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A Quantitative Analysis of Tariffs across U.S. States *

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Abstract

We develop a quantitative framework to assess the cross-state implications of a U.S. trade policy change: a unilateral increase in the import tariff from 2% to 25% across all goods-producing sectors. Although the U.S. gains overall from the tariff increase, we find the impact differs starkly across locations. Changes in real consumption (welfare) range from as high as 3.8% in Wyoming to −0.3% in Florida, depending mainly on how exposed states are to differentially-impacted sectors. As a result, the "preferred" tariff rate varies greatly across states. Foreign retaliation in trade policy substantially reduces the welfare gains across states, while perpetuating the cross-state variation in those gains. The presence of internal trade frictions amplifies the welfare impacts of changes in trade policy.

Keywords: International trade, Interstate trade, Welfare gains from trade
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1 Introduction

One defining characteristic of the United States is that it is a custom union of 50 states with a common external tariff, set by Congress. Due to heterogeneity across states, the impacts of national trade policy can markedly differ geographically. Even if the U.S. as a whole can benefit from a trade policy change, geographic heterogeneity implies that certain transfers across states might be necessary, particularly in the short run, in order to gain sufficient support for any policy change. Thus, it is imperative to evaluate heterogeneous implications of a trade policy change across states, beyond the aggregate-level analysis dominant in the literature. Furthermore, the national impact of trade policy itself might depend on underlying internal adjustments among states.

We develop a quantitative framework to assess the cross-state implications of a U.S. trade policy change: a unilateral increase in the import tariff from 2% to 25% across all goods-producing sectors. Although the U.S. gains overall from the tariff increase, we find the impact differs starkly across locations. Changes in real consumption range from as high as 3.8% in Wyoming to -0.3% in Florida, depending mainly on how exposed states are to differentially-impacted sectors. As a result, the "preferred" tariff rate varies greatly across states. Foreign retaliation in trade policy substantially reduces the welfare gains across states, while perpetuating the cross-state variation in those gains. The presence of internal trade frictions amplifies the welfare impacts of changes in trade policy.

The model features a multi-region, multi-sector, general equilibrium structure with both international and interstate trade to quantify the effects of an increase in U.S. tariffs. The United States is treated as a customs union with many locations. Each location is endowed with capital, skilled and unskilled labor, differs in sectoral productivity, and faces asymmetric bilateral iceberg trade costs and tariffs. Competitive firms in each location carry out production with factor intensities, as well as input-output linkages, unique at the country-sector level. Within each location, a representative household pools factor income in every sector and receives rebates of import tariffs. We focus on the short-run implications where the factors of production are immobile across space and sectors.

The model is calibrated to 59 regions (50 U.S. states, 8 foreign regions, and a rest-of-world aggregate) and 16 sectors (14 goods sectors and 2 services sectors) for the year 2012. Following Levchenko and Zhang (2016), we infer bilateral trade costs and productivity for these sectors and locations from observed trade flows using the gravity approach. However, one challenge of this strategy is the lack of state-to-state trade data in agriculture, mining, and services and state-to-country trade data in services. To overcome this limitation, we construct sensible estimates for these missing trade flows using a gravity specification that links observed bilateral trade flows with various observables including

sector, origin, and destination fixed effects, production and demand at the sector level, and various measures of distance barriers. Finally we ensure these imputed trade flows are consistent with production data at the state level.

We quantify the heterogeneous welfare effects of U.S. trade policy across states in the calibrated model. The trade policy change we consider is a uniform increase of U.S. import tariffs from 2 to 25 percent in all goods-producing sectors.[1] The U.S. population-weighted average welfare increases by 0.5 percent with the increased tariff. The impacts are quite heterogeneous across states. Welfare gains range from -0.3 percent in Florida to 3.8 percent in Wyoming. We decompose the welfare change into (i) the change in real factor income and (ii) the change in real tariff revenue. Most states experience a decline in real factor income, while all states experience an increase in real tariff revenue. The former effect accounts for the variation in welfare gains across states: the correlation between changes in factor income and welfare is 0.7 across states. The latter effect explains the positive, overall gains in the United States.

Differential changes in factor income across states are mainly driven by their sectoral exposure, because the impact of a higher tariff is heterogeneous across sectors. This higher uniform tariff boosts sectors that are least competitive internationally, as those sectors increase their domestic market share. The U.S. has comparative advantages in sectors using skilled-labor intensively, such as Computers and electronics, Chemicals, Paper and printing, and Machines. Real factor income declines the most in these sectors. On the other hand, the comparative disadvantage sectors, such as Textiles, Agriculture, Metals, Wood, and Mining, experience the largest increase in real factor income. States that are more exposed to the adversely impacted sectors experience a larger decline in factor income. Examples include Delaware, New York, and Florida.

In our baseline exercise of uniformly increasing the tariff rate from 2% to 25%, every state experiences higher tariff revenue, boosting welfare. However, the gain from higher tariff revenue also systematically differs across sectors, driven largely by the trade elasticity. Sectors with lower (higher) trade elasticity, such as Agriculture, Mining, and Paper and printing (Metals and Refined products), experience greater (smaller) increases in real tariff revenue. The result is intuitive because a lower trade elasticity implies that it is harder to substitute away from foreign imports in response to a higher tariff. States with high shares of tariff revenue from Mining have larger gains in total tariff revenue (i.e., Montana, Mississippi, etc.). In contrast, states with high shares of tariff revenue from

[1]By imposing uniformity we remove effects stemming from differences in effective tariff rates due to differences in the composition of trade, allowing us to isolate heterogeneous impacts of tariffs free from differences in initial effective levels and differences in effective changes. 2 percent is the effective tariff that the U.S. imposes and a uniform (across sector) 2 percent tariff yields about the same ratio of tariff revenue to GDP as the observed tariffs.

Metals (e.g., West Virginia) have smaller gains in total tariff revenue. The change in tariff revenue is not monotonic with the increase in tariffs. As the tariff rate rises sufficiently high, the country approaches autarky, and tariff revenue falls to zero.

Heterogeneous impacts of a tariff increase across states imply that states have different preferences over trade policy. To see this clearly, we construct a welfare "Laffer" curve by varying the uniform tariff rate from zero to a prohibitively high level. Inherited from the shape of tariff revenue over tariff levels, the welfare Laffer curve tends to be hump shaped, which allows us to determine a welfare-maximizing tariff rate for each state and the country as a whole. The tariff rate that maximizes population-weighted welfare for the U.S. is 23%. Indeed, there is substantial variation across states in the preferred tariff rate. Some states, like Wyoming and North Dakota with a large exposure to Mining, prefer a tariff rate above 300%, while some states, like Florida and New York with high exposure to Computers and electronics and Chemicals, prefer a tariff rate below 3%.

What will happen if foreign countries retaliate with reciprocal import tariffs on U.S. goods? We find that population-weighted U.S. welfare now decreases by 0.2% with a tariff rate of 25% as states experience larger decreases in real factor income and smaller increases in real tariff revenue, relative to the case without retaliation. Foreign retaliation also moves down the welfare Laffer curves. More states now prefer a zero tariff, particularly those specialized at high-skill intensive sectors. Their real factor income declines monotonically with foreign tariffs, given their high exports. On the other hand, states highly concentrated in Mining activity continue to prefer high tariffs. They specialize in low-skill intensive sectors and primarily sell in the domestic market, so they are less impacted by higher tariffs abroad.

The magnitude of internal trade costs is crucial for quantifying the changes in welfare resulting from changes in tariffs. Autarky is much less costly if internal trade costs are lower. When internal trade is less costly, states can substitute foreign imports with products from other U.S. states more easily and thus suffer less from autarky. The implication is reversed at low tariff levels. For instance, when increasing tariffs from 2% to 25%, the U.S. experiences gains in the presence of internal frictions, but loses in the absence of internal trade costs. Under zero internal trade costs, the U.S. trades a lot internally, and much less with foreign countries, so it has relatively small share of tariff revenue in its income. Thus, increasing tariff revenue does not contribute substantially to total income. When the U.S. has large internal frictions, foreign imports are relatively large, so tariff revenue is a sizable share in total income.

Our paper also makes two technical contributions to the literature. First, we estimate both domestic and international trade frictions at the sector level using the gravity rela-

tion prevailing in the trade literature.[2] In this process, we construct sensible estimates for the missing trade flows between states in agriculture, mining and services and between states and foreign countries in services. Inclusion of tradable services is important given that services account for a large share of the consumption bundle. Second, we decompose each location's comparative advantage into fundamental factor endowments, sectoral productivity, and trade barriers. This allows us to gain a deeper understanding on the forces behind welfare gains heterogeneity across states and to conduct specific experiments, such as impacts of internal trade costs, labor mobility or productivity.

Recent studies have evaluated, quantitatively, the impact of U.S tariffs on the aggregate U.S. economy (Amiti, Redding, and Weinstein, 2019; Cavallo et al., 2021) as well as across different states (see Auer, Bonadio, and Levchenko, 2018; Fajgelbaum et al., 2019; Waugh, 2019). Different from these papers that only consider changes in trade flows between the U.S states and foreign countries, our paper models explicitly interstate trade to account for the internal adjustment that takes place when there is a change in trade policy. Other recent studies (see, for instance, Allen and Arkolakis, 2014; Caliendo, Dvorkin, and Parro, 2019; Caliendo et al., 2018) have modelled internal re-allocations within the U.S, but do not study how foreign trade policy, such as changes in tariffs, affect external adjustments.

Our paper builds on several studies that highlight the role of internal trade costs in international trade models. Ramondo, Rodríguez-Clare, and Saborío-Rodríguez (2016) derive an augmented ACR formula (Arkolakis, Costinot, and Rodríguez-Clare, 2012) to illustrate the effect of heterogeneous trade frictions on welfare. Coşar and Demir (2016), Coşar and Fajgelbaum (2016), and Donaldson (2018) show that the internal infrastructure has an important effect on domestic trade flows and comparative advantage. Redding (2016) studies the role of internal trade costs and factor mobility across regions on welfare. Dai, Yotov, and Zylkin (2014) identify trade diversion effects of FTA agreements using domestic trade flows in gravity estimations. Our paper exploits the quantitative implications of trade policy in such a framework with internal trade costs.

2 The model

We build on the workhorse Eaton-Kortum trade model with multi-sectors. Particularly, we introduce U.S. states as locations in the model. The world economy consists of N_s U.S. states and N_c non-US countries and J sectors. The total number of regions is $N = N_s + N_c$, where regions are indexed by $(n, i) = 1, \ldots, N$. There are J sectors,

[2] An alternative approach is to compute internal trade flows using output and expenditure data as in Eckert et al. (2019) and Gervais and Jensen (2019).

indexed by $(j,k) = 1,\ldots,J$. Trade across countries is subject to a physical iceberg cost (trade cost from now on) and tariffs, while trade across U.S. regions is subject to only trade costs. Production requires capital, skilled and unskilled labor. Factor mobility across sectors within a region is used to capture the implications of trade policy over different horizons. Specifically, immobile factors across sectors captures the short-run impact and mobile factors across sectors captures long-run implications.

Firms There is a unit interval of potentially tradable varieties in each sector indexed by $v \in [0,1]$. In each sector and location there is a competitive firm that aggregates all varieties with constant elasticity in order to construct a nontradable composite good according to

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

where η is the elasticity of substitution between any two varieties. The term $q_n^j(v)$ is the quantity of variety v used by country n to construct the sector j composite good. each variety is purchased from the cheapest source. The composite good, Q_n^j, is allocated for domestic use as either an intermediate input or for final consumption or final investment.

Each variety can be produced using capital, labor, and composite goods. Production of each variety is carried out by a competitive firm using the following technology

$$y_n^j(v) = a_n^j(v)\left[A_n^j k_n^j(v)^{\alpha_n^j}\left(h_n^j(v)^{\lambda_n^j}\ell_n^j(v)^{1-\lambda_n^j}\right)^{1-\alpha_n^j}\right]^{\nu_n^j}\left[\prod_{k=1}^{J} m_n^{jk}(v)^{\mu_n^{jk}}\right]^{1-\nu_n^j}. \tag{2}$$

The term $m_n^{jk}(v)$ denotes the quantity of the composite good of type k used by country n to produce $y_n^j(v)$ units of variety v in sector j. $k_n^j(v)$ denotes the amount of capital stock used, $h_{nt}^j(v)$ the amount of high skilled workers employed, and $\ell_{nt}^j(v)$, the low skilled workers.

The country-specific parameter $\nu_n^j \in [0,1]$ is the share of value added in total output in sector j, while $\mu_n^{jk} \in [0,1]$ is the share of composite good k in total spending on intermediates by producers in sector j, with $\sum_k \mu_n^{jk} = 1$. The term α_n^j denotes capital's share in value added, and λ_n^j the share of high skilled workers in labor compensation.

The term A_n^j is the fundamental productivity, which scales value-added, for all varieties in sector j of country n. 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 productivities in sector j for each variety are drawn independently from a Fréchet distribution with sector-specific shape parameter θ^j. The c.d.f. for idiosyncratic productivity draws in sector j is $F^j(a) = \exp(-a^{-\theta^j})$.

Trade Trade between different locations is subject to two types of barriers. One barrier is a trade cost whereby region n must purchase $d_{ni}^j \geq 1$ units of any variety of sector j from region i in order for one unit to arrive; $d_{ni}^j - 1$ units *melt* away in transit. 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 gross tax rate that region n levies on the value of imports from region i in sector j; $\tau_{ni}^j - 1$ is the net tariff rate which is rebated to households in lump sum.

