by weighing the US sectoral impacts by district-level sectoral employment shares. Our quantitative analysis shows that when cross-location heterogeneity manifests predominantly in sectoral employment shares, this calculation is a good approximation.

There exists a large literature, both theoretical and quantitative, that examines optimal trade policy in settings with many goods, sectors and countries (see for instance Ossa, 2011; Costinot, Donaldson, Vogel, and Werning, 2015; Beshkar and Lashkaripour, 2020; Bagwell, Staiger, and Yurukoglu, 2021; Lashkaripour and Lugovsky, 2022). So far, the literature has not quantitatively explored optimal trade policy in a multi-sector setting that involves the distributional impacts across, and political tensions among, members of a customs union. While we do not tackle this question in this paper, our framework provides a foundation for such an analysis.

2 Model

We build on the workhorse Eaton-Kortum trade model with multiple sectors. The world economy consists of US states and foreign countries. Locations are indexed

[1] Ramondo, Rodríguez-Clare, and Saborío-Rodríguez (2016) and Redding (2016) highlight the role of internal trade costs in international trade models. Coşar and Demir (2016), Donaldson (2018), and Allen and Arkolakis (2022) quantify the role of transportation infrastructure specifically.

by $(n,i) = 1,\ldots,N$, and $\mathcal{US}$ denotes the set of locations within the United States. There are J sectors, indexed by $(j,k) = 1,\ldots,J$. Trade across countries is subject to physical iceberg costs (trade costs from now on) and tariffs, while trade across US locations is subject to only trade costs. Production requires high and low skill labor as well as intermediate inputs in a roundabout format as in di Giovanni, Levchenko, and Zhang (2014) and Caliendo and Parro (2015). Both types of labor are treated as specific factors that are immobile both across locations and across sectors.[2]

Households The representative household in location n is endowed with the high- and low-skill labor: $\bar{h}_n^j$ and $\bar{\ell}_n^j$. These factors are supplied inelastically to local firms in the appropriate sector at the rates w_n^{hj} and $w_n^{\ell j}$. Sectoral labor income f_n^j is pooled within a location and constitutes that location's factor income F_n as follows:

$$F_n = \sum_{j=1}^{J} f_n^j \equiv \sum_{j=1}^{J} \left(w_n^{hj}\bar{h}_n^j + w_n^{\ell j}\bar{\ell}_n^j \right). \tag{1}$$

Each location's income also includes indirect business taxes, IBT_n, which consists of tariff revenue that is rebated in lump sum from the government.

The representative household spends total income on sectoral composite goods c_n^j at price p_n^j, which is inclusive of the tariff imposed on imported varieties. These composite goods are aggregated into a consumption basket:

$$C_n = \prod_{j=1}^{J} \left(c_n^j\right)^{\omega_n^j},$$

where C_n denotes aggregate consumption (utility) in a location, and ω_n^j denotes sector j's weight in the country n's consumption bundle, with $\sum_{j=1}^{J} \omega_n^j = 1$.

Household maximize utility C_n subject to the period budget constraint given by

$$P_n^c C_n = \sum_{j=1}^{J} p_n^j c_n^j = F_n + \text{IBT}_n, \tag{2}$$

where F_n is factor income, IBT_n is tariff revenue, and the consumption price level is

$$P_n^c = \prod_{j=1}^{J} \left(\frac{p_n^j}{\omega_n^j}\right)^{\omega_n^j}.$$

[2]Existing evidence indicates that worker mobility is limited in response to trade shocks (Artuç, Chaudhuri, and McLaren, 2010; Dix-Carneiro, 2014).

Firms There is a unit interval of tradable varieties in each sector indexed by $v \in [0,1]$. Production of each variety can be carried out by a competitive firm using using two types of labor and composite intermediate inputs according to

$$y_n^j(v) = a_n^j(v)\left[A_n^j h_n^j(v)^{\lambda^j} \ell_n^j(v)^{1-\lambda^j}\right]^{\nu^j}\left[\prod_{k=1}^{J} m_n^{jk}(v)^{\mu^{jk}}\right]^{1-\nu^j},$$

where $m_n^{jk}(v)$ denotes the quantity of the composite good from country k used by country n to produce $y_n^j(v)$ units of variety v in sector j; $h_n^j(v)$ denotes the amount of high skill workers employed; and $\ell_n^j(v)$ is the amount of low skill workers. The share parameters are sector specific: ν^j is the share of value added in total output, λ^j is the share of high-skill workers in labor compensation, and μ^{jk} is the share of composite good k in intermediate spending by producers in sector j, with $\sum_k \mu^{jk} = 1$.

Fundamental productivity, A_n^j, scales value-added for all varieties in sector j of country n.[3] The term $a_n^j(v)$ scales gross-output of variety v in sector j of country n. Following Eaton and Kortum (2002), gross-output productivity in sector j for each variety is drawn independently from a Fréchet distribution with sector-specific shape parameter θ^j. The cumulative density function in sector j is $F^j(a) = \exp(-a^{-\theta^j})$.

In each sector and location a competitive firm aggregates all varieties with constant elasticity in order to construct a nontradable composite good according to

$$Q_n^j = \left[\int_0^1 q_n^j(v)^{1-1/\eta} dv\right]^{\eta/(\eta-1)},$$

where η is the elasticity of substitution between varieties, and $q_n^j(v)$ is the quantity of variety v used by country n to construct the sector j. Each variety is sourced globally from the cheapest location. The composite good, Q_n^j, is used domestically for intermediate and final use.

Trade Trade between different locations is subject to two types of barriers. One barrier is a trade cost whereby location n must purchase $d_{ni}^j \geq 1$ units of any variety of sector j from location i in order for one unit to arrive. As a normalization, $d_{nn}^j = 1$ for all (n, j). The second type of barrier is an ad-valorem tariff (tariff from now on), whereby τ_{ni}^j is the net tax rate that location n levies on the value of imports from location i in sector j. Domestically produced varieties incur zero tariffs. Every location sources each variety from its respective least-cost supplier.

As in Eaton and Kortum (2002), the fraction of location n's expenditures sourced

[3] The fundamental productivity encompasses unmeasured physical capital endowments, which are potentially important especially for Mining and agriculture.

from location i in sector j is given by:

$$\pi_{ni}^{j} = \frac{\left((A_i^j)^{-\nu^j} u_i^j d_{ni}^j (1+\tau_{ni}^j)\right)^{-\theta^j}}{\sum_{i'=1}^{N} \left((A_{i'}^j)^{-\nu^j} u_{i'}^j d_{ni'}^j (1+\tau_{ni'}^j)\right)^{-\theta^j}}, \tag{3}$$

where the unit cost for a bundle of inputs for producers in sector j in location i is:

$$u_i^j = B^j \left(w_i^{hj}\right)^{\lambda^j \nu^j} \left(w_i^{\ell j}\right)^{(1-\lambda^j)\nu^j} \prod_{k=1}^{J} \left(p_i^k\right)^{\mu^{jk}(1-\nu^j)}. \tag{4}$$

The price of the sector-j composite good in country n is given by:

$$p_n^j = \gamma^j \left[\sum_{i=1}^{N} \left((A_i^j)^{-\nu^j} u_{it}^j d_{ni}^j (1+\tau_{ni}^j)\right)^{-\theta^j}\right]^{-\frac{1}{\theta^j}}. \tag{5}$$

The terms B^j and γ^j are constants.

Governments In each country there is a government that collects tariff revenue and rebates the proceeds to households in a lump-sum fashion. To calculate location n's tariff revenue on imports from location i in sector j, we first divide the sectoral imports measured at tariff-inclusive prices, $p_n^j Q_n^j \pi_{ni}^j$, by the gross tariff rate $1+\tau_{ni}^j$. The tariff-exclusive imports are then multiplied by the net tariff rate to yield the tariff revenue. The total tariff revenue generated in location n is therefore

$$\mathrm{T}_n = \sum_{j=1}^{J} \sum_{i=1}^{N} \left(\frac{p_n^j Q_n^j \pi_{ni}^j}{1+\tau_{ni}^j}\right) \tau_{ni}^j.$$

In foreign countries the tariff revenue is directly rebated to households: $\mathrm{IBT}_n = \mathrm{T}_n$. In the United States the tariff revenue is distributed across states in proportion to state population shares:

$$\mathrm{IBT}_n = \frac{\sum_{j=1}^{J} (\bar{h}_n^j + \bar{\ell}_n^j)}{\sum_{i \in \mathcal{US}} \sum_{j=1}^{J} (\bar{h}_i^j + \bar{\ell}_i^j)} \sum_{i \in \mathcal{US}} \mathrm{T}_i, \quad n \in \mathcal{US}.$$

Equilibrium A competitive equilibrium satisfies the following conditions: i) taking prices as given, the representative household in each country maximizes its utility subject to its budget constraint; ii) taking prices as given, firms maximize profits subject to the available technologies; iii) varieties are purchased from their lowest-cost provider subject to the trade costs and tariffs; iv) government budgets are balanced; and (v) markets clear. See Appendix A for the full set of equations.

The market-clearing conditions are standard in the literature. Different from most of the quantitative multi-sector models, we assume that labor is immobile both across locations and across sectors. As a result, the corresponding wages for each type of labor vary across markets (sector-location pairs). To close the model we assume trade is balanced in every location, with the exception of cross-state transfers of tariff revenue within the US At the country level, indirect business tax rebates equal the tariff revenue collected. At the state level, this need not be the case, so trade imbalances emerge to counter the fiscal transfer imbalances.

3 Calibration

The quantitative exercise is applied to 59 locations: 50 US states, 8 non-US locations (Brazil, Canada, China, the European Union, India, Japan, Mexico, and South Korea), and a rest-of-world aggregate. These non-US locations were selected based on the criteria that they each accounted for at least one percent of US trade in 2012; they collectively account for about 70 percent of US trade. All remaining trading partners of the US are part of a rest-of-world aggregate.

Economic activity is split across 16 sectors of the economy: (1) Agriculture; (2) Mining; (3) Food, beverages, and tobacco; (4) Textiles and apparel; (5) Wood; (6) Paper and printing; (7) Refined petroleum, plastics, and rubbers; (8) Chemicals and pharmaceuticals; (9) Non-metallic minerals; (10) Primary and fabricated metals; (11) Machinery n.e.c.; (12) Computers, electronics, and electrical equipment; (13) Transportation equipment; (14) Furniture and other; (15) Tradable services; and (16) Nontradable services.

It is important to include services, which account for about one-third of US exports and 80 percent of US employment. We split the services sectors into two groups: *Tradable services* and *Nontradable services*. A service industry belongs to Tradable services if the ratio of its global exports to global gross output is above 5 percent and to Nontradable services otherwise.[4] This level of dis-aggregation of the services sectors facilitates the imputation of services trade data across the US states.

We calibrate the model parameters in three steps. In section 3.1, we describe the calibration of country-specific parameters that are directly observable in the data. In section 3.2, we impute missing trade flows across US states using gravity methods

[4]Service industries in Tradable services, beginning with the most tradable, are (i) Transport & warehouse, (ii) Wholesale & retail (iii) Information, (iv) Business services, and (v) Finance & insurance. Service industries in Nontradable services, beginning with the most tradable, are (i) Entertainment, (ii) Utilities, (iii) Education, (iv) Other services, (v) Construction, (vi) Health, and (vii) Real estate.

together with observable trade flows, geography, and state-sector level production. In section 3.3, we calibrate the remaining parameters using the model's structure.

3.1 Parameters Taken Directly from the Data

This subsection describes the parameters that are directly sourced from the data in 2012. We introduce the data sources and discuss the imputations that are done to complete the coverage of our sample. We choose year 2012, because it is the most recent available year for bilateral trade between US states provided by Census Bureau's Commodity Flow Survey. Appendix B provides the detailed data description.

Labor Endowments Each location is endowed with sector-specific high skill labor h_n^j and low skill labor ℓ_n^j. Country-level employment comes from the Penn World Table (Feenstra, Inklaar, and Timmer, 2015, (PWT)). The 2016 release of the Socio Economic Accounts in the World Input Output Database (WIOD) (Timmer, Dietzenbacher, Los, Stehrer, and de Vries, 2015; Timmer, Los, Stehrer, and de Vries, 2016) provides the sectoral shares of total employment for each country, and the 2014 release reports sectoral skill composition for each country.[5] This information allows us to compute high- and low-skill labor endowments at the sector level for each country. Finally, we allocate sectoral endowments to US states as follows. Sectoral employment for each state comes from the Bureau of Economic Analysis (BEA). We have the sectoral skill composition only for the country as a whole. We apply the same ratios to each state to construct high and low skill employment in each state and sector. Details are in Appendix B.

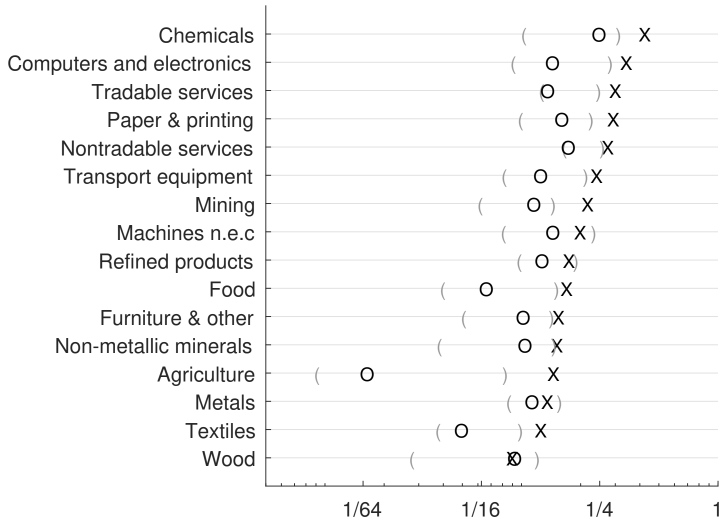
Figure 1 illustrates that the high skill share of workers in the United States exceeds that in most foreign countries across sectors. On the vertical axis, sectors are ranked by the share of high skill workers in the US, marked by "X." The top two sectors are Chemicals and Computers and electronics. The bottom three sectors are Wood and Textiles. The median ratios for foreign countries are illustrated by "O," with brackets reflecting the interquartile range. The shares of high skill workers in foreign countries are highly correlated with those in the US across sectors.

Trade elasticities Trade elasticities for manufacturing sectors are sourced from Giri, Yi, and Yilmazkuday (2021).[6] They do not provide estimates for four of our

[5]Skill type is based on educational attainment. High skill corresponds to at least some tertiary education, while low skill corresponds to no tertiary education.

[6]Their sector classification is not identical to ours. For the sectors where our classification coincides with theirs, we use their value directly. In the case where their classification is finer than ours, we take an average of the values they report for the underlying sub-sectors. In the case where our classification is finer, we use the same elasticity for the sub-sectors.

Figure 1: High-skill Labor Share by Sector



Notes: X denotes the US share of high-skill workers in employment, which is identical across US states; O denotes the median high-skill share in foreign countries, and round brackets reflect the interquartile range. Sectors are ordered by the high-skill share in the US from the lowest on the bottom to the highest on the top.

sectors (Agriculture; Mining; Tradable services; Nontradable services). For these sectors, we assume a value of 4 as estimated for manufacturing by Simonovska and Waugh (2014). The first column of Table 1 reports the trade elasticities. Metals and Refined products have high values, consistent with the fact that goods in those sectors are more homogeneous than goods in other sectors. On the other hand, Paper & printing and Computers and electronics have low values, as goods in those sectors are more differentiated than goods in other sectors.[7]

Preference Weights Sectoral weights in total consumption, ω_n^j, are computed for each country using the nominal shares in final demand (public and private consumption and investment) from the WIOD. We do not observe final demand at the US state level, so we assume the weights for each state are the same as for the Untied States aggregate. The second column of Table 1 reports ω_n^j for the United States. Tradable services and Nontradable services collectively account for more than 80 percent of US final demand. Outside of services, Food and Transport equipment are the next two largest components, accounting for 3.2 and 3.1 percent, respectively. Since they are constant across US states they do not contribute to the heterogeneity in welfare impacts from tariff changes.

[7]The elasticity of substitution between varieties in the composite goods is set to $\eta = 2$, which plays no quantitative role.

Table 1: Sector-Specific Parameters

	θ^j	ω^j_{US}	ν^j	λ^j
Agriculture	4.00	0.004	0.445	0.204
Mining	4.00	0.009	0.712	0.355
Food	3.57	0.032	0.259	0.291
Textiles	4.82	0.010	0.313	0.261
Wood	4.17	0.001	0.301	0.166
Paper & printing	2.97	0.002	0.350	0.441
Refined products	5.75	0.019	0.251	0.300
Chemicals	3.75	0.016	0.442	0.577
Non-metallic minerals	3.87	0.001	0.400	0.233
Metals	7.01	0.003	0.314	0.216
Machines n.e.c	3.87	0.013	0.368	0.298
Computers and electronics	3.27	0.021	0.623	0.490
Transport equipment	4.47	0.031	0.292	0.339
Furniture & other	4.47	0.010	0.452	0.283
Tradable services	4.00	0.275	0.599	0.464
Nontradable services	4.00	0.554	0.643	0.393

Notes: θ^j is the trade elasticity, ω^j_n is sector j's share in locations n's consumption spending (we report US values), ν^j is the share of value added in gross output, and λ^j is the share of high-skill labor in the wage bill.

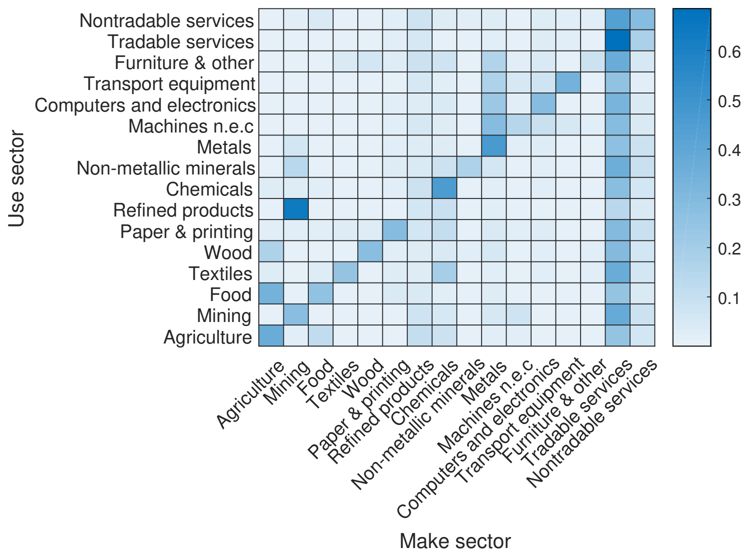
Input and Factor Shares We now describe the sources for the production coefficients: the intermediate input share in gross output ν^j, the skill labor share λ^j, and the intermediate use coefficients μ^{jk}. All these parameters are directly computed using 2012 values from the WIOD for the United States.

The third column of Table 1 reports the share of value added in sectoral output for the United States. The most value-added intensive (least intermediate intensive) sectors are Mining, Computers and electronics, and Nontradable services. The least value-added intensive sectors are Refined products and Food. The last column reports the share of high-skill workers in labor compensation (high-skill intensity) across sectors for the United States. The most high-skill intensive sectors are Chemicals, Computers and electronics, and Tradable services, while Wood, Agriculture, and Metals are the least high-skill intensive.

The input-output structure is another important transmission mechanism in the model. Figure 2 illustrates the linkage between "use" sectors in rows and "supply" sectors in columns, where shares in each row sum to unity. Three patterns emerge from this figure. First, each sector tends to use output from its own sector intensively, as indicated by darker diagonal blocks. Second, Tradable services (including professional & business services) are an important input in most other sectors' production. Third, certain sectors are key inputs to specific sectors, such as the use of

Mining in Refined products, the use of Agriculture in Food, and the use of Metal in Machines. These strong links transmit cost shocks due to changes in tariffs disproportionately across sectors. For example, a tariff-induced increase in the price of Mining disproportionately impacts the price of Refined products.

Figure 2: Input-Output Shares



Notes: Each row represents "use" sector and each column represents "supply" sector. Each row sums to one.

Tariffs We obtain applied effective tariff rates from the World Integrated Trade Solution (WITS) database. For missing values, we use the most-favored nation tariff rate. We utilize the accompanying product-level trade data from WITS to aggregate the tariffs from the HS–6 digit level to our 14 goods-producing sectors (there are no tariffs for service sectors) as follows.[8] For each importing country and each sector, we use a simple average of tariffs for the *most imported products*. Specifically, the most imported products meet two conditions: (i) they cumulatively account for at least 80 percent of total sectoral imports for the importer, and (ii) they individually account for at least 0.005 percent of total sectoral imports.[9]

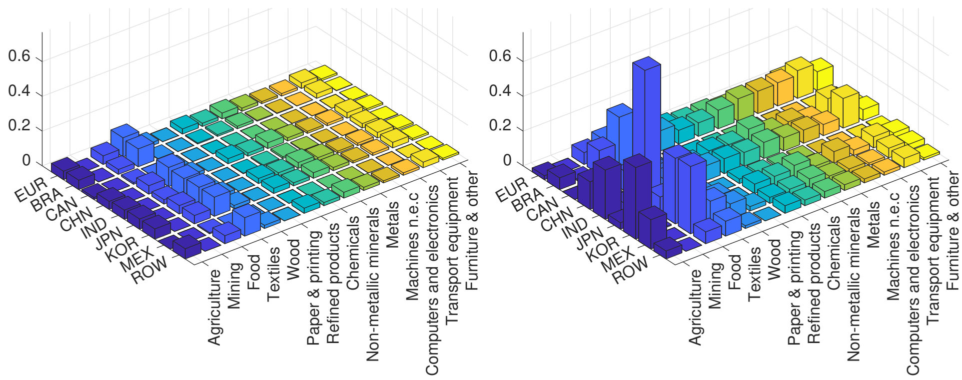
Figure 3 plots US tariff rates by sector and trading partner. The United States imposes lower import tariffs (left panel) than it does on its exports (right panel). In terms of the simple average across countries, the tariff rate ranges from 0 percent in Paper and printing and 0.04 percent in Mining to 4.3 percent in Agriculture and 8.4 percent in Textiles. When averaged across sectors, the US tariff rate ranges from

[8]We complement the product-level trade data using BACI—the world trade database developed by the CEPII—for missing values in the WITS database.

[9]We do not use trade weights to average the product-level tariff rates, to ensure that the sector-level tariffs that each member of the European Union imposes is the same.

0.1 percent for Mexico and 0.2 percent for Canada to 2.8 percent for both South Korea and Japan. US exports face relatively high tariffs in Agriculture and Food, particularly in emerging markets like Brazil, China, and India.

Figure 3: US Tariff Rates



Notes: The left panel shows the tariff rates that the US imposes on imports from foreign countries. The right panel shows the tariff rates that US exports face in foreign markets.