Households The representative household in region n is endowed with the factors of production that are specific to a location. These factors are supplied inelastically to local firms in the appropriate sector at the rates r_n^j, w_n^{hj}, and $w_n^{\ell j}$. Sectoral factor income is pooled within a location and constitutes that location's factor income F_n. Each location's "national" income also includes indirect business taxes, IBT_n, which are comprised of the tariff revenue that is rebated in lump sum to the household.[3] Finally, each location is endowed with a net-foreign asset position (NFA) $\bar{\mathcal{A}}_n$. The NFA yields a common world interest rate of $\bar{q}$, so $\bar{q}\bar{\mathcal{A}}_n$ serves as an exogenous transfer between regions to reconcile trade imbalances.[4]

Households spend their resources on consumption an investment, both of which are comprised of sectoral composite goods. Each sectoral composite good has a price of p_n^j. The sectoral composite goods are aggregated into consumption and investment according to

$$C_n = \prod_{j=1}^{J} \left(c_n^j\right)^{\omega_n^{cj}}, \quad X_n = \prod_{j=1}^{J} \left(x_n^j\right)^{\omega_n^{xj}}, \tag{3}$$

where C_n and X_n denote aggregate consumption and investment. c_n^j denotes consumption of the sector j composite good by country n and ω_n^{cj} denotes sector j's weight in the country n's consumption bundle (i.e., $\sum_{j=1}^{J} \omega_n^{cj} = 1$). Investment aggregation is analogous. Importantly, the weights ω_n^{xj} differ substantially from the weights ω_n^{cj}. Trade shocks that affect prices of machines and equipment will have relatively greater effects on investment than on consumption, while trade shocks that affect prices of food and nontradable

[3] In the baseline model, we assume that U.S. tariffs are distributed across U.S. states in proportion to state-level imports from non-U.S. countries. That is, states are effectively treated as sovereign entities within a customs union for the purposes of tariff revenue. Extensions of the baseline model will allow for these tariff revenue to be distributed differently across states within the U.S.

[4] We consider that the world economy is in its steady state. Thus, the current account is balanced and net imports equals interest earnings from the net foreign asset position. The NFA position is treated as an "endowment", or net transfer from the world; it sums to zero globally. Alternatively, imposing balanced trade at the country level does not substantially effect our results. However, trade imbalances at the state level are large. The presence of these imbalances reflects factors that are far beyond the scope of our analysis, such as fiscal transfers between states, and cross-state ownership of asset and capital.

services will have relatively greater effects on consumption than on investment.

The household maximizes aggregate real consumption C_n subject to the period budget constraint given by

$$P_n^c C_n + P_n^x X_n = F_n + \text{IBT}_n + \bar{q}\bar{\mathcal{A}}_n, \tag{4}$$

where factor income is given by $F_n = \sum_{j=1}^{J} \left(r_n^j k_n^j + w_n^{hj} h_n^j + w_n^{\ell j} \ell_n^j \right)$. Aggregate consumption and investment spending are given by $P_n^c C_n = \sum_{j=1}^{J} p_n^j c_n^j$ and $P_n^x X_n = \sum_{j=1}^{J} p_n^j x_n^j$, and their associated ideal price indexes are given by

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

For tractability in the static version of the model, we build investment using a "Solow"-type assumption where investment spending is a pre-determined share ρ_n of income, i.e.,

$$P_n^x X_n = \rho_n \left(F_n + \text{IBT}_n + \bar{q}\bar{\mathcal{A}}_n \right). \tag{5}$$

Feasibility conditions The goods market clearing conditions are standard in the literature. See Appendix A for the full equation. Here we focus on the factor market clearing conditions. In the case of immobile factors, we have

$$k_n^j = \bar{k}_n^j, \quad h_n^j = \bar{h}_n^j, \quad \ell_n^j = \bar{\ell}_n^j,$$

where $\bar{k}_n^j$, $\bar{h}_n^j$, and $\bar{\ell}_n^j$ are exogenous, sectoral endowments of factors. In the case of mobile factors across setors within a location, we have

$$\sum_j k_n^j = \bar{K}_n, \quad \sum_j h_n^j = \bar{H}_n, \quad \sum_j \ell_n^j = \bar{L}_n,$$

where $\bar{K}_n$, $\bar{H}_n$, and $\bar{L}_n$ are exogenous endowments of factors in a location n.

Equilibrium A competitive equilibrium satisfies the following conditions: i) taking prices as given, the representative household in each country maximizes its lifetime utility subject to its budget constraint, ii) taking prices as given, firms maximize profits subject to the available technologies, iii) intermediate varieties are purchased from their lowest-cost provider subject to the trade barriers, and iv) markets clear.

Accounting for change in consumption Equations (4) and (5) imply that consumption can be decomposed into three components: real factor income, real tariff revenue, and real trade deficit. In the first two components, both the numerator and de-

nominator change with tariffs. In the third component, only the denominator changes. The percent change in consumption following a change from an initial tariff, τ, to a new tariff, $\widetilde{\tau}$, is

$$\frac{\widetilde{C}_n}{C_n} - 1 = (1-\rho_n)\left(\frac{F_n}{P_n^c C_n}\right)\left(\frac{\widetilde{F}_n/\widetilde{P}_n^c}{F_n/P_n^c} - 1\right) + (1-\rho_n)\left(\frac{\mathrm{IBT}_n}{P_n^c C_n}\right)\left(\frac{\widetilde{\mathrm{IBT}}_n/\widetilde{P}_n^c}{\mathrm{IBT}_n/P_n^c} - 1\right) + (1-\rho_n)\left(\frac{\bar{q}\bar{\mathcal{A}}_n}{P_n^c C_n}\right)\left(\frac{P_n^c}{\widetilde{P}_n^c} - 1\right). \quad (6)$$

The percent change in consumption takes on a weighted average representation among the three components: (i) the share of consumption spending in national income times the initial share of factor income in consumption spending times the percent changes in real factor income, (ii) the share of consumption spending in national income times the initial share of tariff revenue income in consumption spending times the percent changes in real tariff revenue, (iii) the share of consumption spending in national income times the initial share of the trade deficit in consumption spending times the percent change in the real value of the trade deficit. Note that the investment rate affects the extent that changes in the three factors affect changes in consumption. A large investment rate, i.e., small $1-\rho_n$, attenuates the change in consumption. Since we assume equal investment rates across U.S. states, this term will have no role in explaining heterogeneity in the welfare implications among the states.

3 Calibration

The quantitative exercise is applied to 59 regions: 50 U.S. states, 8 non-U.S. regions (Brazil, Canada, China, the European Union, India, Japan, Mexico, South Korea), and a rest-of-world aggregate. These 8 non-U.S. regions were selected based on the criteria that they each accounted for at least one percent of U.S. trade in 2012; they collectively account for about 70 percent of U.S. trade. All remaining trading partners of the U.S. are part of the 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; (16) Nontradable services.

Our classification of goods sectors is determined by the maximum number of sectors

for which we can maintain a consistent correspondence across data sources. While we can include a larger number of service sectors, we choose to aggregate them into only two sectors for two reasons. First, our focus is on tariffs but we do not observe tariffs on services. Second, trade data in services at the U.S. state-level is limited and needs to be imputed, and our imputation is *less noisy* when aggregating. Still, we want to include services since they account for about one-third of U.S. exports and about 80 percent of U.S. employment, and services are important in an input-output sense with respect to manufacturing activities. Due to the large heterogeneity in types of services, we split service industries into two sectors, those that are relatively more traded are called *Tradable Services*, and those that are relatively less traded are called *Nontradable Services*. We determined this by ranking all industries in the WIOD by the ratio of global exports to global gross output, and drew the cutoff at 5 percent.[5]

3.1 Missing Trade Flows across U.S. States

To our knowledge, there is no data on bilateral trade flows in agriculture, mining, and service sectors across U.S. states. In addition, there is no data on bilateral trade in service sectors between U.S. states and other countries. What we have is complete bilateral trade flows (state-with-state, state-with-country, and country-with-country) in manufacturing sectors, state-with-country and country-with-country trade in agriculture and mining, and country-with-country trade in services. The Appendix describes how we construct sensible 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, common language, etc. We employ these estimated trade flows to estimate productivity and bilateral trade costs in all sectors for every region.

3.2 Parameters directly from the data

This subsection describes the parameters that are directly sourced from the data in 2012. Particularly, 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 U.S. states provided by Census Bureau's Commodity Flow Survey. Appendix B provides the detailed data description.

[5]The more tradable service sectors, beginning with the most tradable, are (i) Transport & warehouse, (ii) Wholesale & retail (iii) Information, (iv) Business services, and (v) Finance & insurance. These sectors have a ratio greater than 5 percent. The less tradable sectors, beginning with the most tradable, are (i) Entertainment, (ii) Utilities, (iii) Education, (iv) Other services, (v) Construction, (vi) Health, and (vii) Real estate.

Endowments Each region is endowed with sector specific capital, k_n^j, high skilled labor h_n^j, and low skilled labor ℓ_n^j. Let's first describe the country level calibration. Total employment and capital stock come from the Penn World Table (PWT).[6] To compute total employment by skill levels, we use high and low skill employment shares from the World Input Output Database (WIOD) Socio Economic Accounts, July 2014 release. We next calibrate each endowment at the sector level within a country using sectoral composition of capital and two types of labor in the WIOD Socio Economic Accounts, November 2016 release. Finally, we allocate sectoral endowments to U.S. states. State-sector employment comes from the BEA. Within each sector, we assume that the share of high and low skilled employment in each state equals that at the U.S. level. State shares in U.S. capital stock by sector are based on equalizing the ratio of capital to high skilled labor to the U.S. value. Details are described in Appendix B.

Preference weights Sectoral weights in total consumption ω_n^{cj} and investment ω_n^{xj} are computed for each country using the nominal shares of the WIOD for 2012. We do not directly observe final expenditures at the U.S. state level, so we assume the weights for each state are the same as for the U.S.

Trade elasticities The elasticity of substitution between varieties in the composite goods is set to $\eta = 2$, which plays no quantitative role. Trade elasticities for manufacturing sectors are sourced from Giri, Yilmazkuday, and Yi (2018).[7] They do not provide estimates for four of our 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).

Input and factor shares We now describe the sources for the production coefficients: the intermediate input share in gross output ν_n^j, the intermediate use coefficients μ_n^{jk}, the capital shares α_n^j, and the skill labor share λ_n^j. All these parameters are directly computed using 2012 values from the WIOD. Since we do not have the input-output table at the state level, the parameters for each U.S. state are set equal to the U.S. values.

Tariffs We obtain tariffs and international trade product-level data—at the HS–6 digit level from the World Integrated Trade Solution (WITS) database. We use the applied effective tariff rate, and fill missing values using the most favoured nation (MFN)

[6]Capital stock at the country level is measured at PPP prices.

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

tariff rate. We also complement product-level trade data using the BACI—the world trade database developed by the CEPII—for missing values in the WITS. We then aggregate the HS–6 digit tariff data into 14 sectors (there are no tariffs for the service sectors) for each importer country using a simple average of tariffs for the most imported products. Specifically, we keep products that cumulatively account for at least 80% of the total import share of each importer, and at least 0.005% of the import share, individually.[8]

Trade imbalances Region n's initial NFA, $\bar{\mathcal{A}}_n$, is chosen so that the trade deficit is financed by net-foreign income and the current account is balanced: $\text{Def}_n = \bar{q}\bar{\mathcal{A}}_n$. The world interest rate is exogenously set to $\bar{q} = 4.17\%$ and the trade deficit, Def_n, is measured in the data.[9]

Summary of estimated parameters Table 1 reports the parameter values for sectoral trade elasticities and production coefficients for the U.S. states.[10] Starting with trade elasticity θ, we notice that Metals and Refined products have high values, which is consistent with the fact that they are more homogeneous than other sectors. On the other hand, Paper & printing and Computers and electronics have low values as they are more differentiated than other sectors.

We next turn to the sectoral shares in consumption and investment ω^c and ω^x. Tradable services and Nontradable services collectively account for more than 85 percent of consumption spending. Outside of these two sectors, Food and Refined products are the next largest components accounting for 4 percent and 2 percent, respectively. These shares play an important role in the quantitative analysis since we base the welfare measurement on changes in real consumption, which weights changes in real sectoral consumption by these consumption shares. Within investment spending, Tradable services and Nontradable services collectively account for about two thirds. Transport equipment (10 percent), Computers and electronics (8 percent), and Machines (7 percent), are the largest non-service sectors in investment spending.

The most value added intensive (least intermediate intensive) sectors are Mining, Computers and Electronics, and Nontradable services. These shares are important in shaping how changes in tariffs feed through the input-output network into prices. More upstream sectors, such as Mining, use very few intermediate inputs, so marginal costs of

[8]We do not use trade weights to average the product-level tariff rates to ensure that the aggregate tariffs that each member of the European Union imposes on imports are similar.

[9]In an intratemporal model with discount factor β, our calibrated value of $\bar{q}$ would imply choosing a value for β so that the interest rate is 4.17%.

[10]The production coefficients for other sample countries are omitted due to space limitations. They are available upon request.

Table 1: Sector-specific paraemeters

		U.S. parameter values				
	θ^j	ω^{cj}	ω^{xj}	ν^j	α^j	λ^j
Agriculture	4.0	0.005	0.000	0.445	0.720	0.204
Mining	4.0	0.001	0.046	0.712	0.709	0.355
Food	3.6	0.039	0.001	0.259	0.503	0.291
Textiles	4.8	0.012	0.000	0.313	0.280	0.261
Wood	4.2	0.000	0.001	0.301	0.249	0.166
Paper & printing	3.0	0.003	0.002	0.350	0.432	0.441
Refined products	5.8	0.022	0.003	0.251	0.616	0.300
Chemicals	3.8	0.019	0.006	0.442	0.565	0.577
Non-metallic minerals	3.9	0.001	0.001	0.400	0.496	0.233
Metals	7.0	0.002	0.008	0.314	0.335	0.216
Machines n.e.c	3.9	0.001	0.066	0.368	0.344	0.298
Computers and electronics	3.3	0.009	0.076	0.623	0.284	0.490
Transport equipment	4.5	0.014	0.104	0.292	0.321	0.339
Furniture & other	4.5	0.008	0.023	0.452	0.424	0.283
Tradable services	4.0	0.258	0.351	0.599	0.432	0.464
Nontradable services	4.0	0.607	0.314	0.643	0.457	0.393

Notes: ω^{cj} is sector j's share in consumption spending in location j, ω^{xj} is the share in investment spending, ν^j is the share of value added in gross output, α^j is the share of capital in value added, and λ^j is the share of high skilled labor in the wage bill. These parameters are constant across U.S. states but differ across countries; we report only the U.S. values. The trade elasticity is common across all states and countries.

production in Mining are generally not affected by as much as marginal costs in more downstream sectors that purchase a lot of intermediate inputs, such as Refined products.