3.2 Missing Trade Flows across US States

We have complete bilateral trade flows in manufacturing sectors (state-with-state, state-with-country, and country-with-country). For agriculture and mining we have state-with-country and country-with-country trade data, and for services we have country-with-country trade data. To our knowledge, there is no data on bilateral trade flows between US states for agriculture, mining, or service sectors. In addition, there are no data on bilateral trade flows between states and foreign countries for service sectors. In the appendix, we describe our procedure to construct estimates for the missing trade flows using available data on bilateral trade flows and production, as well as gravity variables, such as distance, common border and common language. The idea is to use gravity to predict missing trade flows and then make use of state-sector-level production data to impose adding-up constraints.

3.3 Parameters Estimated Using the Model

We use the model's gravity structure to estimate fundamental productivity and physical trade costs, as in Levchenko and Zhang (2016). Similar to many common workhorse models of trade, the model's gravity structure from equation (3) links bilateral trade shares to comparative advantage forces and trade barriers as follows:

$$\ln\left(\frac{\mathrm{X}_{ni}^j}{\mathrm{X}_{nn}^j}\right) = \underbrace{\theta^j \ln\left(\frac{(A_i^j)^{\nu^j}}{u_i^j}\right)}_{S_i^j} - \underbrace{\theta^j \ln\left(\frac{(A_n^j)^{\nu^j}}{u_n^j}\right)}_{S_n^j} - \theta^j \ln\left(d_{ni}^j\right) - \theta^j \ln\left(1+\tau_{ni}^j\right), \qquad (6)$$

where X_{ni}^j denotes location n's expenditure on location i's sector-j goods inclusive of the tariff.[10] S_n^j captures location n's relative state of technology in sector j as a convolution of its unit input costs, u_n^j, and productivity, A_n^j. Any regional differences in relative trade shares that are not accounted for by tariffs or by regional differences in states of technology are attributed to bilateral trade costs.

Since bilateral trade costs at the sector level are unobservable, we impose a parsimonious relationship with observable gravity variables as follows:

$$\ln\left(d_{ni}^j\right) = \mathrm{ex}_i^j + \sum_{r=1}^{6} \gamma_{d,r}^j \mathrm{dis}_{ni}^r + \gamma_b^j \mathrm{bdr}_{ni} + \gamma_c^j \mathrm{cur}_{ni} + \gamma_l^j \mathrm{lng}_{ni} + \gamma_f^j \mathrm{fta}_{ni} + \epsilon_{ni}^j. \qquad (7)$$

The specification includes various symmetric terms. One is a distance indicator, dis_{ni}^r, indexed by $r = 1, \ldots, 6$, capturing whether the distance (in miles) between locations n and i falls in certain intervals: $[0, 350)$, $[350, 750)$, $[750, 1500)$, $[1500, 3000)$, $[3000, 6000)$, and $[6000, \infty)$. The remaining symmetric terms—bdr_{ni}, cur_{ni}, lng_{ni}, and fta_{ni}—indicate whether locations share a common border, a common currency, a common official language, and whether they belong to a free trade agreement. The coefficients γ^j capture the effects of symmetric indicators on the bilateral trade costs in sector j. Asymmetry in trade costs is captured by an exporter fixed effect, ex_i^j, based on Waugh (2010). Standard assumptions about independence of the error term apply.

Combining equations (6) and (7) and imposing the observed tariff rates together with calibrated θ^js yield a gravity equation:

$$\begin{aligned} \ln\left(\frac{\mathrm{X}_{ni}^j}{\mathrm{X}_{nn}^j}\right) + \theta^j \ln\left(1+\tau_{ni}^j\right) &= M_n^j + E_i^j \\ &+ \left(\sum_{r=1}^{6} \beta_{d,r}^j \mathrm{dis}_{ni}^r + \beta_b^j \mathrm{bdr}_{ni} + \beta_c^j \mathrm{cur}_{ni} + \beta_l^j \mathrm{lng}_{ni} + \beta_f^j \mathrm{fta}_{ni}\right) + \varepsilon_{ni}^j. \qquad (8) \end{aligned}$$

To improve precision in estimating the effect of geography $(\widehat{\beta}_{d,r}^j, \widehat{\beta}_b^j, \widehat{\beta}_c^j, \widehat{\beta}_l^j, \widehat{\beta}_f^j)$ we exploit as much geographic variation as we can. We first estimate equation (8) using data on bilateral trade between all 50 states and 42 non-US countries.[11] To

[10] The trade data in WIOD are "Free on Board producer prices," so we multiply these trade flows by the corresponding gross tariff rate to convert to purchaser prices, in line with the theory.

[11] These estimates map to $(\widehat{\gamma}_{d,r}^j, \widehat{\gamma}_b^j, \widehat{\gamma}_c^j, \widehat{\gamma}_l^j, \widehat{\gamma}_f^j)$ as $\gamma = -\beta/\theta$.

avoid imposing an ad-hoc aggregation of the fixed effects (M_n^j, E_i^j) across the EU-28 countries, we revert to our original sample of 50 US states, the EU-28 aggregate, and 7 other foreign countries to re-estimate these regions' fixed effects, using the predicated symmetric components of their trade costs: $\sum_{r=1}^{6} \widehat{\beta}_{d,r}^j \text{dis}_{ni}^r + \widehat{\beta}_b^j \text{bdr}_{ni} + \widehat{\beta}_c^j \text{cur}_{ni} + \widehat{\beta}_l^j \text{lng}_{ni} + \widehat{\beta}_f^j \text{fta}_{ni}$.

We follow Levchenko and Zhang (2016) to recover the sectoral productivity and trade costs from the estimated fixed effects. The reduced-form estimates map into structural parameters as follows: $M_n^j = -S_n^j$, and $E_i^j = S_i^j - \theta^j \text{ex}_i^j$. We then construct bilateral trade costs between each location using the specification in equation (7).

The available degrees of freedom imply that in each sector the states of technology, S_n^j, are identified up to a normalization; we take Alabama as the reference location based on alphabetical ordering: $S_{AL}^j = 0$ for all sectors j. Information on sector-specific relative productivity levels across locations, A_n^j, is contained in the estimated relative states of technology, S_n^j. Recall that the state of technology is

$$S_n^j = \ln\left(\left(A_n^j\right)^{\nu^j\theta^j}\left(u_n^j\right)^{-\theta^j}\right), \tag{9}$$

where the unit cost of an input bundle u_n^j is given by equation (4).

Factor prices (the rental rate and both wage rates) are computed as the compensation to the appropriate factor divided by the endowment of that factor; the measurement of each of these variables is described in Appendix B. We do not have data on sectoral prices either across countries or states. We therefore recover sectoral prices based on equation (5) using the estimated trade costs and states of technology:

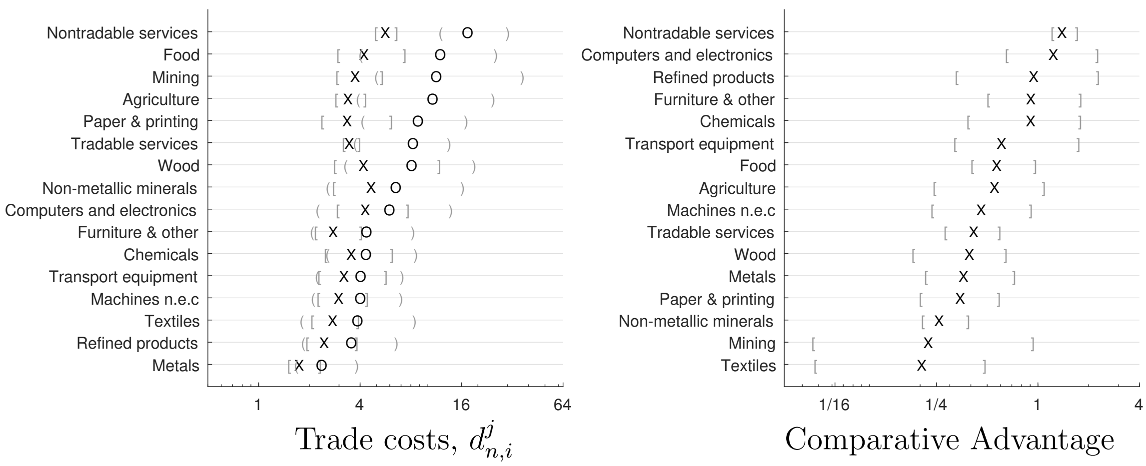
$$\left(p_n^j\right)^{-\theta^j} = \gamma^j \sum_{i=1}^{N} \left(\left(A_i^j\right)^{-\nu^j} u_i^j d_{ni}^j (1+\tau_{ni}^j)\right)^{-\theta^j} = \gamma^j \sum_{i=1}^{N} \exp\left(S_i^j\right) \left(d_{ni}^j (1+\tau_{ni}^j)\right)^{-\theta^j},$$

where the term $\gamma^j = \Gamma(1 + \frac{1}{\theta^j}(1-\eta))^{1/(1-\eta)}$, and $\Gamma(\cdot)$ is the Gamma function. These inferred prices, together with factor prices, characterize the unit costs and hence identify the productivity from the state of technology from equation (9).

Finally, we impute the exporter fixed effect coefficient, ex_n^j, and the states of technology, S_n^j, for the ROW aggregate by regressing the respective estimates for all other locations against their log GDP per capita and log GDP, then recover a value for ROW using its log GDP per capita and log GDP.

Estimated Trade Costs We first present the estimated iceberg trade costs in the left panel of figure 4. The median state-to-state trade cost in each sectors are illustrated with "X," and the median state-to-country trade costs with "O." Not surprisingly, in every sector the median state-to-state trade cost is lower than the median state-to-country trade cost. Moreover, the median state-to-state trade cost covaries with median state-to-country trade costs across sectors, with a correlation of 0.76. *Nontradable services* has the highest median trade costs, and *Metals* has the lowest median trade costs. For any sector, trade costs vary substantially not only across countries but also across states, as shown by square and round brackets reflecting the respective interquartile ranges. Not-metallic minerals have the greatest interstate dispersion in trade costs, and Mining has the greatest international dispersion.

Figure 4: Median trade costs and comparative advantage



Notes: In the left panel, "X" denotes the median state-to-state trade cost and square brackets reflect the interquartile range; "O" denotes the median state-to-country trade cost and round brackets reflect the interquartile range. Sectors are ordered by the median state-to-country trade cost from lowest (bottom) to highest (top). In the right panel, "x" denotes the median US state external comparative advantage and square brackets reflect the interquartile range across states. Sectors are ordered by US external comparative advantage from lowest (bottom) to highest (top). Comparative advantage is defined as the ratio of the median US state's competitiveness to median foreign competitiveness: $\exp(S^j_{\text{median-USA}})/\exp(S^j_{\text{median-foreign}})$.

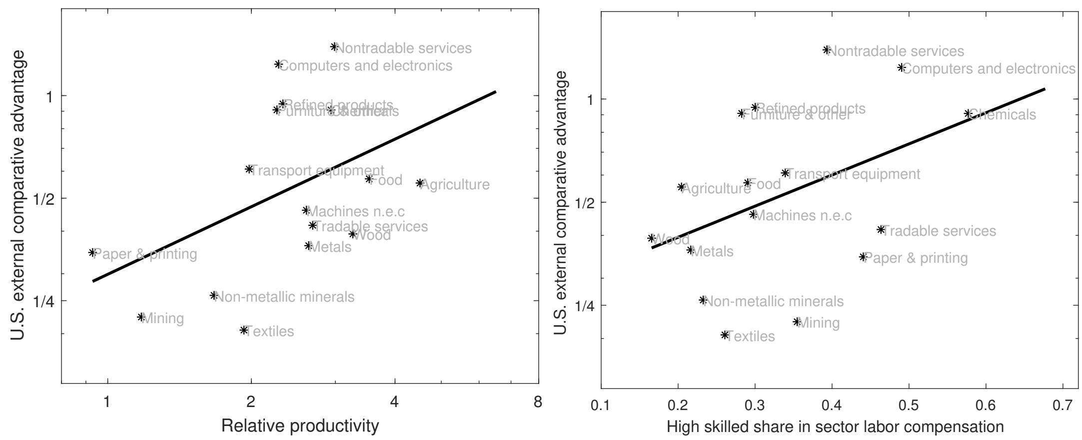
Estimated Comparative Advantage We next show the patterns of estimated comparative advantage. Location n's competitiveness in sector j is summarized by $\exp(S^j_n)$. We first look at the overall competitiveness of the United States relative to trading partners across sectors. To do so, we define *US external comparative advantage* as the ratio of the median $\exp(S^j_n)$ of US states relative to the median of foreign countries, which is marked as "X" for each sector in the right panel of Figure 4. Among goods-producing sectors, the United States has comparative advantage in Computers and electronics, Refined products, Furniture & other, and Chemicals, and it has comparative disadvantage in Textiles, Mining, and Non-metallic minerals.

States also widely differ in their competitiveness within each sector.[12] This can be seen from the square brackets, which depict the interquartile range across states for each sector. In Mining, the state at the 75th percentile is 20 times more competitive than the state at the 25th percentile. This dispersion determines *state internal comparative advantage*, or the ratio of a state's $\exp(S_n^j)$ and the median $\exp(S_n^j)$ of US states. The pattern of state internal comparative advantage plays a critical role in understanding the differential impact of changes in trade policy across states.

3.4 Sources of Comparative Advantage

We now shed light on the sources of US external comparative advantage and state internal comparative advantage. US external comparative advantage comes from both Ricardian and Heckscher-Olin sources. Sectoral relative productivity—the ratio of the median US state productivity to the median foreign productivity— is positively correlated with US external comparative advantage across sectors, as shown in the left panel of Figure 5. The correlation is 0.27. Sectoral skill intensity, λ^j, is also positively correlated with US external comparative advantage across sectors, as illustrated in the right panel of Figure 5; the correlation is 0.44. Given that the United States is relatively abundant in high-skill labor, Heckscher-Ohlin forces give rise to its external comparative advantage in sectors in skill-intensive sectors.

Figure 5: Sources of US External Comparative Advantage



Notes: US external comparative advantage is defined as the ratio of the median US state's competitiveness to median foreign competitiveness: $\exp(S^j_{\text{median-USA}})/\exp(S^j_{\text{median-foreign}})$. Relative productivity is defined as the ratio of the median US state's fundamental productivity to median foreign fundamental productivity: $A^j_{\text{median-USA}}/A^j_{\text{median-foreign}}$. High-skilled share in sector labor compensation is defined as λ^j.

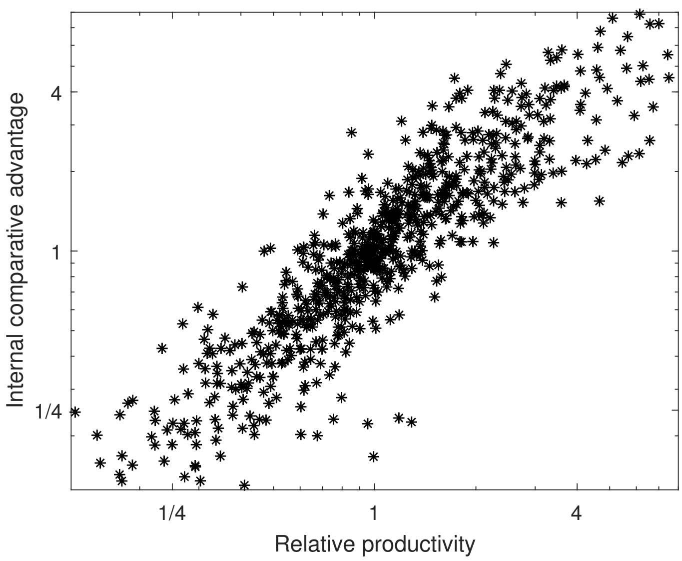
Consider two goods sectors of US external comparative advantage (Computers

[12] Our competitiveness measure incorporates both the fundamental productivity and the cost of factor inputs. The former boosts competitiveness, while the latter reduces it.

and Chemicals) and two sectors of external comparative disadvantage (Mining and Textiles). Computers and Chemicals have higher relative productivity and also higher skill intensities than Mining and Textiles. Specifically, the skill intensity is 0.58 for Chemicals and 0.49 for Computers and electronics compared with 0.36 for Mining and 0.26 for Textiles. Agriculture stands out with the highest relative productivity but the second-to-lowest skill intensity, which jointly determines its near-median position across sectors in terms of external comparative advantage.

Now we consider state internal comparative advantage. Due to the limitation of the data, all US states share the same production function and the same endowment ratio of high-skill to low-skill labor in each sector. As a result, the internal comparative advantage of a state is determined by Ricardian forces through sector relative productivity. Figure 6 demonstrates that when a state's sectoral productivity, relative to the median US sectoral productivity, $A_n^j/A_{\text{median}}^j$, is high, its internal comparative advantage, $\exp(S_n^j)/\exp(S_{\text{median}}^j)$, is also high. The slope of the relationship is close to one, and deviations from this relationship are due to heterogeneous factor prices across states resulting from general equilibrium effects based on geography and heterogeneous trade costs.

Figure 6: Sources of State Internal Comparative Advantage



Notes: State internal comparative advantage is defined as the ratio of state n's competitiveness to the median US state's competitiveness: $\exp(S_n^j)/\exp(S_{\text{median-USA}}^j)$. Relative productivity is defined as the ratio of state n's fundamental productivity to the median US state's fundamental productivity: $A_n^j/A_{\text{median-USA}}^j$.

The ranking of fundamental productivity across states within each sector is intuitive. For example, Michigan has the highest fundamental productivity in Transport equipment among US states, Oregon the highest in Wood, and Louisiana in Refined products. These inferred productivity levels reflect the patterns of trade, particularly through export intensity. We also obtain sensible predictions for the service sectors as well. In Tradable services, New York wields the highest fundamental productivity, followed by Massachusetts and Connecticut, each of which have a high concentration of finance and insurance activity. In Nontradable services, the three states with the highest fundamental productivity are Hawaii, Nevada, and Alaska, each of which attracts a large share of tourism and in turn relatively large hospitality industries.

We conclude the calibration by checking the model fit along several dimensions. The correlation between model and data bilateral trade shares ranges from 0.66 to 0.95 across sectors. The cross-country correlation between the model and data for sectoral value added ranges from 0.51 to 1.00, and the cross-state correlation from 0.85 to 0.99.

4 Heterogeneous Impacts of Tariff Changes

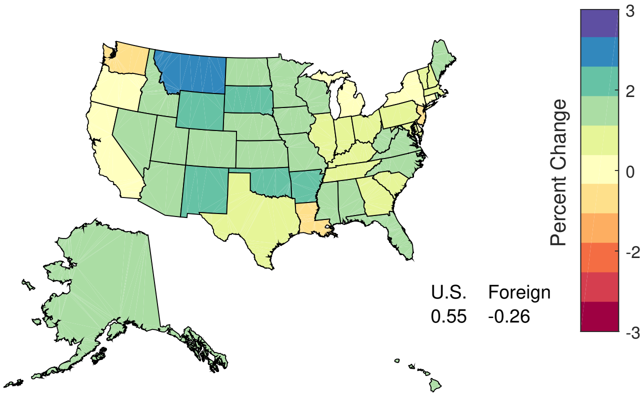
In this section we quantify the welfare effects following a uniform increase in US import tariffs across sectors. We decompose welfare changes into contributions stemming from changes in real factor income and from changes in real tariff revenue. In turn, we assess the extent to which cross-state heterogeneity in welfare changes is due to differential sectoral exposure versus differential state characteristics, such as geography. We then identify the underlying characteristics of US states that drive differences in the overall gains. In addition, we consider the implications when foreign countries implement a tit-for-tat retaliation, and we study the effects of sector-specific tariff changes and alternative transfers of tariff revenue between states.

4.1 A Uniform Tariff Increase across Sectors

Our baseline scenario is based on observed tariff rates. In the main counterfactual, we increase the US import tariff rates in each sector by 25 percentage points, while the tariff rates levied by foreign countries remain unchanged at the baseline levels. This counterfactual illustrates the impact of changes in tariffs imposed unilaterally by the United States. We define the welfare change as the percent change in consumption from the baseline tariff schedule τ to a counterfactual one $\widetilde{\tau}$. In terms of population-weighted averages, the United States gains 0.55 percent, while the foreign countries lose 0.26 percent. This increase in US import tariffs leads to a large decline in US imports, from 11.2 to 6.7 percent of US GDP.

The aggregate impact of the tariff increase masks a large dispersion of its impact across states. Figure 7 illustrates the impact across US states: welfare changes range from -0.8 percent percent in Oregon to 2.1 percent in Montana. To understand the

Figure 7: Percent Change in Welfare across US States



Notes: Changes in welfare associated with increasing US import tariffs in each sector uniformly by 25 percentage points. In terms of population-weighted averages, the United States gains 0.55 percent, while foreign countries lose 0.26 percent.

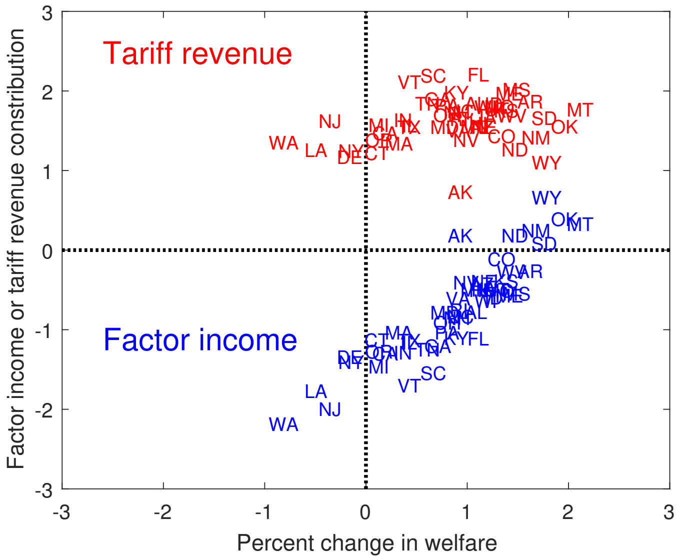
mechanisms behind cross-state heterogeneity, we express the welfare change for each US state based on equation (2) as follows:

$$\frac{\widetilde{C}_n}{C_n} - 1 = \overbrace{\underbrace{\left(\frac{F_n}{P_n^c C_n}\right)}_{\substack{\text{Initial factor}\\ \text{income share}}} \underbrace{\left(\frac{\widetilde{F}_n/\widetilde{P}_n^c}{F_n/P_n^c} - 1\right)}_{\substack{\%\Delta \text{ in real}\\ \text{factor income}}}}^{\text{Factor income contribution}} + \overbrace{\underbrace{\left(\frac{\mathrm{IBT}_n}{P_n^c C_n}\right)}_{\substack{\text{Initial tariff}\\ \text{revenue share}}} \underbrace{\left(\frac{\widetilde{\mathrm{IBT}}_n/\widetilde{P}_n^c}{\mathrm{IBT}_n/P_n^c} - 1\right)}_{\substack{\%\Delta \text{ in real}\\ \text{tariff revenue}}}}^{\text{Tariff revenue contribution}}, \tag{10}$$

where variables with $\sim$ are outcomes from the counterfactual under tariff schedule $\widetilde{\tau}$, and those without $\sim$ are outcomes from the baseline. The welfare change can be decomposed into two components: the factor income contribution and the tariff revenue contribution. Specifically, the factor income contribution is the percent change in real factor income, weighted by the initial share of factor income in consumption spending. Similarly, the tariff revenue contribution is the percent change in real tariff revenue, weighted by the initial share of tariff revenue income in consumption spending. Figure 8 plots the factor income contributions (blue) and the tariff revenue contributions (red) against the total welfare changes for each state.