Agriculture, Mining, and Refined products are the most capital-intensive sectors, while Textiles, Wood, and Computers and electronics are the least. The most skill intensive sectors are Chemicals, Computers and electronics, and Tradable services, while Wood, Agriculture, and Metals are the least. Both of these shares play an important role in shaping comparative advantage at the U.S. level, relative to other countries, since the U.S. has a relatively large endowment of high-skilled labor and of capital.

Within intermediate inputs, the sector composition of spending differs by sector, as reflected in Figure 1. In the figure, each row depicts a "use" sector and each column depicts a "supply" sector, so that each row sums to unity. First, each sector tends to use output from its own sector intensively. Second, Tradable services (which includes professional & business services) are an important input in most other sectors' production. Third, certain sectors are key inputs to only specific sector. For instance, Mining (which includes crude oil) accounts for a disproportionately large share in Refined products production, Agriculture's share in Food production, Chemical's share in Textiles production, and Metal's share in production of durable goods.

Figure 1: U.S. input-output shares

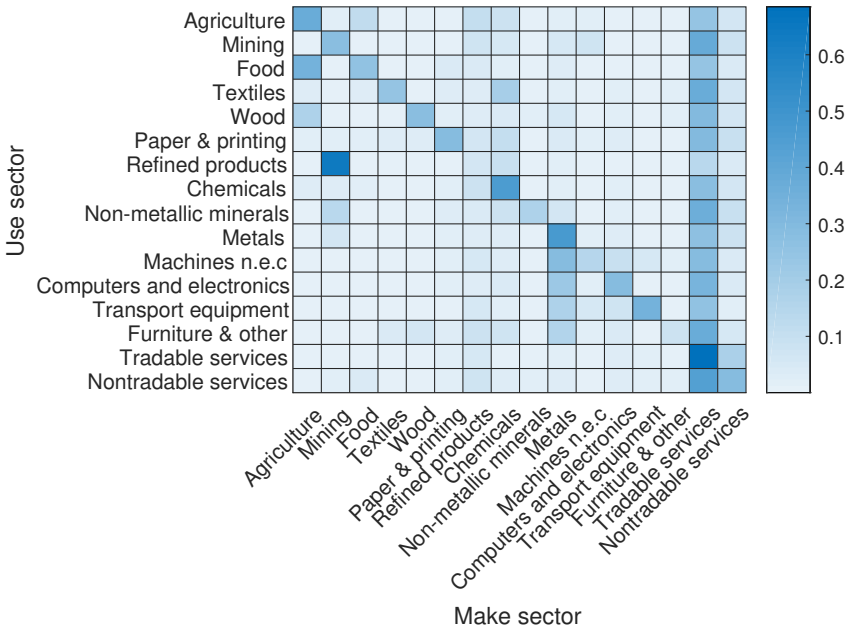
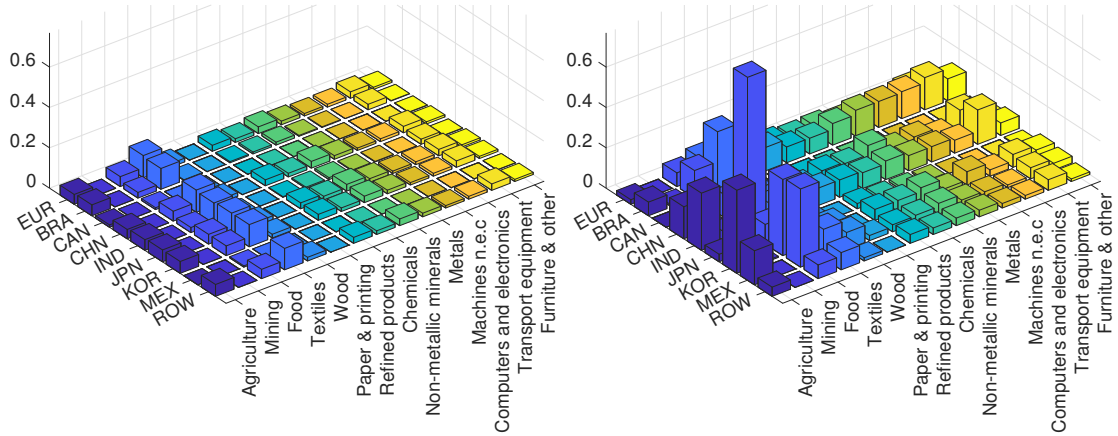


Figure 2 plots the U.S. tariff rates by sector and trading partner, both inward and outward. Relatively speaking, the U.S. imposes lower tariffs than it faces. The U.S. imposes larger tariffs in Textiles than in any other sector and imposes lower tariffs across all industries on Canada and Mexico than on other countries. It faces relatively high tariffs in Agriculture and Food in lower income markets like Brazil, China, and India.

Figure 2: U.S. tariff rates



U.S.-imposed tariff Foreign-imposed tariff

3.3 Parameters estimated using the model

Some of the country-specific parameters are directly observable, while others need to be inferred using structural relationships implied by the model. Productivity and trade

costs are not directly observable. Instead, we use the model's structure to guide our measurement. Specifically, we employ a gravity approach as in Levchenko and Zhang (2016). The usual gravity equation that is derived from the Eaton-Kortum model, as well as other work horse models, links bilateral trade shares to comparative advantage forces and trade barriers as follows:

$$\ln\left(\frac{\text{Trd}_{ni}^{j}}{\text{Trd}_{nn}^{j}}\right) = \underbrace{\ln\left(\left(A_i^j\right)^{\nu_i^j\theta^j}\left(u_i^j\right)^{-\theta^j}\right)}_{S_i^j} - \underbrace{\ln\left(\left(A_n^j\right)^{\nu_n^j\theta^j}\left(u_n^j\right)^{-\theta^j}\right)}_{S_n^j} - \theta^j\ln\left(d_{ni}^j\right) - \theta^j\ln\left(\tau_{ni}^j\right). \quad (7)$$

The term Trd_{ni}^{j} denotes the value of trade flows in sector j originating in location i destined for location n. S_n^j captures location n's relative competitiveness in sector j as a convolution of its input costs and productivity. Any regional differences in relative trade shares that are not accounted for by regional differences in relative states of technology are captured by the bilateral trade barriers. The goal is to isolate each location's level of productivity in each sector.

Since bilateral trade costs at the sector level are unobservable, they are assumed to be parsimoniously described by observable gravity variables as follows:

$$\ln\left(d_{ni}^j\right) = \text{ex}_i^j + \sum_{r=1}^{6}\gamma_{d,r}^j\text{dis}_{ni}^r + \gamma_b^j\text{bdr}_{ni} + \gamma_c^j\text{cur}_{ni} + \gamma_l^j\text{lng}_{ni} + \gamma_f^j\text{fta}_{ni} + \epsilon_{ni}^j. \quad (8)$$

The coefficients γ^j capture the effects of various indicator variables on the bilateral iceberg cost. The parsimonious specification in equation (8) consists of various symmetric terms (i.e., distance is the same going from n to i and from i to n) in addition to a term that introduces asymmetry in the bilateral trade costs. In line with Waugh (2010), ex_i^j indicates whether location i is an exporter or not, and implies that systematic differences in trade costs across countries are captured by an exporter fixed effect. There are 6 distance indicators, indexed by $r = 1, \ldots, 6$ capturing whether locations n and i are in certain intervals measured in miles: $[0, 350)$, $[350, 750)$, $[750, 1500)$, $[1500, 3000)$, $[3000, 6000)$, and $[6000, \infty)$. The remaining indicators capture whether locations n and i share a common border, share a common currency, share a common official language, and belong to a free trade agreement. The residual captures forces that are not explicitly measured, while the usual assumptions about independence apply. Combining equations (7) and (8) yields an estimable gravity equation:

$$\ln\left(\frac{\text{Trd}_{ni}^{j}}{\text{Trd}_{nn}^{j}}\right) + \theta^j\ln\left(\tau_{ni}^j\right) = M_n^j + E_i^j + \sum_{r=1}^{6}\beta_{d,r}^j\text{dis}_{ni}^r + \beta_b^j\text{bdr}_{ni} + \beta_c^j\text{cur}_{ni} + \beta_l^j\text{lng}_{ni} + \beta_f^j\text{fta}_{ni} + \varepsilon_{ni}^j, \quad (9)$$

where the reduced form parameters map into structural parameters as follows: $\beta^j = -\theta^j\gamma^j$, $\varepsilon^j_{ni} = -\theta^j\epsilon^j_{ni}$, $M^j_n = -S^j_n$, and $E^j_i = S^j_i - \theta^j \text{ex}^j_i$. The left hand of the equation is the log ratio of trade shares, adjusted by the impact of observed tariffs.

Our estimation procedure consists of two stages. In the first stage, we estimate equation (9) using data on bilateral trade between all 50 states and 42 non-U.S. countries. That is, we unpack the EU-28 into 28 individual countries and extract 7 individual countries contained in the Rest-of-world aggregate in order to obtain more cross-country variation and, ultimately, more precise estimates of the effect of geography. In this first stage we use OLS at the sector level and obtain coefficients for distance, common border, common currency, common language, and FTAs through $\widehat{\beta}_{d,r}, \widehat{\beta}_b, \widehat{\beta}_c, \widehat{\beta}_l$, and $\widehat{\beta}_f$.

Table 2 displays the estimates for the coefficients on the symmetric explanatory variables for each sector from the first stage. For the most part, having a common border, a common currency, a common language, or being part of a FTA contribute positively to bilateral trade between regions. Figure 3 plots the estimated coefficients on distance. In each sector, trade declines with distance. In addition, distance tends to matter more for some sectors (e.g., Food) compared to others (e.g., Computer and electronics).

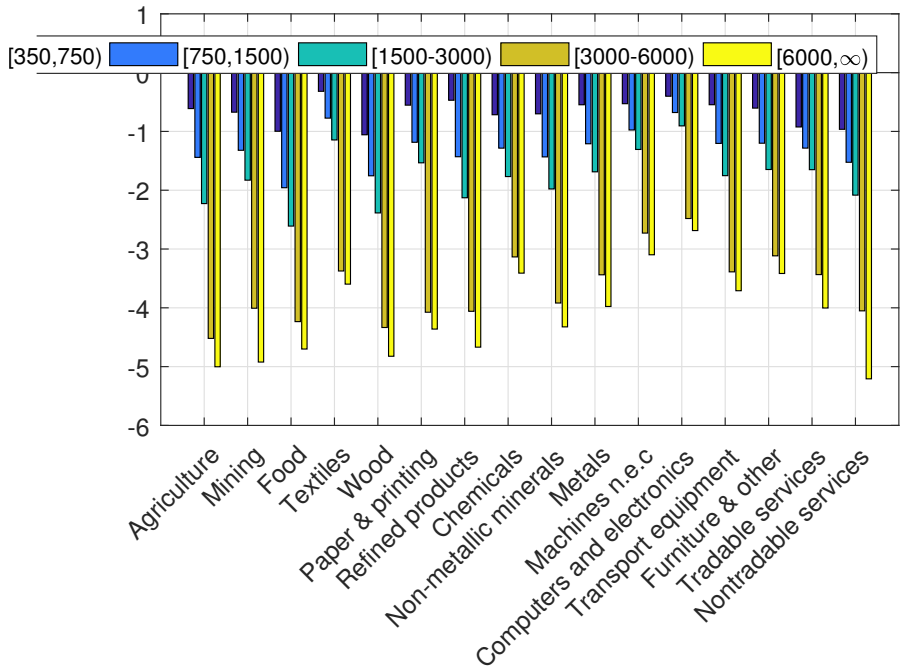
Table 2: Determinants of bilateral trade flows

	Common border β^j_b	Common currency β^j_c	Common language β^j_l	Part of FTA β^j_f
Agriculture	1.25 (0.11)	0.51 (0.11)	1.51 (0.10)	0.16 (0.22)
Mining	1.31 (0.13)	1.24 (0.13)	1.58 (0.12)	-0.21 (0.28)
Food	1.09 (0.11)	0.60 (0.10)	1.10 (0.10)	0.55 (0.22)
Textiles	0.74 (0.11)	0.83 (0.10)	0.69 (0.10)	0.24 (0.21)
Wood	1.50 (0.11)	0.86 (0.11)	0.58 (0.11)	0.21 (0.25)
Paper & printing	0.85 (0.10)	0.58 (0.09)	0.24 (0.09)	0.65 (0.21)
Refined products	1.53 (0.12)	0.57 (0.11)	0.50 (0.11)	0.23 (0.26)
Chemicals	1.16 (0.11)	0.40 (0.11)	0.16 (0.10)	0.84 (0.23)
Non-metallic minerals	1.36 (0.11)	0.69 (0.10)	0.47 (0.10)	0.11 (0.23)
Metals	0.94 (0.10)	0.75 (0.10)	0.87 (0.09)	0.58 (0.21)
Machines n.e.c	1.02 (0.09)	0.40 (0.08)	0.16 (0.08)	0.54 (0.18)
Computers and electronics	0.54 (0.10)	0.55 (0.09)	0.43 (0.09)	0.70 (0.19)
Transport equipment	1.27 (0.13)	0.35 (0.12)	0.43 (0.11)	0.42 (0.26)
Furniture & other	0.95 (0.10)	0.63 (0.09)	0.85 (0.09)	0.64 (0.20)
Tradable services	0.16 (0.05)	0.62 (0.05)	0.79 (0.05)	0.08 (0.10)
Nontradable services	0.03 (0.08)	1.21 (0.07)	1.43 (0.07)	-0.44 (0.15)

Note: Estimates of the $(\beta^j_b, \beta^j_c, \beta^j_l, \beta^j_f)$ coefficients in equation (9) applied to 92 locations (42 individual non-U.S. countries and 50 U.S. states) in each of the 16 sectors. Standard errors are in parenthesis.