The first thing to notice from Figure 8 is that the factor income contribution is negative in most states, with an average loss of 0.75 percent. Mechanically, nominal factor income rises in the US following the unilateral tariff increase as a result of greater demand for domestically produced goods. The loss in real factor income thus reflects higher consumer prices. Specifically, nominal factor returns across US states increase by about 8 percent, on average; the consumer price level increases more than 9 percent. The price increase is substantially less than the 25 percent tariff increase for two reasons. One is that imports constitute only part of the final consumption

Figure 8: Welfare change across US states: tariff revenue vs. factor income



Notes: The decomposition of welfare changes into factor income contributions (blue), and the tariff revenue contributions (red) are based on equation (10). The two contributions sum to the percent change in welfare.

basket. The other is through the terms-of-trade effect: the US is a large economy, so when it raises tariffs, world demand for foreign goods declines, reducing the free-on-board prices of imports. Thus, only a portion of the tariff increase is passed through to US consumers, and the rest is absorbed as lower prices in foreign countries.

Second, the tariff revenue contribution is positive in all states, with an average of 1.6 percent. We unpack this number using a back-of-the-envelope calculation at the US level. In the baseline, the average tariff rate is 2 percent across sectors, with imports amounting to 11.2 percent of GDP, implying that the tariff revenue is about 0.21 percent of GDP. In the counterfactual, the average tariff rate rises to about 27 percent across sectors, while imports drop to 6.7 percent of GDP and tariff revenue rises to about 1.8 percent of GDP – an eight-fold increase. At the same time, the average final consumption price increases by 9 percent. Taking the ratio of the increase in tariff revenue to the increase in the price level results in an increase in real tariff revenue of 680 percent. Given an initial share of the tariff revenue in GDP of 0.21 percent, the tariff revenue contribution for the US is 0.21 percent of 680 percent, which is close to 1.6 percent.

Regarding cross-state heterogeneity, we find substantial variation in the factor income contribution and limited variation in the tariff revenue contribution. The cross-state variance of factor income contributions is 0.40, close to the variance of welfare changes of 0.41. In contrast, the variance of tariff revenue contributions is only 0.08. Moreover, as Figure 8 shows, welfare changes across states positively co-vary with factor income contributions far more than with tariff revenue contributions; the respective correlations are 0.90 and 0.27. For instance, Wyoming gains 1.78 percent in welfare compared with only 0.13 percent for Oregon, which primarily reflects the difference in factor income contributions: 0.67 percentage points for Wyoming and −1.27 percentage points for Oregon. Meanwhile, the difference in tariff revenue contributions is less stark: 1.11 percentage points for Wyoming and 1.40 for Oregon. Hence, to understand heterogeneity in welfare changes across states, we need to unpack the variation in real factor income contribution.

Variation in Factor Income Contribution: State versus Sector We define real sectoral factor income in state n, sector j as f_n^j/P_n^c, where f_n^j is the factor income and P_n^c is the consumer price level. The total real factor income in a location is the sum of real sectoral factor income, weighted by sector shares in nominal factor income. In response to changes in tariffs, both high - and low-skilled workers in a given location realize proportionately equal changes in wages, while these changes vary across sectors.[13] Moreover, all workers in a location consume the same basket of goods and thus experience the same change in the consumer price level. The change in real factor income in a location is

$$\frac{\widetilde{F}_n/\widetilde{P}_n^c}{F_n/P_n^c} - 1 = \sum_{j=1}^{J} \underbrace{\left(\frac{f_n^j}{F_n}\right)}_{\text{sectoral share}} \underbrace{\left(\frac{\widetilde{f}_n^j/\widetilde{P}_n^c}{f_n^j/P_n^c} - 1\right)}_{\text{sectoral change}}. \tag{11}$$

We first focus on the "sectoral change" component of equation (11) and decompose the variance of sectoral changes in real factor income across states into state and sector fixed effects by running the following regression:

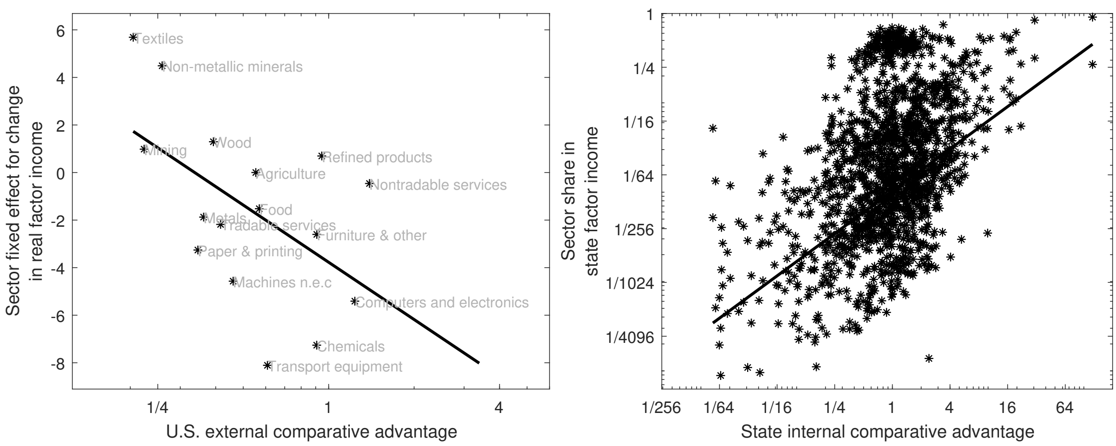
$$\left(\frac{\widetilde{f}_n^j/\widetilde{P}_n^c}{f_n^j/P_n^c} - 1\right) = \mathbf{FE}^j + \mathbf{FE}_n + \epsilon_n^j. \tag{12}$$

where $\mathbf{FE}^j$ are sector fixed effects and $\mathbf{FE}_n$ are state fixed effects. The regression yields an R^2 of 0.77, with sector fixed effects accounting for 79 percent of the total variance and state fixed effects accounting for only 3 percent. These results indicate the presence of a significantly strong sector component and a relatively weak state component. Intuitively, the impact of tariff changes on a typical worker depends primarily on the sector of employment and less on the location of the worker.

[13] Since there are no differential impacts across high and low skilled workers, our model does not speak to distributional impacts across skill/income levels. Carroll and Hur (2022) study a model where consumers have different expenditure shares in their baskets across income levels and thus are impacted differently from changes in trade costs.

We now argue that the sector fixed effects are largely governed by US external comparative advantage. The left panel of Figure 9 shows that sectors in which the United States has a comparative advantage exhibit lower sector fixed effects (i.e., smaller gains or larger losses). Similarly, sectors in which the United States has a comparative disadvantage present larger fixed effects (i.e., larger gains or smaller losses). Intuitively, protection benefits sectors for which the United States has a comparative disadvantage, since production increases in these sectors boosting the factor income to workers in those sectors.

Figure 9: Sectoral Implications of the Tariff Increase, Percent Change



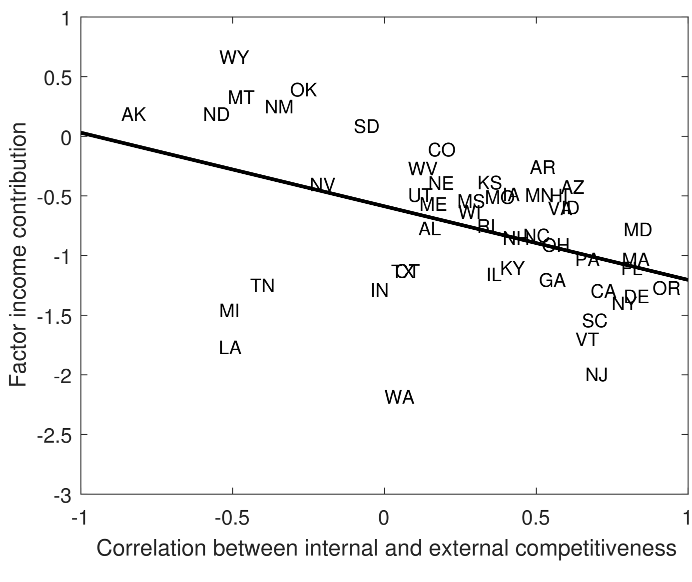
Notes: The sector fixed effect for change in real factor income is defined as the fixed effect $\mathbf{FE}^j$ in equation (12). US external comparative advantage is defined as the ratio of the median US state's competitiveness to median foreign competitiveness: $\exp(S^j_{\text{median-USA}})/\exp(S^j_{\text{median-foreign}})$. State internal comparative advantage is defined as the ratio of state n's competitiveness to the median US state's competitiveness: $\exp(S^j_n)/\exp(S^j_{\text{median-USA}})$.

Since the majority of the variance in real sectoral factor income changes is due to sector effects, variation in total real factor income at the state level ultimately reflects cross-state variation in *exposure* to different sectors. This exposure is captured by the sector share in factor income, i.e., the "sectoral share" term in equation (11). We find that sectoral exposure at the state level is determined by state internal comparative advantage. As shown in the right panel of Figure 9, state-sector pairs realize greater increases in real factor income when a sector accounts for a large share of that state's factor income. In other words, states tend to be more concentrated in, and thus exposed to, sectors for which they are relatively more competitive, internally.

Sources of Cross-State Variation in Factor Income Contribution According to equation (11), the change in a state's real factor income is equal to the inner product between its initial sectoral shares in factor income and the change in its sectoral factor income. State sectoral shares reflect states' internal competitiveness: states concentrate more in, and thus are exposed more to, sectors that they are internally competitive in. Sector fixed effects account for most of the variation in the state-level sectoral changes in factor income, which reflects US external competitiveness across sectors. Specifically, sectors in which the US is more externally competitive suffer larger losses with a higher import tariff. Overall, these findings suggest that a state suffers more (benefits less) from high tariffs when its internal competitiveness highly correlates with US external competitiveness.

Figure 10 demonstrates this point: a state's factor income contribution is negatively correlated with the "similarity" of its sectoral competitiveness to that of the US Our preferred measure of "similarity" is a weighted correlation between a state's sectoral competitiveness and the median US state's sectoral competitiveness. The state-specific weights are defined as each state's sectoral shares in factor income. For instance, Oregon's sectoral competitiveness profile correlates positively with that of the US since its relative competitiveness is high in Computers and electronics and low in Mining. Conversely, Wyoming's competitiveness profile correlates negatively with that of the US since its relative competitiveness is low in Computers and electronics and high in Mining. Thus, Wyoming gains more than Oregon in terms of the factor income contribution in response to higher tariffs.

Figure 10: Gains versus Similarity in Competitiveness



Notes: The vertical axis is the factor income contribution to each state's welfare change when US tariffs are unilaterally increased by 25 percentage points in all sectors. The horizontal axis is the weighted correlation between a state's sectoral competitiveness and the median US state's competitiveness across sectors. The state-specific weights are defined as the sector shares in factor income for the given state.

The similarity of a state's competitiveness to US competitiveness plays a first-order role in determining the impact of higher tariffs on factor income across states.

Nonetheless, heterogeneity in external trade costs across states also plays a role. As shown in Figure 10, some states, such as Louisiana and Michigan, have a negative correlation between internal competitiveness and US external competitiveness, but experience negative factor income contributions. These states tend to have lower-than-average external import costs (weighted by sector and foreign trading partner). That is, deviations from the predicted line in the figure have a strong positive correlation with foreign import costs.

In sum, cross-state heterogeneity in welfare changes depends mainly on the variation in the factor income contribution and less on variation in the tariff revenue contribution. The factor income contribution of a state hinges on its sectoral concentration because the tariff increase has significantly differential impacts across sectors rather than across geographic locations. US external comparative advantage determines how each sector is impacted, whereas internal comparative advantage determines how exposed each state is to each sector. As a result, states whose sectoral productivity profile correlates negatively with that of the median US state benefit the most from an increase in tariff rates.

4.2 Outcomes Under Retaliatory Tariffs

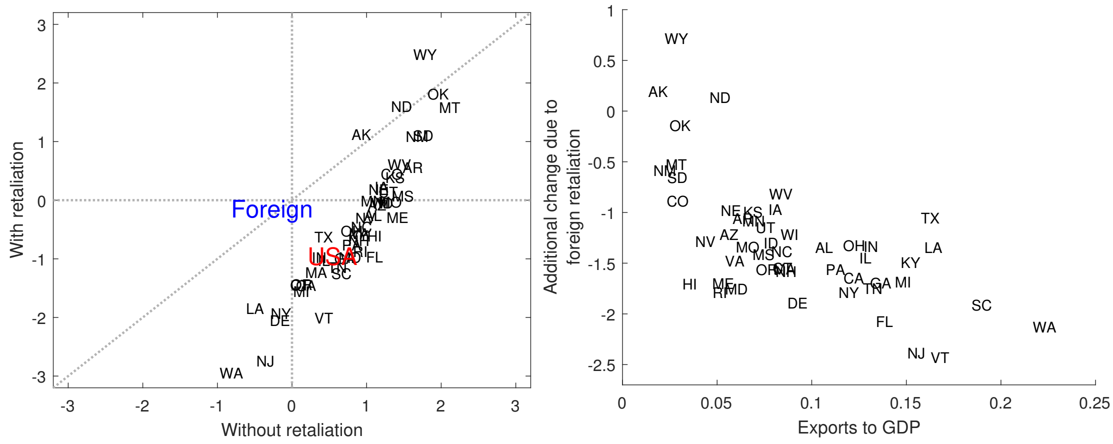
So far we have examined unilateral increases in tariffs imposed by the United States. In practice, foreign countries respond through disputes with the World Trade Organization (WTO) or by imposing retaliatory tariffs. We now study the effects when foreign countries impose tit-for-tat retaliation, whereby foreign countries increase their tariff by 25 percentage points on their imports from the US across all sectors. We assume that all tariffs between non-US country pairs remain unchanged.

Relative to the baseline, the US population-weighted average welfare decreases by 0.94 percent, in contrast to an increase of 0.55 percent without retaliation. Population-weighted welfare for foreign countries decreases by 0.13 percent with retaliation, compared with a decrease of 0.26 percent with no retaliation. Indeed, retaliation mitigates the losses for foreign countries as the terms of trade tilt back toward their advantage.

At the state level, most states gain less, or lose more, under a trade war than under a unilateral tariff increase, as shown in the left panel of Figure 11. The right panel illustrates that the additional welfare loss from retaliation, relative to a unilateral tariff increase, is smaller for states that export less to foreign countries.[14] We also find that the additional change in welfare from retaliation, relative to a unilateral

[14]Santacreu and Peake (2020) find empirically that states that were more exposed to trade experienced lower output and employment growth following the US-China trade war.

Figure 11: Welfare Change across US States with Foreign Retaliation



Notes: The left panel plots the welfare change from unilateral tariff increases on the horizontal axis and the welfare change from a trade war with retaliation on the vertical axis. The diagonal dotted line is the 45-degree line. The right panel plots the difference in gains with and without retaliation against exports to GDP. Exports to GDP for a state are defined as a state's exports to foreign countries as a share of its GDP at the baseline tariffs.

tariff increase, is positive for Wyoming, North Dakota, and Alaska. Not only do these state export very little to foreign countries, but they benefit at the expense of lower wages and hence lower prices of goods purchased from other states such as Oregon.

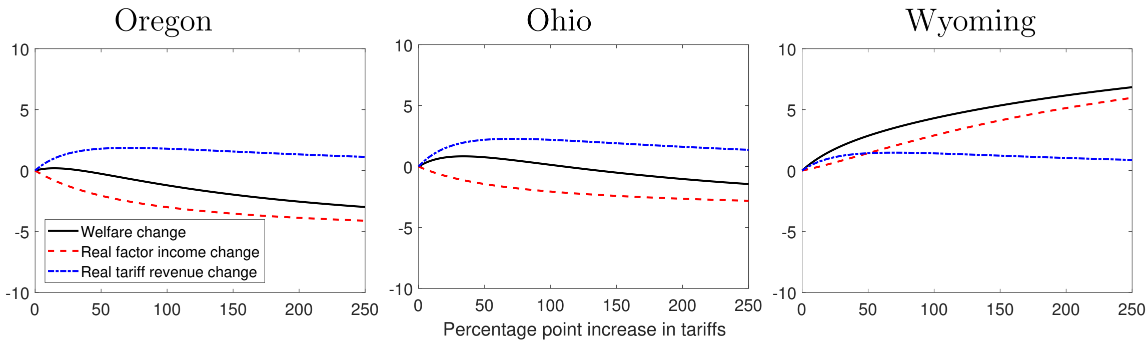
4.3 Heterogeneous Preferences for Tariffs across States

The cross-state heterogeneity that we have documented above implies that US states have different preferences over tariffs. Hence, setting a common external tariff across sectors for the US customs union involves tensions across states. This tension exists even when the customs union can select a particular sector to impose tariff increases.

A Uniform Tariff Increase across Sectors To highlight heterogeneous preferences over tariff changes, we ask the following question: If each state could individually raise US tariffs uniformly across sectors, how much would it choose to increase? To answer this question, we construct a welfare curve for each state by tracing out its welfare change, relative to the baseline tariff schedule, as the tariffs in all sectors increase uniformly without foreign retaliation. Figure 12 plots the welfare curves for three selected states: Oregon, Ohio, and Wyoming. The black solid lines describe the percentage change in welfare over a wide range of tariff increases. The contributions from both real factor income and real tariff revenue are depicted by the red-dashed lines and the blue-dotted lines, respectively.

For all three states, the tariff revenue contribution exhibits similar hump shapes across the tariff changes. However, the pattern for the factor income contribution

Figure 12: Percent Change in Welfare Relative to Baseline Tariffs



Notes: The horizontal axis depicts the range of percentage-point increases in tariffs across all sectors. The solid black line represents the welfare gain for each percentage point increase, relative to the baseline tariff schedule. The dashed red line represents the factor income countribution, and the blue dash-dotted line represents the tariff revenue countribution.

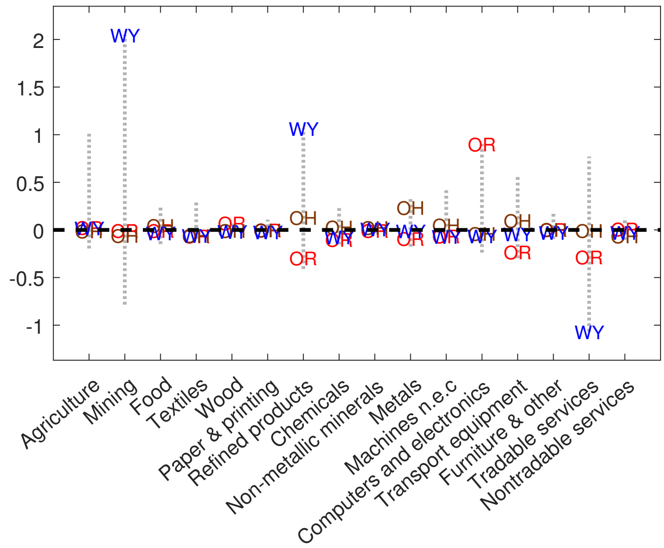
differs. In Oregon and Ohio the factor income contribution declines monotonically as the tariff increases. In Wyoming, the factor income contribution rises monotonically with the tariff. As a result, for states like Oregon and Ohio there exists a finite optimal tariff rate that maximizes their welfare, whereas states like Wyoming prefer an infinite tariff rate. Overall, we find that the states that prefer large tariff rates are those that gain the most from a uniform 25 percentage point tariff increase.

The reason that Wyoming has a preference for such high tariffs is because it belongs to a large customs union: the high external tariff does not affect its trade with other states. Instead, Wyoming absorbs the production of the "lost" imports and supplies goods duty-free to other US states, boosting its nominal factor returns. Even though external tariffs increase, its consumer price increase is limited as imports account for only a small share of total spending. This result hinges on the fact that the magnitude of iceberg costs is low within the union. Consequently, Wyoming's real factor income rises with tariffs.

Sector-Specific Tariff Increases So far we have emphasized how states are impacted differentially by a uniform tariff change across all sectors. We now explore the heterogeneity across states in response to sector-specific tariff changes. To do this we increase the US import tariff rate by 25 percentage points in one sector at a time, holding the tariff rates in all other sectors at their baseline values. In each case the tariff change is implemented unilaterally by the United States with no foreign retaliation. Figure 13 shows the range of welfare changes across US states for each sector-specific tariff increase. It also indicates the position of three states in the distributions: Wyoming, Ohio and Oregon.

One result that emerges is that there is no sector where every state either simultaneously gains or simultaneously looses from an increase in that sector's tariff rate. Wyoming gains substantially from higher tariffs in two sectors: Mining and Refined products. Meanwhile, tariff increases in any other sector result in welfare losses for Wyoming. In a similar vein, Oregon is the biggest gainer among US states when the tariff increases for Computers and electronics, but it tends to lose with tariff increases in other sectors. The effects of raising the tariff in any given sector are mild for Ohio, because Ohio has neither a strong comparative advantage nor disadvantage in any sector, as the number of states exceeds the number of sectors.

Figure 13: Percent Change in Welfare From Sector-Specific Tariff Changes



Notes: The vertical dotted lines depict the range of welfare changes across US states when the US import tariff is increased by 25 percentage points in each sector, on sector at a time. The positions of Wyoming, Ohio, and Oregon are shown in each case.

Redistribution of Tariff Revenue In all of the above analysis we assume that US tariff revenue is transferred across states in proportion to each state's population share. From an empirical point of view, there does not exist a specific budgeting rule that we can leverage, because the federal government does not earmark tariff revenue for specific types of expenditure. That said, since the United States is a fiscal union, from a policy perspective there are no obvious restrictions on how these transfers can be allocated. Hence, in principle, the federal government could implement fiscal transfers across states to balance the gains. That is, if the "size of the pie" grows, then it is presumably possible to benefit each state through transfers. The question then becomes: how should the transfers be allocated? In some sense, the answer is straightforward: Give more resources to states whose real factor income declines the most (increases the least). However, it is not obvious that the overall size of the pie would remain invariant to the transfers, and it is even less obvious that the change in each state's real factor income is invariant to the transfers.