In the second stage, we aggregate the trade flows into 59 locations: 50 U.S. states, the EU-28, 7 individual non-U.S. countries, and a rest-of-world aggregate, impose the estimates on the symmetric components of trade costs from stage 1, and re-estimate the

Figure 3: Relationship between distance and bilateral trade shares



Notes: Estimates of the $\beta^j_{d,r}$ coefficients in equation (9) applied to 92 locations (42 individual non-U.S. countries and 50 U.S. states) in each of the 16 sectors. Distance intervals are measured as miles between capital cities using the great circle method. All estimates are relative to distance interval $[0, 350)$.

fixed effects, sector-by-sector. We do not aggregate the estimates of country fixed effects from the first stage because we do not want to impose an ad-hoc aggregation across countries to construct these objects for the EU-28, as they reflect states of technology that aggregate in a nonlinear fashion through the lens of the theory. The estimation equation for the fixed effects M^j_i and E^j_n is given by

$$\ln\left(\frac{\text{Trd}^j_{ni}}{\text{Trd}^j_{nn}}\right) + \theta^j \ln\left(\tau^j_{ni}\right) - \sum_{r=1}^{6} \widehat{\beta}^j_{d,r}\text{dis}^r_{ni} - \widehat{\beta}^j_b \text{bdr}_{ni} - \widehat{\beta}^j_c \text{cur}_{ni} - \widehat{\beta}^j_l \text{lng}_{ni} - \widehat{\beta}^j_f \text{fta}_{ni}$$
$$= M^j_n + E^j_i + \varepsilon^j_{ni}. \tag{10}$$

We thus obtain $S^j_i + ex^j_i$ and S^j_n for the 50 states, the EU-28, and 7 individual non-U.S. countries using equation (10).

For the Rest-of-world aggregate, we impute the exporter fixed effect coefficient, ex^j_n, and the states of technology, S^j_n, by regressing the respective estimates for all other locations against log GDP per capita and log GDP, and then recover the corresponding estimates for ROW using its GDP per capita and GDP. Bilateral trade costs between each region are then constructed using the parsimonious specification in equation (8).

We follow Levchenko and Zhang (2016) to recover the sectoral productivity and trade

costs from the estimated fixed effects. The available degrees of freedom imply that, in each sector, the location-specific states of technology, S_n^j, are identified only 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 regions, A_n^j is contained in the estimated relative states of technology, S_n^j. Recall that the state of technology is given by

$$S_n^j = \ln\left(\left(A_n^j\right)^{\nu_n^j \theta^j} \left(u_n^j\right)^{-\theta^j}\right), \tag{11}$$

where u_n^j is the unit cost of an input bundle:

$$u_n^j = B\left[\left(r_n^j\right)^{\alpha_n^j}\left(\left(w_n^{hj}\right)^{\lambda_n^j}\left(w_n^{\ell j}\right)^{1-\lambda_n^j}\right)^{1-\alpha_n^j}\right]^{\nu_n^j}\left[\prod_{k=1}^{J}\left(p_n^k\right)^{\mu_n^{jk}}\right]^{1-\nu_n^j},$$

where B is the constant. 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; measurement of each of these variables is described in Appendix B. We do not have data on sectoral prices both across countries and states. We therefore recover sectoral prices from the estimated trade costs and states of technology:

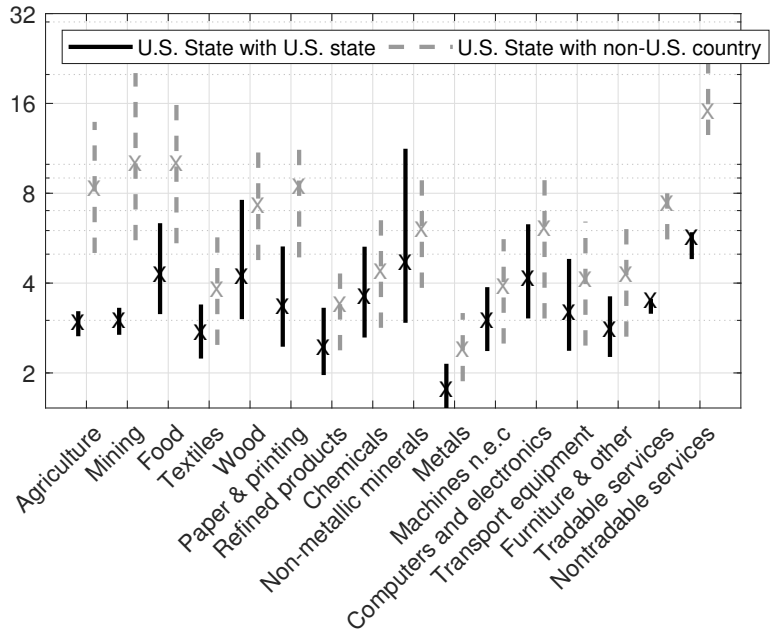
$$p_n^j = \gamma^j\left[\sum_{i=1}^{N}\left((A_i^j)^{-\nu_i^j} u_i^j d_{ni}^j \tau_{ni}^j\right)^{-\theta^j}\right]^{-1/\theta^j} = \gamma^j\left[\sum_{i=1}^{N}\exp\left(S_i^j\right)\left(d_{ni}^j\tau_{ni}^j\right)^{-\theta^j}\right]^{-1/\theta^j},$$

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 (11).

Figure 4 plots the estimated trade costs of U.S states when trading with other U.S states and when trading with foreign countries. Not surprisingly, the estimated median trade costs are lower between US states than between countries in all sectors. Nontradable services (Metals) have the highest (lowest) median trade costs among all sectors across US states and across countries. Food, Wood, and Non-metallic minerals bear the next highest median trade costs when trading with other states; Agriculture, Mining, Food, and Paper and printing are the next highest trade costs when trading with foreign countries. For any sector, trade costs vary substantially not only across countries but also across states. Not-metallic minerals have the widest dispersion in trade costs across states, and Mining has the most variation in trade costs across countries.

We conclude the calibration by checking on the model fit on the two key variables: the sectoral bilateral trade flows across locations and the sectoral composition of value

Figure 4: Interstate and international trade costs for U.S. states



Notes: Black lines span the 30th-70th percentiles of the distribution of bilateral trade costs between U.S. states. Gray lines span the same percentiles of trade costs between U.S. states and non-U.S. countries. 'X' denotes the median.

added (factor income) in each location. Table 3 reports the correlation between variables in the baseline model and those in the data. The model fits the data on bilateral trade flows quite well at both the state and country levels: all correlation coefficients are above 98%. The model also fit the data on value added well, particularly at the state level. The average correlation across sectors is 99% across states and 90% (??) across countries.

Table 3: Correlations between model and data

	Bilateral trade share		Value added	
	Countries	States	Countries	States
Agriculture	0.99	0.99	0.97	0.99
Mining	1.00	0.99	0.99	1.00
Food	1.00	0.99	0.93	0.98
Textiles	1.00	0.99	0.88	0.98
Wood	1.00	0.99	0.92	0.98
Paper & printing	1.00	0.99	0.94	1.00
Refined products	0.99	0.99	0.90	0.99
Chemicals	1.00	0.99	0.91	1.00
Non-metallic minerals	1.00	0.99	0.91	0.99
Metals	1.00	0.99	0.87	1.00
Machines n.e.c	1.00	0.99	0.89	1.00
Computers and electronics	0.98	0.99	0.78	0.99
Transport equipment	1.00	0.99	0.92	0.98
Furniture & other	1.00	0.99	0.97	1.00
Tradable services	0.99	0.99	0.98	1.00
Nontradable services	0.98	0.99	0.97	0.99

Note: The correlation between the model and the data across countries is reported as the first value, and the correlation across U.S. states is reported as the second value in each cell.

4 Quantitative analysis

In this section we quantify the welfare implications of an increase in US import tariffs across sectors and regions. We start with a unilateral trade policy change in the United States. Heterogeneous welfare implications across states are the outcome of different sectoral specialization across states. We also carry out our analysis with trade retaliation from foreign countries.

4.1 Impact of US Import Tariff Increases

While all states in the U.S. levy a common external tariff, their effective tariffs differ because U.S. tariffs vary across sectors and across trading partners and because states differ in their composition of imports along both dimensions. Thus, we first consider a common tariff that is uniform across sectors and across trading partners so as to equalize the effective tariff rate across states. With an initial uniform tariff of 2 percent, the ratio of U.S. tariff revenue to GDP is the same as in the true baseline model with observed tariffs. The uniform tariff is applied by each U.S. state to imports of goods (all sectors excluding tradable and nontradable services) from all foreign countries. Given that US import tariffs are generally low, particularly compared with trade costs, the uniform tariff

scenario implies a similar outcome as in the baseline. We assume that tariffs levied by foreign countries are the same as in the data.

We then increase the uniform U.S. tariff to 25 percent and compute the implied welfare changes by this trade policy across US states. We focus on the first two components of the gains from trade in equation (6), and leave aside the effect of trade imbalances on welfare.[11] Recent studies analyzing short-run effects of tariffs have also focused on the first two components of equation (6) (see Fajgelbaum et al., 2019; Auer, Bonadio, and Levchenko, 2018). Thus, the percent change in welfare is defined as

$$\frac{\widehat{W}_n}{1-\rho_n} = \underbrace{\left(\frac{F_n}{P_n^c C_n}\right)}_{\substack{\text{Initial factor} \\ \text{income share}}} \underbrace{\left(\frac{\widetilde{F}_n/\widetilde{P}_n^c}{F_n/P_n^c} - 1\right)}_{\substack{\%\Delta \text{ in real} \\ \text{factor income}}} + \underbrace{\left(\frac{\text{IBT}_n}{P_n^c C_n}\right)}_{\substack{\text{Initial tariff} \\ \text{revenue share}}} \underbrace{\left(\frac{\widetilde{\text{IBT}}_n/\widetilde{P}_n^c}{\text{IBT}_n/P_n^c} - 1\right)}_{\substack{\%\Delta \text{ in real} \\ \text{tariff revenue}}}. \tag{12}$$

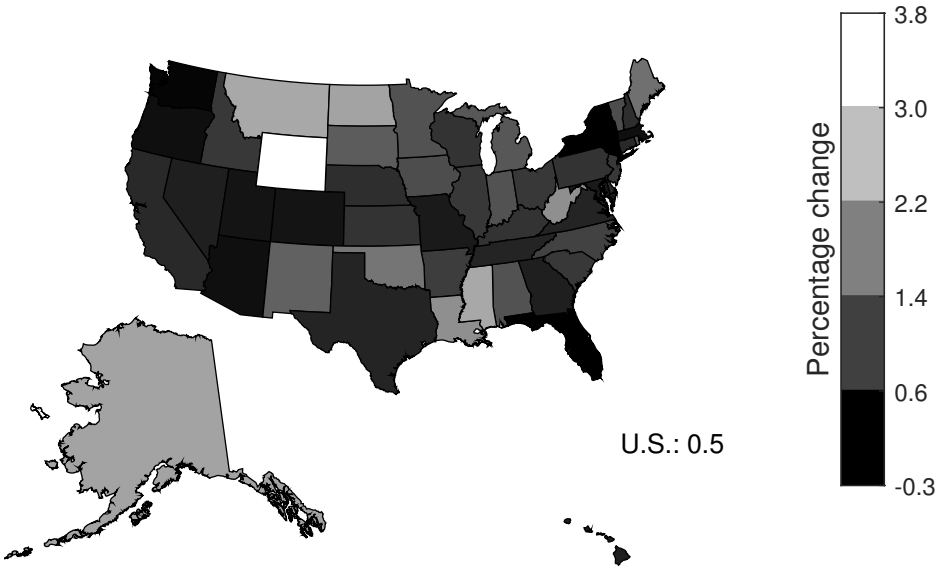
After raising the uniform tariff, U.S. external trade with non-U.S. countries declines. The ratio of U.S. imports to GDP falls from 11.4 to 8.7 percent. Since trade imbalances are held constant, the ratio of U.S. exports to GDP also falls, from 9.5 to 6.8 percent. Figure 5 illustrates the welfare changes in the U.S. The U.S. population-weighted average welfare change is 0.5 percent. The impacts are quite heterogeneous across states. Welfare gains range from -0.3 percent in Florida to 3.8 percent in Wyoming.

The positive change in welfare in most states is due to the terms of trade effect which is manifested in the increased tariff revenue. Figure 6 plots welfare change in each state along with the contribution from factor income and the contribution from tariff revenue. Most states experience a decline in real factor income, while all states experience an increase in real tariff revenue. However, the variation across states is largely accounted for by differences in the factor income component. The correlation between factor income and welfare is 0.7, while the correlation between tariff revenue and welfare is 0.28. The correlation between factor income component and tariff revenue component is -0.49.

We explore what determines heterogeneity in changes in real factor income across states along two dimensions. Is it because effects primarily occur at the sector level and certain states are just more exposed to the sectors that are affected the most? Or is it really a feature about states, other than their sectoral composition, such as their geography? We find that the former is the primary source of variation.

[11] State-level trade imbalances are imputed based on the estimated state-to-state bilateral trade flows, which are measured with error. Trade imbalances at the state level obtained in this way are very large. As a result, even small changes in consumer prices yield significant changes in real consumption, and hence on welfare. Because there are other factors driving trade imbalances that we have not taken into account yet to discipline them, we leave aside this term in this analysis.

Figure 5: Percent change in welfare across U.S. states



Notes: Changes in welfare associated with increasing U.S. external tariff uniformly from 2 percent to 25 percent. Welfare gain computed using equation (12). States are ranked from highest to lowest welfare gains.

State versus sector contributions to welfare heterogeneity To enable this analysis we define sectoral real factor income at the state level as f_n^j/P_n^c, where f_n^j is the nominal factor income generated in sector j in location n. The real sectoral factor income can be thought of as the real income of a "worker" in sector n. Of course, in the model workers from all sectors in a location pool their income into a representative household. We decompose the change in real factor income in a location into a weighted average of the sectoral real factor income changes, weighted by sectoral shares in value added:

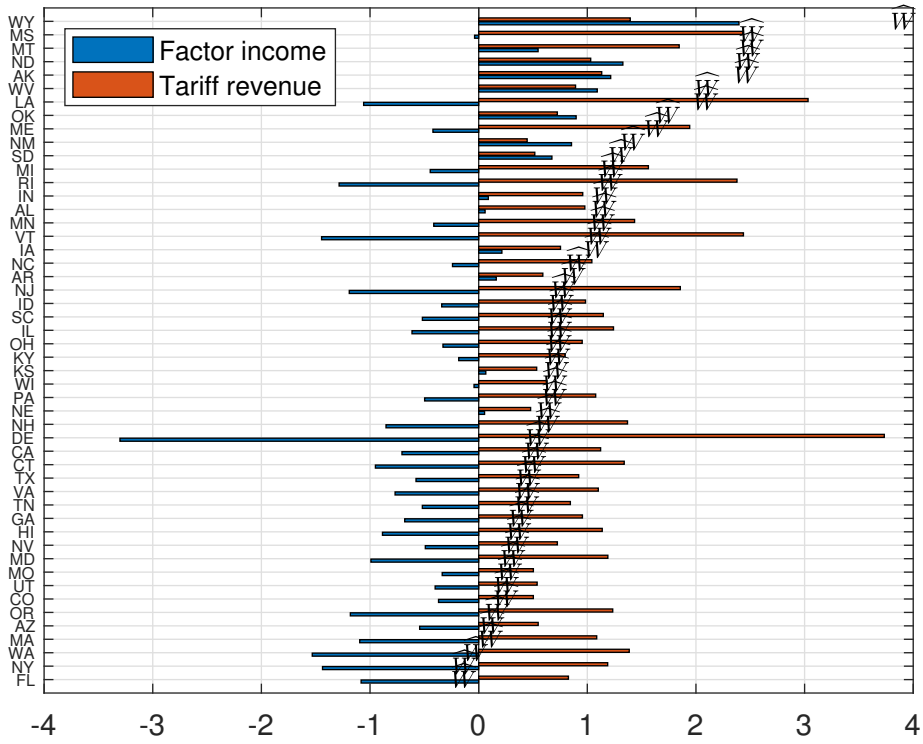
$$\frac{\widetilde{F}_n/\widetilde{P}_n^c}{F_n/P_n^c} - 1 = \sum_{j=1}^{J} \underbrace{\left(\frac{f_n^j}{F_n}\right)}_{\text{sectoral share}} \underbrace{\left(\frac{\widetilde{f}_n^j/\widetilde{P}_n^c}{f_n^j/P_n^c} - 1\right)}_{\text{sectoral change}}. \tag{13}$$

We decompose the variance in sectoral changes in real factor income across states into state and sector fixed effects by running the following regression:

$$\left(\frac{\widetilde{f}_n^j/\widetilde{P}_n^c}{f_n^j/P_n^c} - 1\right) = \mathbf{FE}_j + \mathbf{FE}_n + \epsilon_n^j. \tag{14}$$

This yields an R^2 of 0.78, with state fixed effects accounting for 4 percent of the total variance and sector fixed effects accounting for 81 percent. This suggests that there is a significant sector component that accounts for the change in real factor income, independent of the location. Thus, locations that have greater exposure to certain sectors

Figure 6: Contribution to welfare change across U.S. states



Notes: Associated with changing U.S. external tariff uniformly from 2 percent to 25 percent. '$\widehat{W}$' denotes the welfare gain computed using equation (12). The unit of the horizontal axis is percent.

are more susceptible to those sectoral effects. Equalizing the sectoral changes in real factor income across states using the median for the U.S. in equation (14), but allowing for states to differ in each sectors share, accounts for 40 percent of the overall variation in changes in real factor income across states.

We conduct a similar calculation for changes in real tariff revenue:[12]

$$\frac{\widetilde{\text{IBT}}_n/\widetilde{P}_n^c}{\text{IBT}_n/P_n^c} - 1 = \sum_{j=1}^{J-2} \underbrace{\left(\frac{\text{ibt}_n^j}{\text{IBT}_n}\right)}_{\text{sectoral share}} \underbrace{\left(\frac{\widetilde{\text{ibt}}_n^j/\widetilde{P}_n^c}{\text{ibt}_n^j/P_n^c} - 1\right)}_{\text{sectoral change}}. \tag{15}$$

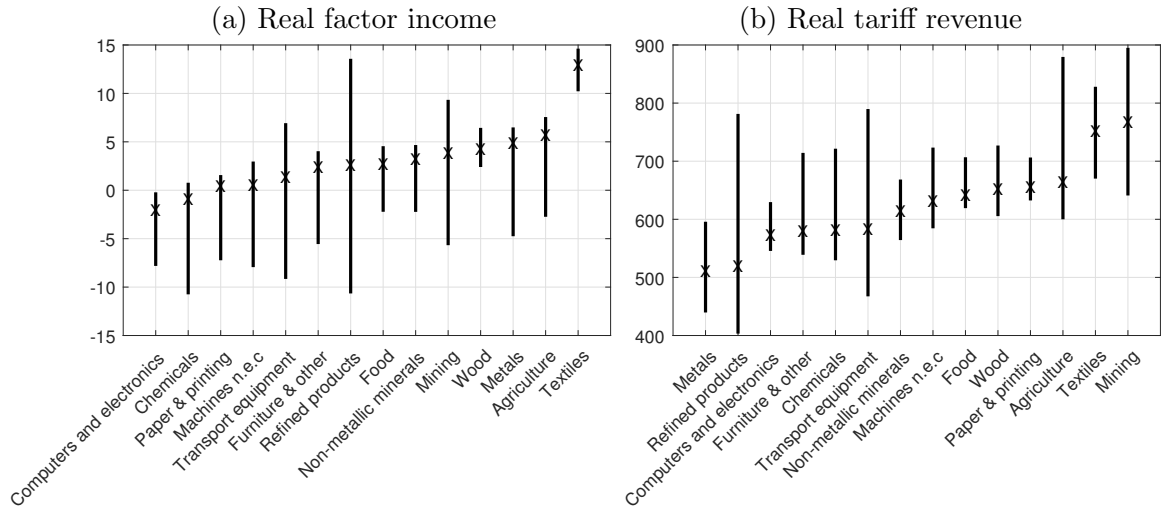
When projecting the sectoral changes in real tariff revenue across states on the sector and state fixed effects, we find that sector fixed effects account for 80% of total variation, while state fixed effects account for only 5%, similar to the findings for the factor income. Using equation (15), we hold the sectoral changes in real tariff revenue constant across states (using the median for the U.S.) and compute the implies change in real tariff revenue across states by feeding in state-specific initial sectoral shares in tariff revenue.

[12]We ignore the two service sectors since those sectors have zero tariffs in our calculations.

Differential sectoral exposure across states accounts for 55 percent of the total variation of changes in real tariff revenue across states.

The analysis for both components of welfare changes to a uniform increase in U.S. tariffs shows that the sector variation is the first step to understand the implications. Figure 7 illustrates how real factor income and tariff revenue change in response to the tariff change. For each sector, we plot the median percent change, together with the range from the minimum to maximum percent change, across states. In the left panel, the sectors that gain (lose) the most in median real factor income are Textiles, Agriculture, Metals, Wood, and Mining (Computers, Chemicals, Papers and printing, and Machines). In the right panel, the sectors that gain (lose) the most in median real tariff revenue are Mining, Textiles, and Agriculture (Metals, Refined products, and Computers). Also, there is a large variation across states within each sector. For example, in Refined products, some states gain as much as 14% in real factor income, but others lose 11%.

Figure 7: Sectoral Implications of the Tariff Increase, Percent Change



Notes: Lines indicate the range in the change in sectoral real factor income and tariff revenue across U.S. states, from the minimum to the maximum. 'X' denotes the median value among U.S. states. The unit of the vertical axis is percent. Both service sectors have zero tariffs and are omitted from the figure.

We explore the determinants of these differential implications across sectors by correlating sectoral fixed effects with sectoral characteristics. For factor income, the sector fixed effects are highly positively correlated with the high skilled share in labor, λ^j. In other words, the ordering of the sectors in the left panel of Figure 7 is highly correlated with the ordering of sectors by high skill intensity. The U.S. has comparative advantages in sectors that are high skill intensive, like Computers and electronics and Chemicals.[13].

[13]Revealed comparative advantage for the U.S., defined as $(\text{Exp}^j_{US}/\text{Exp}_{US})/(\text{Imp}^j_{US}/\text{Imp}_{US})$, correlates highly with the high skill share across sectors: correlation is 0.74 with p-value < 0.01).

These sectors benefit the least from a higher import tariff that shields domestic industries from foreign competition, so they gain the least in factor income.

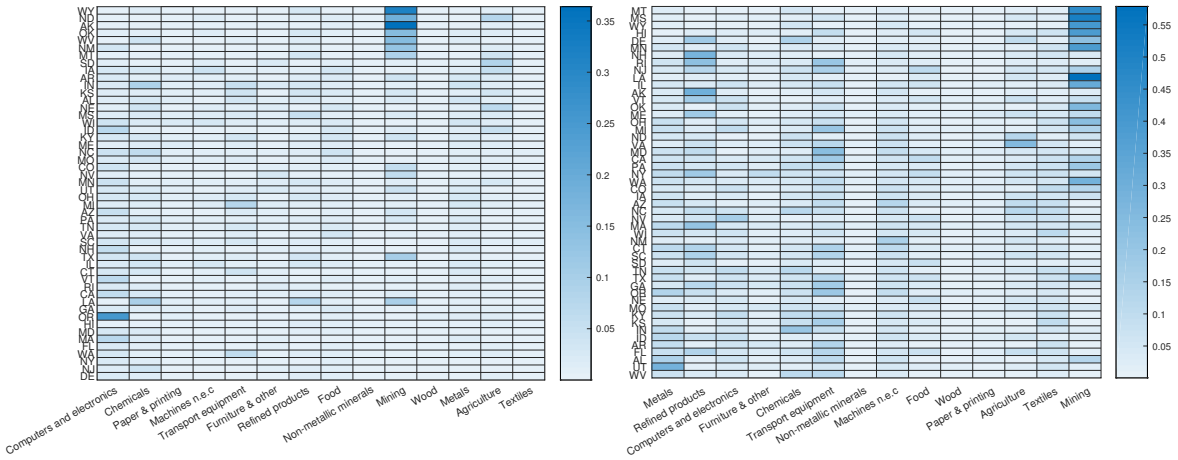
For tariff revenue, we find that the sector fixed effects are highly negatively correlated with the trade elasticity, θ^j. The ordering in the right panel of Figure 7 is highly negatively correlated with the ordering of sectors by trade elasticity. The intuition is straightforward: sectors that are more elastic to prices experience larger decreases in tariff revenue, because domestic consumers reduce foreign imports by more in these sectors in response to a uniform tariff increase across sectors.

Heterogeneity in state exposure across sectors States with a larger share of real factor income or tariff revenue originating from the sectors that gain more in response to the tariff increase generally experience a larger increase in their welfare. The left panel of Figure 8 illustrates each state's sectoral exposure in factor income. The horizontal axis is sectors ordered by the median change in real factor income, excluding the service sectors. The vertical axis is states ordered by gains in total real factor income (state at the top have the highest gains). Each cell depicts a sector's share in each state's factor income. Darker shades represent a larger share, and each row sums to 1. Cells in the upper right and lower left quadrants tend to have higher numbers (i.e., darker cells) than the rest of the matrix. Mining, which ranks the fifth place in terms of gains across sectors, stands out. States with high shares of factor income from Mining have high gains in total real factor income (i.e., Wyoming, North Dakota, etc.). States with high shares of factor income from Computer an electronics (e.g., Oregon) tend to experience larger losses, as this sector loses the most among all sectors.

The right panel of Figure 8 depicts analogous information pertaining to the effects through tariff revenue. Mining realizes the greatest increases in real tariff revenue across sectors. States with high shares of tariff revenue from Mining have larger gains in total tariff revenue (i.e., Montana, Mississippi, etc.). States with high shares of tariff revenue from Metals (e.g., West Virginia) have smaller gains in total tariff revenue, as this sector gains the least among all sectors.

Notably, being exposed to Mining tends to yield positive gains through both real factor income and real tariff revenue. This positive relationship within the Mining sector deviates from the overall negative correlation between changes in real factor income and changes in real tariff revenue. Thus, states that concentrate resources in this sector gain a great deal from a higher external tariff.

Figure 8: Sector exposure across U.S. states



(a) Factor Income (b) Tariff Revenue

Notes: Horizontal axis is ordered in terms of the median change in U.S. factor income (tariff revenue) from lowest to highest. The vertical axis is ordered in terms of state change in factor income (tariff revenue) from lowest to highest. Each cell depicts a sector's share in each state's factor income (tariff revenue). Each row sums to 1. Both service sectors have zero tariffs and are omitted from the figure.