We solve for the tariff revenue rebates that equalize welfare gains across states in the baseline scenario of a uniform 25-percentage-points increase in the tariff rate across sectors. We find that a state's factor income contributions and the size of the US "pie" are essentially invariant to alternative transfers. To equalize welfare gains across states, the per-capita transfers need to be perfectly negatively correlated with the factor income contribution. That is, states that lose more in real factor income need to be compensated by the states that gain the most in real factor income. For example, the transfer to Washington is more than 20 times more than that to Wyoming on a per-capita basis (4.3 percent compared with 0.2 percent).

5 Conclusion

US trade policy has heterogeneous impacts across US states. We seek to identify the sources of heterogeneity underpinning such spatial variation. We develop a multi-sector, multi-location model of international and interstate trade. Locations differ in terms of their factor endowments, sectoral productivity, and trade costs, each of which shapes the pattern of trade and sectoral specialization across locations. Starting from observed tariff schedules, we consider a unilateral increase in the US import tariff of 25 percentage points across all sectors. In spite of higher consumer prices the US as a whole experiences, on net, welfare gains because of a favorable shift in its terms of trade. However, the gains are not distributed equally across states, ranging from from -0.8 percent in Oregon to 2.1 percent in Montana. This variation depends on how labor income changes in response to the higher tariffs.

The impact of higher tariffs on a state's labor income depends on how its internal comparative advantage interacts with US external comparative advantage. US external comparative advantage—driven by both Ricardian and Heckscher-Ohlin forces—governs the sectoral effects across US states. Sectors of US external comparative advantage (e.g. Computers and electronics) suffer from higher tariffs, while sectors of US comparative disadvantage (e.g. Mining) benefit. State internal comparative advantage—driven by Ricardian forces—determines each state's exposure to different sectors. States with internal comparative advantage in sectors in which the US has an external comparative disadvantage realize large increases in labor income, and so prefer high tariffs. For instance, Wyoming has an internal comparative advantage in Mining, so higher tariffs cause US states to redirect spending away from foreign imports to Wyoming, benefiting Mining workers in Wyoming.

Heterogeneity within a customs union complicates the design of optimal trade policy in terms of selecting the optimal tariff schedule and overcoming political economy tensions between member states. Our quantitative model provides a starting point to do such analysis. Abstracting from strategic considerations in choosing tariffs, our analysis suggests that the US can choose a tariff to maximize the "size of its pie" and then use transfers to distribute tariff revenue so as to balance the gains across states. This result emerges because the cross-state transfer schedule barely impacts the size of the pie. Of course, further work is needed to incorporate strategic interactions across countries and other dimensions of trade policy, such as export subsidies or sector-specific taxes and subsidies.

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A Equilibrium conditions

This appendix describes the equilibrium conditions in the static model with immobile factors of production.

Household optimization The optimal sectoral consumption expenditure of the representative household in location n is

$$p_n^j c_n^j = \omega_n^j P_n^c C_n.$$

Firm optimization At the sector level, factor expenses exhaust the value of output, which implies:

$$w_n^h h_{nt}^j = \lambda^j \nu^j p_n^j y_n^j, \quad w_n^\ell \ell_{nt}^j = (1-\lambda^j)\nu^j p_n^j y_n^j, \quad p_n^k m_{nt}^{jk} = (1-\nu^j)\mu^{jk} p_n^j y_n^j.$$

Market-clearing conditions Within each location n, markets for the composite sectoral good must clear: $c_n^j + \sum_{k=1}^J m_n^{kj} = Q_n^j$, for any j.

The value of sector-j output produced by location n is equal to the (pre-tariff) value of sector j goods that all countries purchase from country n:

$$p_n^j y_n^j = \sum_{i=1}^N \left[\left(p_i^j c_i^j + \sum_{k=1}^J p_i^j m_i^{kj} \right) \left(\frac{\pi_{in}^j}{1+\tau_{in}^j} \right) \right].$$

Factor markets must clear: $k_n^j = \bar{k}_n^j$, $h_n^j = \bar{h}_n^j$, and $\ell_n^j = \bar{\ell}_n^j$.

Finally, the aggregate resource constraint must hold in each country:

$$\sum_{j=1}^J \sum_{i=1}^N \left(\frac{p_n^j Q_n^j \pi_{ni}^j}{1+\tau_{ni}^j} \right) = \sum_{j=1}^J p_n^j y_n^j - \mathrm{T}_n + \mathrm{IBT}_n,$$

where the left-hand side is country n's (pre-tariff) gross absorption. The right-hand side is the sum of gross output and the net government transfer $\mathrm{IBT}_n - \mathrm{T}_n$. The transfer is zero at the country level but may deviate from zero at the state level.

B Data

The primary data sources include Bureau of Economic Analysis Regional Economic Accounts (BEA); Census Bureau Commodity Flow Survey (CFS); Census Bureau Foreign Trade Database (FTB); version 10.0 of the Penn World Table (Feenstra, Inklaar, and Timmer, 2015, (PWT)); World Input-Output Database (Timmer, Dietzenbacher, Los, Stehrer, and de Vries, 2015; Timmer, Los, Stehrer, and de Vries, 2016, (WIOD)), including the July 2014 and November 2016 releases of the WIOD Socio Economic Accounts (SEA14 and SEA16, respectively); Centre d'Etudes Prospectives et d'Informations Internationales (CEPII), and World Integrated Trade Solution (WITS) database. We merge the different data sources into 16 sectors and 59 locations. Unless stated otherwise, all data are for year 2012, which is the latest year available for the state-to-state trade data.

B.1 Location and sector aggregation

We construct our 16 sectors by aggregating 3-digit NAICS (2012) classifications as shown in Table B.1. The 59 locations consist of 50 US states and 9 non-US locations, which are listed in Table B.2. Among the 9 non-US locations there are 7 individual non-US countries, each of which accounts for at least 1 percent of US imports and 1 percent of US exports, a EU-28 aggregate, and a Rest-of-world aggregate. Our Rest-of-World aggregate includes the "rest-of-world" aggregate, as constructed in the WIOD, plus the following individual countries: Indonesia, Norway, Russia, Switzerland, Taiwan, and Turkey.

Table B.1: Sector classification

Sector name	3-digit NAICS code
Agriculture	11*
Mining	211–213
Food, beverages, and tobacco	311, 312
Textiles and apparel	313–316
Wood	321
Paper and printing	322, 323
Refined petroleum, plastics, and rubbers	324, 326
Chemicals and pharmaceuticals	325
Non-metallic minerals	327
Primary and fabricated metals	331, 332
Machinery n.e.c.	333
Computers, electronics, and electrical equipment	334, 335
Transportation equipment	336
Furniture and other	337, 339
Tradable services	42*, 44*, 45*, 48*, 49*, 51*, 52*, 54*–56*
Nontradable services	22*, 23*, 53*, 61*, 62*, 71*, 72*, 81*, 92*

Note: *ab** refers to three-digit categories beginning with digits *ab*. For example, 11* refers to three-digit codes 110, 111, 112, etc.

B.2 Input-output data

For each country, data on sectoral value added and gross output (in current US dollars) are obtained from WIOD. We define value added as the difference between gross output and intermediate spending to abstract from taxes, subsidies, and international transport margins. Data on sectoral value added in each US state come from the BEA. In each sector, we scale the state-level value added data so that the sum across states equals US value added. We construct sectoral gross output for each state by assuming that in each sector the ratio of value added to gross output is the same as the ratio for the US

Data on intermediate inputs come directly from the WIOD at the country level. Final demand is the sum of private and public consumption and investment expenditure. Data on country-level final demand across sectors also come from the WIOD.

Table B.2: Location names and codes

US states			
Alabama	AL	Montana	MT
Alaska	AK	Nebraska	NE
Arizona	AZ	Nevada	NV
Arkansas	AR	New Hampshire	NH
California	CA	New Jersey	NJ
Colorado	CO	New Mexico	NM
Connecticut	CT	New York	NY
Delaware	DE	North Carolina	NC
Florida	FL	North Dakota	ND
Georgia	GA	Ohio	OH
Hawaii	HI	Oklahoma	OK
Idaho	ID	Oregon	OR
Illinois	IL	Pennsylvania	PA
Indiana	IN	Rhode Island	RI
Iowa	IA	South Carolina	SC
Kansas	KS	South Dakota	SD
Kentucky	KY	Tennessee	TN
Louisiana	LA	Texas	TX
Maine	ME	Utah	UT
Maryland	MD	Vermont	VT
Massachusetts	MA	Virginia	VA
Michigan	MI	Washington	WA
Minnesota	MN	West Virginia	WV
Mississippi	MS	Wisconsin	WI
Missouri	MO	Wyoming	WY

Non-US countries and regions	
European Union (EU-28)	EUR
Brazil	BRA
Canada	CAN
China	CHN
India	IND
Japan	JPN
South Korea	KOR
Mexico	MEX
Rest-of-world	ROW

Notes: Our Rest-of-World aggregate includes the "rest-of-world" aggregate as constructed in the WIOD, plus Indonesia, Norway, Russia, Switzerland, Taiwan, and Turkey.

B.3 Factor endowments

We construct data on the two types of labor (high and low skill) from various sources. High-skill workers are those that completed a post-secondary degree, while low-skill workers are those with less than a completed post-secondary degree.

Data on aggregate employment (the number of persons engaged) at the country level come from PWT 10. Sectoral employment data for each country come from the SEA16. We scale sectoral employment to match total employment from PWT. Sectoral employment for each country is further broken down into high-skill and low-skill employment using data from the SEA14.[15] The SEA14 does not have the

[15]The SEA14 provides data on the share of high-skill working hours in total hours by sector. We

high-skill labor share for all countries and sectors. We impute the missing high-skill labor share by regressing the observed values across countries on aggregate real income per capita within a sector.

Sectoral employment data for US states come from the BEA. Some states report zero employment in certain sectors with positive value added. For these observations we impute sectoral employment such that the ratio of value added to employment is equal to the median value across states in that sector. Accordingly, we scale the state-level employment to match employment at the US level in each sector. For each state, the skill shares in total employment are set equal to the US shares.

B.4 Factor compensation

We obtain compensation to the two primary factors of production (high and low skill labor) from the SEA14. (The SEA14 release reports data from 1995-2011, so we compute each number as the median value over time.) The high skill share in labor is measured as the ratio of high skill labor compensation times total labor compensation, relative to compensation of employees. This share is then multiplied by labor compensation to obtain high skill labor compensation. Low skill labor compensation is the residual labor compensation.

B.5 Bilateral trade

We first use various sources of trade data to construct bilateral trade flows across regions at the sector level as far as possible. We then use a gravity specification to impute missing trade flows. All data reported Free on Board.

Country-to-country trade Bilateral trade data across countries for every sector are taken from WIOD.

State-to-country trade Bilateral trade between US states and non-US countries is taken from the FTB for agriculture, mining, and all 12 manufacturing sectors. For each of these sectors, we scale the trade flows proportionately across states so that in each sector (i) the sum of all states' exports to any non-US country equals US exports to that country in WIOD and (ii) the sum of all states' imports from any non-US country equals US imports from that country in WIOD.

We make two adjustments to the data. First, in some sectors, all states have zero reported trade with some countries, while the aggregate US data report a positive amount.[16] We impute state-level trade as US trade multiplied by each state's share in US value added in the relevant sectors. Second, in some sectors, the sum of a state's exports to all foreign countries exceeds its gross output due to measurement problems.[17] This is either because exports are over-reported due to re-export issues or

take the share of hours by high-skill workers to be the share of employment by high-skill workers.