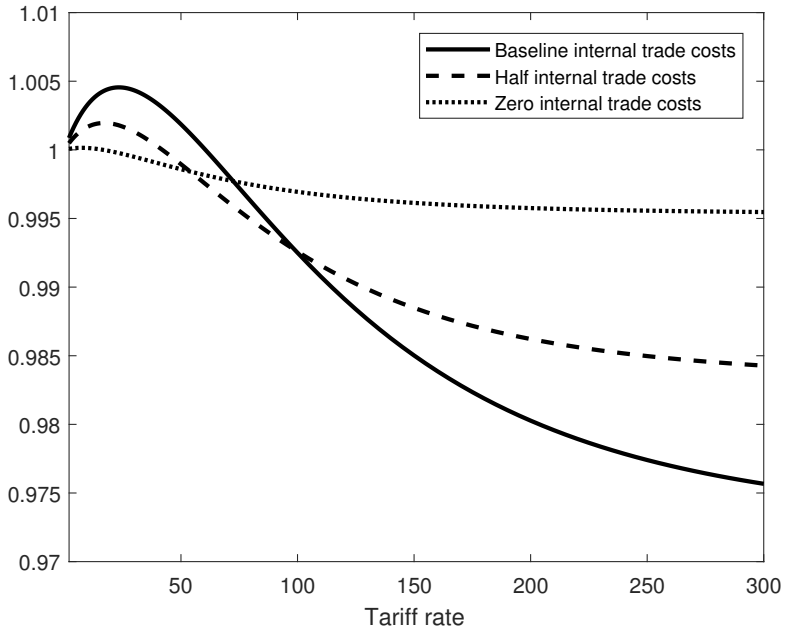
4.2 Interstate trade adjustments

In contrast to recent papers in the literature studying the heterogeneous impact of U.S tariffs across states, we model not only international trade adjustments but also interstate adjustments. Here we show that accounting for these internal adjustments is important when evaluating the welfare effects of trade policy. To do this, we compare two scenarios of different levels of internal trade costs with the baseline case. The first scenario uses half internal trade costs whereby trade costs between states are reduced by half: $\widetilde{d}^j_{ni} = 1 + (d^j_{ni} - 1)/2$ for $(n, i) \in \mathcal{US}$. The second scenario uses zero internal trade costs and imposes frictionless trade between U.S. states: $\widetilde{\widetilde{d}}^j_{ni} = 1$ for $(n, i) \in \mathcal{US}$. In each scenario we construct a "welfare Laffer curve" over a large range of uniform tariff rates. For each uniform tariff rate, we compute the U.S welfare relative to that under a zero uniform tariff. The U.S. welfare change is constructed as the population weighted sum of welfare changes across U.S. states based on equation (12).

Figure 9 depicts the U.S. welfare relative to zero tariffs across a range of tariff values. The solid line is for the baseline case, and the welfare change displays a hump shape over the tariff rate. As discussed in the previous subsection, the welfare change is characterized by the sum of two components: real factor income and tariff revenue. The hump shape is mainly driven by the behavior of real tariff revenue across tariff levels. Initially, tariff revenue rises at low levels of tariffs, then declines as tariffs become high. The real factor income component generally declines monotonically with the tariff rate at the national

level. In the baseline case, prohibitively high tariffs or autarky are damaging, and the welfare loss is around 2.5% for the United States.

Figure 9: U.S. welfare changes with tariffs: varying internal trade costs



Notes: The horizontal axis is the tariff rate that the U.S. uniformly imposes on imports from all countries in all sectors. The vertical axis is the level of welfare computed using equation (12) relative to that under zero tariffs. U.S. welfare is computed as an average across states, weighted by population. The baseline internal trade costs case uses the calibrated trade costs d_{ni}^{j}. The zero internal trade costs case sets $\widetilde{d}_{n,i}^{j} = 1$ for all $(n, i) \in \mathcal{US}$ and all good sectors, while the half internal trade costs case refers to $\widetilde{d}_{ni}^{j} = 1 + (d_{ni}^{j} - 1)/2$.

Autarky is much less costly if internal trade costs are lower. As shown by the dashed and dotted lines in Figure 9, the welfare loss of autarky is around 1.5% in the half internal trade costs case and around 0.5% in the zero internal trade costs case. This result is not surprising. When internal trade is less costly, states can substitute foreign imports with products from other U.S. states more easily and thus suffer less from autarky.

Interestingly, such an implication is not true at low level of tariffs. For instance, when increasing tariffs to about 25 percent, the U.S. gains in the presence of internal frictions, while it is worse off from the same tariff increase in the absence of internal trade costs. The reason is the following. Under zero internal trade costs, the U.S. trades a lot internally, and much less with foreign countries, so it has relatively small share of tariff revenue in its income. Thus, increasing tariff revenue does not contribute substantially to total income. When the U.S. has large internal frictions, foreign imports are relatively large, so tariff revenue is a sizable share in total income.

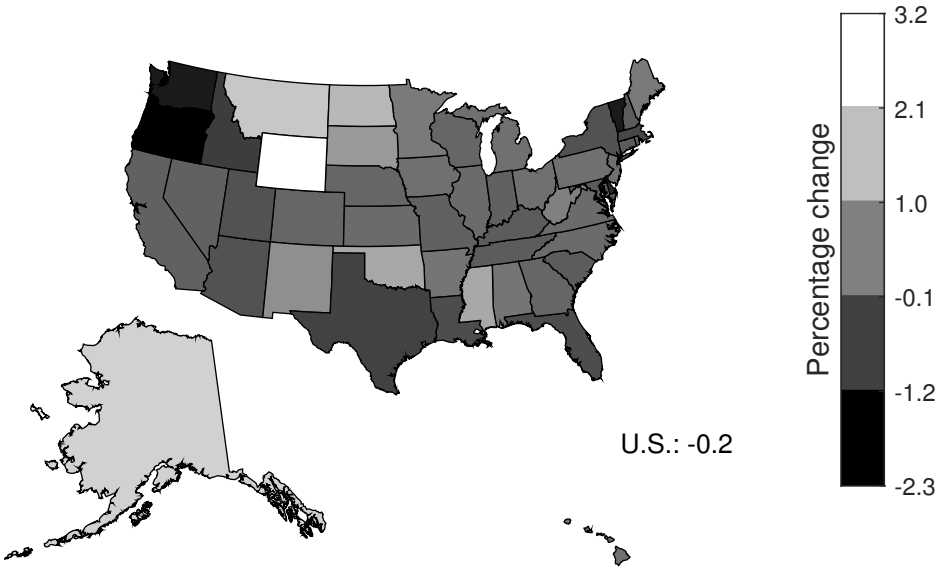
As in Arkolakis, Costinot, and Rodríguez-Clare (2012), the change in welfare in a location can be described by that location's change in its home trade share. Under autarky, the share of foreign imports in total absorption goes to zero in each state. Absent

other domestic trading opportunities, the home trade share would increase by exactly the same amount as the decrease in the foreign import share, implying a large welfare loss of autarky. However, in our model, the US. economy consists of many locations that trade with each other. Each state's home trade share is not the residual of the foreign import share since it also purchases from other states: $\pi^j_{nn} = 1 - \sum_{i \notin US} \pi^j_{ni} - \sum_{i \in US, i \neq n} \pi^j_{ni}$.[14] As the foreign import share declines in each state, the home trade share increases by a smaller magnitude since domestic states can substitute for some of the those lost foreign imports. As a result, the welfare loss of reverting to trade autarky with foreign countries is smaller. To summarize, the more trading opportunities there are within the U.S., the less consequential is the impact of external tariffs.

4.3 Outcomes under retaliatory tariffs

So far we have only examined unilateral increases in tariffs imposed by the U.S. In practice, foreign countries respond through disputes with the WTO or by imposing retaliatory tariffs. We examine the implications across U.S. states of tit-for-tat retaliation, whereby foreign countries increase the tariff from 2% to 25% on their imports from the U.S. across all goods sectors. We assume that all tariffs between non-U.S. country pairs are unchanged.

Figure 10: Percent change in welfare across U.S. states with foreign retaliation



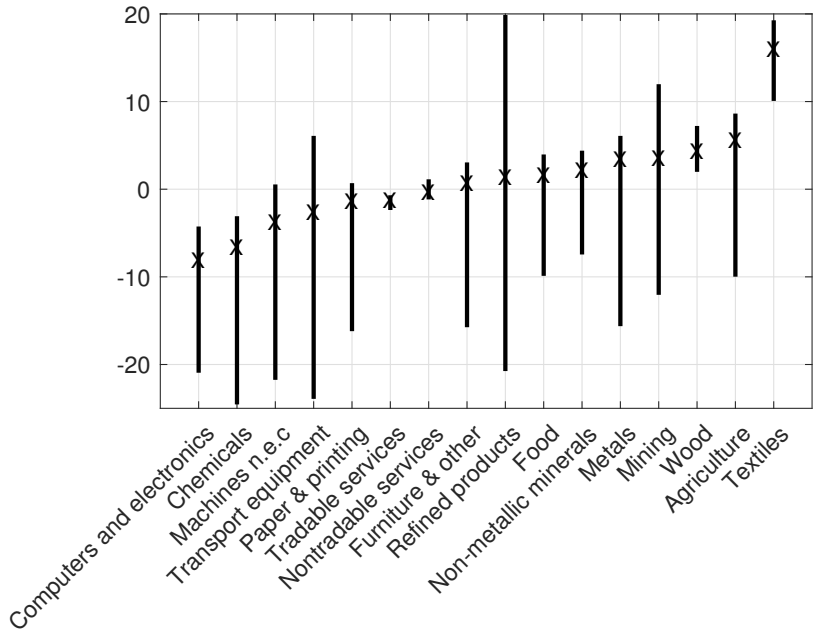
Notes: Associated with changing U.S. external tariff uniformly from 2 percent to 25 percent with tit-for-tat retaliation. Welfare gain computed using equation (12).

[14] Ramondo, Rodríguez-Clare, and Saborío-Rodríguez (2016) derive an augmented ACR formula in which welfare depends not only on international trade costs but also on domestic trade frictions.

Figure 10 plots the welfare impacts across U.S. states. The U.S. population-weighted average welfare decreases by 0.2 percent. This contrasts to a 0.5 percent increase in the case without retaliation. Welfare gains from trade are heterogeneous across states: Wyoming is again the state that gains the most from an increase in U.S. tariffs with foreign tit-for-tat retaliation (3.2%), whereas Oregon is the state that loses the most (−2.3%). More generally, the ranking of states by magnitude of welfare changes is similar to the case without retaliation. However, the gains (losses) are smaller (greater) when there is retaliation. As in the case without retaliation, heterogeneity in gains is determined primarily by changes in real factor income.

Heterogeneity in welfare gains across states reflects heterogeneity in sectoral exposure to trade policy and heterogeneity in the sectoral composition across U.S. states. Figure 11 plots the change in sectoral real factor income across different sectors in the U.S., in addition to the range across states within each sector. Textiles, Agriculture, and Wood experience the largest increases, whereas Computers and electronics and Chemicals experience the largest decreases. Within each sector, we observe a lot of heterogeneity across U.S states. As in the case without retaliation, all states experience increases in real factor income in the Textiles sector.

Figure 11: Change in U.S. sectoral real factor income with retaliation

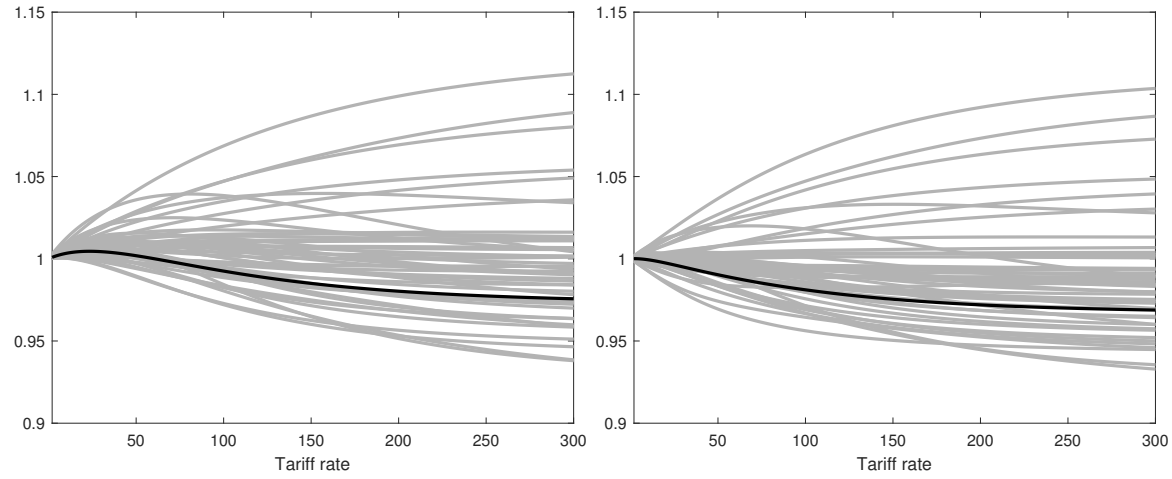


Notes: Lines indicate the range in the change in sectoral real factor income across U.S. states, from the minimum to the maximum. 'X' denotes the median value among U.S. states.

4.4 Welfare-maximizing tariff

The effect of a change in tariffs is heterogeneous across U.S. states, as states differ in their sectoral composition, and sectors are impacted differently by tariff changes. Hence, the preferences for the tariff differ substantially across states. To highlight cross-state heterogeneity in tariff preferences, we compute the welfare-maximizing tariff rate for each state. To do so, we compute the welfare Laffer curve of each state by varying the uniform tariff rate from zero to a large number. The left panel of Figure 12 plots the change in welfare under unilateral U.S. tariff changes without foreign retaliation, and the right panel plots the same outcome with foreign retaliation. The tariff rate that is associated with the peak of one of these Laffer curves is the preferred U.S. tariff rate by a state.

Figure 12: Welfare Laffer curves across states



Notes: The horizontal axis is the tariff rate that the U.S. uniformly imposes on imports from all countries in all sectors. The vertical axis is the level of welfare computed using equation (12) relative to that under zero tariffs. Each gray line corresponds to a U.S. state. The black line is the U.S. computed as an average of each state weighted by population. The left panel is without foreign retaliation, while the right panel is with tit-for-tat retaliation.