[16]There are 8 such instances in total: imports from Luxembourg in Agriculture; imports from Luxembourg, Malta, Bulgaria, and Slovakia in Mining; imports from Malta in Paper and printing; and imports from Slovakia and Slovenia in Chemicals and pharmaceuticals.

[17]These cases are Alaska and Louisiana in Agriculture; Delaware, Michigan, Maine, and North Dakota in Paper and printing; Delaware, Montana, North Dakota, and Oregon in Chemicals and

because gross output is constructed below the actual levels due to our assumption of a constant gross-output-to-value-added ratio across states. To address this problem, we adjust down these states' exports using the following procedures.

For each sector, we categorize a state into a problematic group if its ratio of foreign exports to gross output exceeds 0.8, or into a non-problematic group otherwise. Using the non-problematic group, we compute the maximum ratio of foreign exports to gross output. We define an adjustment ratio as the midpoint of 0.8 and the maximum ratio. For the problematic states, we scale down their foreign exports to be the product of their gross output and the adjustment ratio. We construct "lost exports" as the difference between the observed exports and the scaled exports. To be consistent with US exports data, we reallocate the lost exports to non-problematic states in proportion to their observed shares in US exports in a given sector.

State-to-state trade The CFS provides survey-based trade data between US cities for manufacturing. We aggregate these manufactured products into our 12 manufacturing sectors and aggregate the cities to the state level. We then scale these flows so that each state's gross output in each manufacturing sector equals its sales to foreign countries plus its sales to all US states (including to itself).

Inferring missing bilateral trade flows As noted above, there are no data for state-to-foreign-country trade in services or for state-to-state trade in agriculture, mining, or services. We use a gravity specification informed by observed trade flows, along with sector, state, and country characteristics and geography to impute these missing bilateral trade flows as follows:

$$\begin{aligned}\ln(\mathrm{Trd}_{ni}^j) = {} & \alpha_j + \delta_n + \gamma_i + \rho_0 \ln(1+\tau_{n,i}^j) + \rho_1 \ln(\mathrm{GO}_i^j) + \rho_2 \ln(\mathrm{FD}_n^j) \\ & + \rho_3 \mathbb{I}_{n\in\mathcal{US}, i\notin\mathcal{US}} \ln(\mathrm{Trd}_{\mathrm{US},i}^j) + \rho_4 \mathbb{I}_{n\notin\mathcal{US}, i\in\mathcal{US}} \ln(\mathrm{Trd}_{n,\mathrm{US}}^j) \\ & + \sum_{r=1}^{6} \beta_{d,r}^j \mathrm{dis}_{ni}^r + \beta_b^j \mathrm{bdr}_{ni} + \beta_c^j \mathrm{cur}_{ni} + \beta_l^j \mathrm{lng}_{ni} + \beta_f^j \mathrm{fta}_{ni} + \beta_h^j \mathrm{hbs}_{ni} + \epsilon_{ni}^j. \end{aligned} \tag{B.1}$$

The trade flow Trd_{ni}^j is the Free on Board value. First, we include sector, importer, and exporter fixed effects: α_j, δ_n, and γ_i. Second, we include the bilateral tariff associated with the particular trade flow. Third, we include sectoral gross output of the exporter, $\ln(\mathrm{GO}_i^j)$, and sectoral final demand by the importer, $\ln(\mathrm{FD}_n^j)$.[18] Sectoral final demand for each state is calculated by assuming its ratio of final demand to GDP is the same as the ratio for the United States. Fourth, we include the sectoral bilateral trade flows between the US and each foreign country when predicting each US state's sectoral bilateral trade with that foreign country. Specifically, US imports in sector j to country i are denoted by $\ln(\mathrm{Trd}_{\mathrm{US},i}^j)$, and US exports in sector j to country i are denoted by $\ln(\mathrm{Trd}_{n,\mathrm{US}}^j)$. Finally, we include sector-specific geographic

pharmaceuticals; Florida, Hawaii, Nevada, and Vermont in Computers and electronics; Alaska, Delaware, and Florida in Machinery n.e.c.; and Alaska, Delaware, Hawaii, and New Jersey in Transportation equipment.

[18] Ideally we would use gross absorption rather than final demand, but we do not have data on gross absorption for US states in agriculture, mining, and service sectors.

effects captured by dummy variables. The first five terms are the same as those we used in our estimation in Section 3.3 (distance, shared border, common currency, common language, and belonging to a free-trade agreement). The sixth term is a home-bias dummy indicating whether the exporter is the same as the importer. Estimates are reported in table B.3. The R^2 is 0.74, and almost all of the coefficients are statistically significant.

We impute the missing bilateral trade flows given the observed predictors on the right-hand side of the estimated equation (B.1). For two service sectors, we scale the state-to-country trade flows proportionately so that in each sector, the sum of exports (imports) across states with any foreign country equals US exports to (imports from) that country in WIOD. For agriculture, mining, and the two service sectors we proportionately scale the state-to-state trade flows so that each state's gross output equals its sales to foreign countries plus its sales to all 50 states.

B.6 Tariffs

Tariff data are from the WITS database. We use the HS-2012 classification, which contains products at the 6-digit level. We focus on a sample of regions and countries (the United States, 27 EU countries,[19] Brazil, Canada, China, India, Japan, South Korea, and Mexico). For reporters, we have 8 individual countries along with one aggregated entity for the European Union (EU). For partners, the EU is disaggregated into 27 member countries. If the tariff rate for a partner of a reporting country is missing, we fill in missing values with the maximum tariff value by this reporter in this product. We use effectively applied rates reported in the database.

We construct the bilateral tariff rates in two steps. First, we build the bilateral rate matrix at the 6-digit level. Particularly, we need to disaggregate the EU into its 27 individual countries. For each EU country, we set tariff at zero if the partner is also a EU member, and the reported tariff rate otherwise. Second, we aggregate these matrices up to our sectoral level. We find the "most traded" HS-6 products for each importer within each sector and compute the simple average tariff across these products. These most-traded products are defined as the smallest set that cumulatively accounts for at least 80 percent of an importer's sectoral imports and that individually account for at least 0.005 percent of imports. The HS-6 trade data come from the BACI dataset developed by CEPII for 2012.

[19]Belgium and Luxembourg are merged because of trade data availability.

Table B.3: Estimates for Missing Trade Flows

			dis^2_{ni}	dis^3_{ni}	dis^4_{ni}	dis^5_{ni}	dis^6_{ni}	bdr_{ni}	cur_{ni}	lng_{ni}	fta_{ni}	hbs_{ni}
$\ln(1+\tau^j_{n,i})$	-0.61	Agriculture	-0.55	-1.38	-1.81	-4.65	-4.99	1.01	0.52	1.45	-0.27	2.79
	(0.21)		(0.14)	(0.14)	(0.16)	(0.17)	(0.17)	(0.14)	(0.08)	(0.09)	(0.10)	(0.22)
$\ln(\text{GO}^j_i)$	1.01	Mining	-1.15	-1.89	-2.69	-4.38	-5.29	1.50	0.46	1.23	0.09	2.12
	(0.01)		(0.12)	(0.12)	(0.13)	(0.15)	(0.16)	(0.12)	(0.08)	(0.09)	(0.10)	(0.21)
$\ln(\text{FD}^j_n)$	0.10	Food	-0.86	-1.68	-2.31	-3.98	-4.30	1.22	0.83	1.05	0.70	2.15
	(0.01)		(0.12)	(0.12)	(0.13)	(0.14)	(0.15)	(0.12)	(0.07)	(0.09)	(0.09)	(0.21)
$\mathbb{I}_{n\in\mathcal{US},i\notin\mathcal{US}}\ln(\text{Trd}^j_{\text{US},i})$	0.03	Textiles	-0.40	-0.85	-1.07	-3.28	-3.34	0.77	0.90	0.82	0.62	1.51
	(0.00)		(0.12)	(0.12)	(0.13)	(0.14)	(0.15)	(0.12)	(0.07)	(0.09)	(0.09)	(0.21)
$\mathbb{I}_{n\notin\mathcal{US},i\in\mathcal{US}}\ln(\text{Trd}^j_{n,\text{US}})$	0.04	Wood	-1.02	-1.75	-2.34	-4.61	-4.99	1.54	0.71	0.82	-0.06	2.26
	(0.01)		(0.12)	(0.12)	(0.13)	(0.15)	(0.16)	(0.12)	(0.08)	(0.09)	(0.10)	(0.21)
Origin Fixed Effects	Y	Paper & printing	-0.46	-1.11	-1.60	-3.64	-3.88	0.89	0.97	1.18	0.40	1.64
Destination Fixed Effects	Y		(0.12)	(0.12)	(0.13)	(0.14)	(0.15)	(0.12)	(0.07)	(0.08)	(0.09)	(0.21)
Sector Fixed Effects	Y	Refined products	-0.72	-1.68	-2.45	-4.34	-4.81	1.31	0.40	0.49	0.49	2.03
			(0.12)	(0.12)	(0.13)	(0.15)	(0.15)	(0.12)	(0.07)	(0.09)	(0.09)	(0.21)
		Chemicals	-0.73	-1.37	-2.02	-3.77	-3.95	1.11	0.33	0.12	0.49	1.93
			(0.12)	(0.12)	(0.13)	(0.14)	(0.14)	(0.12)	(0.07)	(0.09)	(0.09)	(0.21)
		Non-metallic minerals	-0.83	-1.68	-2.19	-3.66	-4.26	1.25	0.62	0.96	0.54	2.40
			(0.12)	(0.12)	(0.13)	(0.15)	(0.15)	(0.12)	(0.07)	(0.09)	(0.09)	(0.21)
		Metals	-0.57	-1.27	-1.75	-3.73	-4.16	0.94	0.58	0.83	0.65	1.78
			(0.12)	(0.12)	(0.13)	(0.14)	(0.15)	(0.12)	(0.07)	(0.09)	(0.09)	(0.21)
		Machines n.e.c	-0.48	-0.93	-1.31	-2.76	-3.24	1.08	0.55	0.31	0.59	1.87
			(0.12)	(0.12)	(0.13)	(0.14)	(0.14)	(0.12)	(0.07)	(0.08)	(0.09)	(0.21)
		Computers and electronics	-0.35	-0.69	-1.02	-2.61	-2.94	0.56	0.53	0.33	0.84	1.47
			(0.12)	(0.12)	(0.13)	(0.14)	(0.15)	(0.12)	(0.07)	(0.08)	(0.09)	(0.21)
		Transport equipment	-0.44	-1.13	-1.67	-3.24	-3.61	1.32	0.27	0.30	0.79	2.22
			(0.12)	(0.12)	(0.13)	(0.14)	(0.15)	(0.12)	(0.07)	(0.09)	(0.09)	(0.21)
		Furniture & other	-0.66	-1.31	-1.65	-3.25	-3.47	0.92	0.38	0.98	0.71	2.17
			(0.12)	(0.12)	(0.12)	(0.14)	(0.14)	(0.12)	(0.07)	(0.08)	(0.09)	(0.21)
		Tradable services	-0.93	-1.38	-1.71	-4.01	-4.85	0.12	0.59	0.51	0.19	3.58
			(0.21)	(0.21)	(0.25)	(0.24)	(0.25)	(0.22)	(0.21)	(0.13)	(0.13)	(0.36)
		Nontradable services	-1.04	-1.81	-2.50	-4.85	-5.87	-0.10	0.89	0.42	-0.30	5.33
			(0.21)	(0.21)	(0.25)	(0.24)	(0.25)	(0.22)	(0.21)	(0.13)	(0.13)	(0.36)

Notes: Standard errors are in parentheses.