Let's start with the black lines, which are the U.S. population-weighted average welfare. The tariff rate that maximizes this U.S. welfare is 23 percent under no foreign retaliation. Under tit-for-tat retaliation, the U.S. preferred tariff rate becomes 2 percent, which is close to the observed effective (trade-weighted) U.S. tariff rate. For some states there is no "interior" preferred tariff. That is, some states, such as North Dakota and Wyoming, prefer an infinite tariff, even with tit-for-tat retaliation. The reason is that these states have a relatively large share of factor income from Mining and natural resource activity, which benefit the most from high tariffs. For others, such as New York and New Jersey, the preferred tariff rates are very small. Their factor income is accounted for primarily by sectors that benefit the least from high tariffs, like Computers and Electronics and Chemicals.

5 Conclusion

The global economy has experienced rapid trade integration since the World War II. Trade flows across borders have risen tremendously as tariffs and transportation costs declined and countries shifted from protectionist trade policies toward a rules-based trading system. However, this process has been interrupted by recent developments. The United States enacted various import tariffs on major trading partners across many goods-producing industries. Such unilateral trade policy has large distributive impacts across industries and U.S. states, particularly in the short run. Understanding these impacts is the key to the analysis and debates of trade policy.

We develop a quantitative general equilibrium trade framework to assess the cross-state implications of a U.S. trade policy change. Specifically, we consider a unilateral increase in the import tariff from 2% to 25% across all goods-producing sectors. The impact of this policy varies substantially across states from 3.8% in Wyoming to -0.3% in Florida in terms of real consumption (welfare). This differential impact depends mainly on how exposed states are to differentially-impacted sectors. States with a high share of factors allocated to sectors that the U.S. has a comparative disadvantage in (i.e., low skill-intensive sectors such as Mining and Textiles) experience the greatest increase in factor returns. At the same time, every state realizes an increase in tariff revenue, which positively contributes to the change in welfare. States that import more in sectors with a low price elasticity experience the greatest increase in tariff revenue.

As the tariff rate increases unilaterally, the tariff revenue first increases at low levels of tariffs, then eventually decreases as high tariffs effectively shut down trade. Factor income declines monotonically for some states, and increases monotonically for others, depending on their sectoral production shares. Thus, there is a unique tariff rate for each state that maximizes its welfare – the sum of tariff revenue and factor returns. This "preferred" tariff rate varies greatly across states: from below 3% for Florida and New York to infinite in Wyoming and North Dakota. Foreign retaliation in trade policy substantially reduces the welfare gains across states, and thus lowers their preferred tariff rates for most of them. Internal trade costs are important in the analysis of trade policy too: higher internal trade costs amplify the responses to a higher import tariff.

Our analysis focuses on the short-run outcome where factors are immobile across sectors and space. It will be interesting for future work to investigate the sectoral, spatial adjustment as well as the transitional dynamics to the long-run equilibrium. This spatial, internal trade model can be also useful in studying regional adjustments over time in response to changes in sectoral TFPs, tax policy, and infrastructure policy.

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A Equilibrium conditions

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

Household optimization Household in location n has resources from factor income, from indirect business taxes, and from transfers trough net-foreign assets. Income is spent on sectoral composite goods to satisfy consumption and investment. Since the investment rate and NFA position are exogenous, total household consumption spending equals

$$\underbrace{\sum_{j=1}^{J} p_n^j c_n^j}_{P_n^c C_n} = (1-\rho_n)\left(\sum_{j=1}^{J}\left(r_n^j k_n^j + w_n^{hj} h_n^j + w_n^{\ell j}\ell_n^j\right) + IBT_n\right) + q\mathcal{A}_n,$$

where total consumption spending is denoted by $P_n^c C_n$, with P_n^c indicating the ideal price index for consumption and C_n to aggregate consumption index. Similarly, total investment spending is given by

$$\underbrace{\sum_{j=1}^{J} p_n^j x_n^j}_{P_n^x X_n} = \rho_n\left(\sum_{j=1}^{J}\left(r_n^j k_n^j + w_n^{hj} h_n^j + w_n^{\ell j}\ell_n^j\right) + IBT_n\right)$$

Sectoral consumption and investment demand is given by

$$c_n^j = \omega_n^{cj}\left(\frac{P_n^c C_n}{p_n^j}\right), \qquad x_n^j = \omega_n^{xj}\left(\frac{P_n^x X_n}{p_n^j}\right).$$

Firm optimization The price of the sector j composite good in location n is

$$p_n^j = \gamma_j\left[\sum_{i=1}^{N}\left((A_i^j)^{-\nu_i^j} u_{it}^j d_{ni}^j \tau_{ni}^j\right)^{-\theta^j}\right]^{-\frac{1}{\theta^j}},$$

where the term $\gamma^j = \Gamma(1+\frac{1}{\theta^j}(1-\eta))^{1/(1-\eta)}$, where $\Gamma(\cdot)$ is the Gamma function. the term u_i^j is the unit cost for a bundle of inputs for producers in sector j in location i:

$$u_i^j = \left[\left(\frac{r_i}{\alpha_i^j}\right)^{\alpha_i^j}\left(\left(\frac{w_i^{hj}}{\lambda_i^j(1-\alpha_i^j)}\right)^{\lambda_i^j}\left(\frac{w_i^{\ell j}}{(1-\lambda_i^j)(1-\alpha_i^j)}\right)^{(1-\lambda_i^j)}\right)^{(1-\alpha_i^j)}\right]^{\nu_i^j}\prod_{k=1}^{J}\left(\frac{p_i^k}{\mu_i^{jk}(1-\nu_i^j)}\right)^{\mu_i^{jk}(1-\nu_i^j)}.$$

Define total factor usage and output in sector j by aggregating across the individual

varieties:

$$k_n^j = \int_{0,1} k_n^j(v)dv, \qquad h_n^j = \int_{0,1} h_n^j(v)dv, \qquad \ell_n^j = \int_{0,1} \ell_n^j(v)dv,$$
$$m_n^{jk} = \int_{0,1} m_n^{jk}(v)(v)dv, \qquad y_n^j = \int_{0,1} y_n^j(v)(v)dv.$$

The term $k_n^j(v)$ denotes the quantity of capital stock used in the production of variety v in sector j in location n. If location n imports variety v, then $k_n^j(v) = 0$. Hence, k_n^j is the total quantity of capital stock used in sector j in location n. Similarly, h_n^j and ℓ_n^j are the quantities of high and low skilled labor employed in sector j in location n. m_n^{jk} denotes the quantity of composite good k that location n uses as an intermediate input in production in sector j. y_n^j is the quantity of the sector j output produced by location.

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

$$\begin{aligned} r_n^j k_n^j &= \alpha_n^j \nu_n^j p_n^j y_n^j, \\ w_n^h h_{nt}^j &= \lambda_n^j (1-\alpha_n^j) \nu_n^j p_n^j y_n^j, \\ w_n^\ell \ell_{nt}^j &= (1-\lambda_n^j)(1-\alpha_n^j) \nu_n^j p_n^j y_n^j, \\ p_n^k m_{nt}^{jk} &= (1-\nu_n^j) \mu_n^{jk} p_n^j y_n^j. \end{aligned}$$

Trade flows In sector j, the fraction of locations n's expenditures allocated to varieties produced by location i is given by

$$\pi_{ni}^j = \frac{\left((A_i^j)^{-\nu_i^j} u_i^j d_{ni}^j \tau_{ni}^j \right)^{-\theta^j}}{\sum_{i'=1}^{N} \left((A_{i'}^j)^{-\nu_{i'}^j} u_{i'}^j d_{ni'}^j \tau_{ni'}^j \right)^{-\theta^j}}.$$

Government budget constraint Government budget must balance, meaning that tax revenue from tariffs must equal the indirect business taxes rebated to the household:

$$IBT_n = \sum_{i=1}^{N} \underbrace{\left(p_n^j c_n^j + p_n^j x_n^j + \sum_{k=1}^{J} p_n^j m_n^{kj} \right) \left(\frac{\pi_{ni}^j}{\tau_{ni}^j} \right)}_{\text{pre-tariff value of trade for } i \text{ to } n} \times \underbrace{\left(\tau_{ni}^j - 1 \right)}_{\substack{\text{net tariff levied} \\ \text{on trade flow}}}$$

Note that the bilateral trade flows are deflated by the gross bilateral tariff rate since the prices are inclusive of tariffs. That is, the after tax value of location n's gross absorption is $\left(p_n^j c_n^j + p_n^j x_n^j + \sum_{k=1}^{J} p_n^j m_n^{kj} \right)$. The fraction of this spending that is sourced from location i is π_{ni}^j. Netting out the tariff levied on location n yields the pre-tariff value of trade. Finally, the tariff rate is applied to the pre-tariff value of the trade flow, and the tax revenue is rebated to the household.

Market clearing conditions Within each location markets for sectoral composite must clear:

$$c_n^j + x_n^j + \sum_{k=1}^{J} m_n^{kj} = Q_n^j.$$

This condition requires that the use of sector j composite good equal its supply. Its use consists of final demand by the representative household, for consumption and investment, and intermediate use by domestic firms. Its supply is the quantity of the composite good, consisting of both domestically- and foreign-produced varieties.

The next conditions require that 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:

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

Next, factor markets must clear:

$$k_n^j = \bar{k}_n^j, \qquad h_n^j = \bar{h}_n^j, \qquad \ell_n^j = \bar{\ell}_n^j.$$

Finally, the aggregate resource constraint must hold in each country; net-foreign income equals the (pre-tariff) trade deficit:

$$q\mathcal{A}_n = \sum_{j=1}^{J} \left[\sum_{i=1}^{N} \left(p_n^j c_n^j + p_n^j x_n^j + \sum_{k=1}^{J} p_n^j m_n^{kj} \right) \left(\frac{\pi_{ni}^j}{\tau_{ni}^j} \right) \right] - \sum_{j=1}^{J} p_n^j y_n^j,$$

where the term inside the square brackets is country n's (pre-tariff) gross absorption and the last term is its gross output. This condition, combined with the other market clearing conditions above, implies the more familiar condition that $Y = C + I + NX$ (with a heavy abuse of notation). That is, the left-hand side is negative of net-foreign income, meaning that debt payments (transfers) must be financed by trade surpluses. This last condition holds automatically once all of the other equilibrium conditions are met.

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 9.0 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 (@@reference to tariff data@@). We merge the different data sources into 16 sectors and 59 locations. Unless stated otherwise, all data are for 2012 since that 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 U.S. states and 9 non-U.S. regions, which are listed in Table B.2. Among the 9 non-U.S. regions there are 7 individual non-U.S. countries, each of which accounts for at least 1 percent of U.S. imports and 1 percent of U.S. exports, a EU-28 aggregate, and a Rest-of-world aggregate.

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*

B.2 Input-output data

We construct data on production (value added and gross output), intermediate inputs, and final demand (consumption and investment) from various sources.

Production For each country, value added and gross output (in current U.S. dollars) in each sector are each 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.

Value added in each U.S. state and sector come from the BEA. In each sector, we scale the state-level value added data so that the sum across states equals U.S. value added.

We construct gross output for each state-sector by assuming that in each sector the ratio of value added to gross output is equal across states and the same as that for the U.S., then gross up the value added using that ratio.

Table B.2: Location names and codes

U.S. 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-U.S. 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

Intermediate inputs Spending on intermediate inputs is measured directly in the WIOD. These data are available only at the country level. For each state we assume that the ratio of intermediate spending to gross output is equal to the U.S. ratio.

Final demand We define consumption as the sum of private and public spending and define investment as the sum of gross fixed capital formation and changes in inven-

tories. We measure each of these at the country level in the WIOD. For each state, we assume the share of investment in national income (GDP plus indirect business taxes) is the same as the U.S. level. We also assume the sectoral composition of consumption spending, investment spending.

B.3 Factor endowments

We combine data on three types of endowments: capital stocks, high skilled labor, and low skilled labor from various sources.

Labor Aggregate employment at the country level come from PWT. Employment counts the number of persons engaged.

Sectoral employment data for each country come from the SEA16. Within each country, sectoral employment is scaled so that total employment equals the country level employment from the PWT.

Sectoral employment for each country is further broken down into high and low skilled employment using data from the SEA14. Specifically, high skilled employment in each country-sector is defined as the employment times share of hours by high skilled persons engaged in total hours. High skilled means a worker completed at least a post-secondary degree. Low-skilled is anything less than that and constitutes the remainder of the labor force.

Sectoral employment across for each U.S. state come from the BEA. Some states-sectors have zero employment, this occurs for many states in transportation equipment (a sector with high spatial concentration). For these observations we impute a the employment such that the ratio of value added to employment is equal to the median value across states in that sector. The state-level employment numbers are scaled proportionately so that sum of U.S. state-level data match the U.S. level in each sector.

In each state-sector, employment is divided into two types: high skilled and low skilled. High skilled workers are those that completed a post-secondary degree, while low skilled types are those with less than a completed post-secondary degree. For each sector and country these shares are computed from the SEA14 as the employment times the share of hours by high skilled persons engaged. There are some missing data at the country-sector level for high skilled employment. We impute the missing data by regressing the observed values across countries within a sector on aggregate real income per capita, then using the estimates with the observed income per capita in the country with the missing high skilled employment data. For each state, the skill shares in total employment are set equal to the U.S. shares.

Capital stocks Aggregate capital stocks at the country level come from PWT. The capital stock is measured at current PPPs.

Sectoral capital stocks, measured in current local prices, for each country come from the SEA16. Within each country, we scale sectoral capital so that the sum across sectors equals the country level capital stock from the PWT.

We impute state-sector level capital stocks in two steps. In the first step, we impose that, within each sector, each state's share in U.S. capital stock equals its share in U.S. high skill employment. That is, the ratio of capital to high skilled employment within

each sector is equal across states. In the second step we scale the sectoral capital stocks in each state so the the sum within each sector equals the U.S. level.

B.4 Factor compensation

We obtain compensation to the three primary factors of production (capital, high skilled labor, and low skilled labor) from SEA14. Specifically, labor's share in value added for each country-sector is measured as the ratio of compensation of employees to gross value added at current basic prices. (The SEA14 release reports data from 1995-2011 so we compute each number as the median value from 1995-2011.) This share is then multiplied by the value added numbers computed from WIOD to obtain labor compensation. Capital compensation is defined as the residual value added. Similarly, high-skilled share in labor is measured as the ratio of high skilled labor compensation, times labor compensation, relative to compensation of employees. (We use the median values from 1995-2011.) This share is then multiplied by labor compensation to obtain high skilled labor compensation. Low skilled labor compensation is the residual labor compensation.

B.5 Bilateral trade

We merge bilateral trade data from various sources in order to combine country-level trade flows with state-level trade flows.

Trade between countries Bilateral trade data across countries for every sector are taken from WIOD.

Trade between U.S. states and non-U.S. countries Bilateral trade between U.S. states and non-U.S. countries is taken from the FTB. These data are available for agriculture, mining, and all 12 manufacturing sectors. For each of these sectors, we scale the trade flows proportionately across states so that (i) the sum of all states exports to any non-U.S. country equals the value for U.S. exports to that country obtained from WIOD and (ii) the sum of all states imports from any non-U.S. country equals the value for U.S. imports from that country obtained from WIOD.

There are a few adjustment we need to make to the data. First, in some sectors, each state has zero observed trade with some countries, while the aggregate U.S. data reports a positive amount. 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; imports from Slovakia and Slovenia in Chemicals and pharmaceuticals. To deal with these instances, we impute each state's share in U.S. exports based on its share in U.S. final demand in the relevant sectors.

Second, it remains possible that the sum of a state's foreign exports exceeds its gross output. This is the case for the following state-sectors: Alaska and Louisiana in Agriculture; Delaware, Michigan, Maine, and North Dakota in Paper and printing; Delaware, Montana, North Dakota, and Oregon in Chemicals and pharmaceuticals; Florida, Hawaii, Nevada, and Vermont in Computers and electronics; Alaska, Delaware, and Florida in Machinery n.e.c.; Alaska, Delaware, Hawaii, and New Jersey in Transportation equipment. The measurement problems can be rationalized in two ways. The first is that the

reported state-level exports over-count actual exports for some states because of re-export concerns. The second is that our measure of each state's gross output may under-count is actual output because we assumed a constant gross-output-to-value-added ratio across states. Since there is little we can do about the latter, we can make reasonable adjustments to each state's exports so that gross output always exceeds foreign exports by a 'comfortable' amount.

We define a "comfortable" tolerance for the ratio of foreign exports to gross output to be 0.8. However, some sectors are just more tradable, so for each sector we compute a maximum 'good' ratio as the maximum observed ratio in that sector that is below 0.8. As an example, we then define the excess exports the difference between its foreign exports and a 'fraction' times its gross output ('fraction' is the midpoint between 0.8 and the maximum 'good ratio', which captures the fact that some sectors may have a higher comfortable ratio as indicated by the maximum 'good' ratio). We want to remove these excess exports from the problem state and re-appropriate them to other states. Consider how we do this for Alaska. We begin by calculating how its excess exports are broken down by destination, using each destination's share is Alaska's agriculture exports. Then, for each destination, we compute a surplus export for each remaining U.S. state (other than Alaska) as those state's share in each foreign destination in agriculture, multiplied by Alaska's excess exports to that foreign country. We then subtract Alaska's excess exports to each foreign country and then add to each state their computed surplus exports. The result leaves unchanged the total exports of the U.S. to each foreign country by sector. It also respects each state's trade share in foreign countries, modulo the problematic states which needed to be adjusted downward.

Internal trade between U.S. states Bilateral trade between U.S. states for a subset of sectors is obtained from the CFS for manufactured products only. We aggregate these commodity groups into our 12 manufacturing sectors and obtain bilateral trade flows between states. The data also include trade originating from U.S warehouses. In addition to the manufacturing commodities, these warehouse flows also include flows categorized as agriculture and refined petroleum (part of Mining). The idea being that when an import enters the U.S. from, say, Canada, customs does not condition on whether the flow originated from a Canadian factory or a Canadian warehouse; the flow is simply accounted for based on its commodity type. We treat the state trade flows the same way, in that a trade flow originating from a warehouse in Illinois is treated the same as a trade flow originating in a factory in Illinois. The presumption is that if the good was manufactured somewhere other than Illinois, then it will show up as an Illinois import in another observation. We only use the warehouse flows in our procedure in which we impute missing trade flows to help obtain estimates of the effects of distance ,etc, in agriculture and mining, but we then overwrite these trade flows after we do our imputation.

We then scale these flows for the manufacturing sectors so that each state's gross output in each manufacturing sector is equal sales to non-U.S. countries plus sales to all U.S. states. More specifically, letting $\mathcal{US}$ denote the set of U.S. states, we use the

following condition:

$$GO_i^j = \underbrace{\sum_{n \notin \mathcal{US}} Trd_{ni}^j}_{\text{Sales to non-U.S.}} + \underbrace{\sum_{n \in \mathcal{US}} Trd_{n,i}^j}_{\text{Sales to U.S. states}}, \tag{B.1}$$

which says that sectoral output in a given state i must equal the sum of that states sales to all locations (including itself). This condition will not hold for the raw data because of at least two reasons: (i) combining different data sources, (ii) CFS is based on a survey. In other words, we scale state i's sales to all U.S. states—$Trd_{ni}^j, n \in \mathcal{US}$—(including to itself), proportionately, so that equation (B.1) holds. There are 4 cases worth mentioning for which gross output minus exports to foreign countries is negative: Louisiana-agriculture, Alaska-agriculture, Delaware-mining, and Hawaii-machinery and equipment. We believe that the state-level gross output data is more accurately measured than that state-level export data. As such, in these cases we adjust the state's exports to all foreign countries proportionately so that it sums to equal exactly that state's gross output.

Inferring missing bilateral trade flows There are no bilateral trade data available for the following: U.S. states with foreign countries in service sectors; U.S. states with other U.S. states for agriculture, mining, and service sectors. We use a gravity specification informed by all of the trade flows that we observe, along with state/country characteristics and geography to impute the missing bilateral trade flows. Recall that we have very limited observations of state-to-state trade flows in agriculture and in mining in cases where the trade flow originates from a warehouse. We uses these data to inform our regressions to impute missing trade flows, but then we impute new trade flows for these sectors.

First, we impute missing bilateral trade flows between U.S. states and non-U.S. countries for each of the 10 service sectors

$$\begin{aligned}
\ln(Trd_{ni}^j) = {} & Sec^j + Imp_n + Exp_i \\
& + \ln(GO_i^j) + \ln(FD_n^j) \\
& + \mathbb{I}_{n \in \mathcal{US}} \times \mathbb{I}_{i \notin \mathcal{US}} \times \ln(Trd_{Ui}^j) \\
& + \mathbb{I}_{n \notin \mathcal{US}} \times \mathbb{I}_{i \in \mathcal{US}} \times \ln(Trd_{nU}^j) \\
& + \sum_d \mathbb{I}_{dist(n,i)}^d + \mathbb{I}_{brdr(n,i)} + \mathbb{I}_{lang(n,i)} + \mathbb{I}_{curr(n,i)} + \mathbb{I}_{fta(n,i)} + \mathbb{I}_{hmbs(n,i)} \\
& + \mathbb{I}_{j \in TS} \times \left(\sum_d \mathbb{I}_{dist(n,i)}^d + \mathbb{I}_{brdr(n,i)} + \mathbb{I}_{lang(n,i)} + \mathbb{I}_{curr(n,i)} + \mathbb{I}_{fta(n,i)} + \mathbb{I}_{hmbs(n,i)} \right) \\
& + \mathbb{I}_{j \in NS} \times \left(\sum_d \mathbb{I}_{dist(n,i)}^d + \mathbb{I}_{brdr(n,i)} + \mathbb{I}_{lang(n,i)} + \mathbb{I}_{curr(n,i)} + \mathbb{I}_{fta(n,i)} + \mathbb{I}_{hmbs(n,i)} \right)
\end{aligned} \tag{B.2}$$

- In the first line we include a sector fixed effect, an importing region fixed effect,

and an exporting region fixed effect.

- In the second line we include sectoral gross production of the exporter and sectoral final demand by the importer. If the exporting region produces a lot in a sector, it presumably also exports a lot as well. A similar intuition goes for the final demand by the importer. Note that ideally we would use gross absorption rather than final demand, but we do not have such data for U.S. states in agriculture, mining, and service sectors. We compute sectoral final demand for each state as by assuming the ratio of final demand to GDP is identical across states and equal to the ratio for the United States. Final demand includes private and public consumption and investment.

- In the third line we interact three terms. The first term is a dummy for whether the importer is a U.S. state. The second term is a dummy for whether the exporter is a non-U.S. country. The third term is the trade flow from the exporter to the United States. The idea being that, if we want to impute the trade flow from Canada to Illinois in a service sector, then we want to condition on how much the U.S. imports from Canada in that sector.

- The fourth line has a similar explanation as the third line, but is used to impute exports by U.S. states to non-U.S. countries.

- The fifth line includes standard gravity information. The first is a set of 6 dummies pertaining to the distance between the importer and exporter: less than 350 miles, between 350 and 750 miles, between 750 and 1500 miles, between 1500 and 3000 miles, between 3000 and 6000 miles, and over 6000 miles. The second term is a dummy for whether the importer and exporter share a common border. The third term is a dummy for whether the importer and exporter share a common currency. The fourth term is a dummy for whether the importer and exporter share a common official language. The fifth term is a dummy for whether the importer and exporter belong to either a free trade agreement, customs union, or economic union. The sixth term is a dummy for home bias, i.e., whether the exporter is the same as the importer.

- The sixth line includes the same gravity information as the fifth line, but interacts the gravity dummies with another dummy that indicates whether the trade flow pertains to the Tradable service sector or not. The idea being that the effect of gravity may differ for trade in services than for trade in physical merchandise.

- The seventh (final) line includes the same gravity information as the fifth and sixth lines, but interacts the gravity dummies with another dummy that indicates whether the trade flow pertains to the Nontradable service sector or not. The idea being that the effect of gravity may differ for trade in certain types of "nontradable" services than for "tradable" services or for physical merchandise.

As before, for each of the service sectors, we scale the trade flows proportionately across states so that (i) the sum of all states exports to any non-U.S. country equals the value for U.S. exports to that country obtained from WIOD and (ii) the sum of all states

imports from any non-U.S. country equals the value for U.S. imports from that country obtained from WIOD.

Second, we impute missing bilateral trade flows between U.S. states for agriculture, mining, and each of the 10 service sectors. For each of these sectors we scale the state-to-state bilateral trade, proportionately, so that equation (B.1) holds for each state, ensuring that, at the state-sector level, sales to all locations equates with gross production.

B.6 Tariffs

Source: Tariff data is from the World Integrated Trade Solution (WITS) software developed by the World Bank. This database contains data at the product level (BEC, CCCN, CPC, GTAP, ISIC Rev. 2, ISIC Rev. 3, SIC, MTN, NACE Rev. 1, HS Combined, and SITC Rev.1 - SITC Rev. 4) for about 100 countries and the period 1996-2019. There are three duty types reported in the database: Effectively Applied rates, MFN Applied rates, and MFN Bound rates.

For this analysis, we focus on a sample of 42 countries, including the United States (initially 43 countries, which turn to 42 after merging Belgium-Luxembourg because of trade data availability). For reporters in the WITS database, we have 15 individual countries listed as reporters along with one aggregated entity for the European Union (28 countries). On the partner side, the EU is disaggregated for all EU member countries, so we have 43 partners in the raw data. We focus on year 2012 and use also data from 2013 to fill missing values from 2012. We use the HS 2012 classification, which contains products at the 6-digit level of disaggregation. We obtain data for both tariffs and international trade flows for non EU member reporters with all partner-countries.[15]

Data transformations: We start by disaggregating the EU as reporter into its 28 individual countries and impute tariff data for each of the individual countries with all other partners. When the partner is a EU member tariffs are set to zero. When the partner is not a EU member, we use a uniform tariff value for each reporter in the EU to that partner. Then, we fill missing values in the tariff data as follows. For instances where we found missing values across tariff values between countries and EU partners, we chose to use the maximum tariff value by reporter, type of tariff, and product for all EU partners. In the case of Australia (AUS) as a reporter, however, tariff values of AUS trading with EU partners were lower for a particular group of countries: Poland, Bulgaria, Hungary, Czech Republic, Slovenia, Slovak Republic, Romania, Cyprus and Malta. In that case, we separated EU reporters into East Europe (Poland, Bulgaria, Hungary, Czech Republic, Slovenia, Slovak Republic, Romania, Cyprus and Malta) and West Europe. For West Europe countries, we applied the the maximum tariff value by reporter, type of tariff, and product. For East Europe countries, we applied the minimum tariff.

Supplemental data on imports: We complement international trade flows data for EU importers with all its partners using the BACI dataset developed by CEPII. BACI

[15]We are missing data from WITS on Russia as an importer for the year 2013, and on Turkey as an importer for the year 2012.

provides bilateral trade values and quantities of exports at the HS 6 digit product disaggregation, for over 200 countries from 1995-2017 (updated annually). In particular, we use the HS 2012 classification for 6 digit code goods for years 2012 and 2013.[16]

Aggregation: Finally, we aggregate the HS-6 digit tariff data using a broader category of sectors. in particular, we use the 14 goods sectors from our sample. In order to aggregate the tariff data we proceed as follows. First, for each importer and broad category of sectors, we keep those products that are more heavily imported across all the exporters. In particular, we order the products by their import share and keep those that represent, in total, 80% of the trade share and at least 0.005% of the trade share, individually. We then fill the missing tariff data at the product level using MFN rates and, for each broad sector category, we compute the simple average across all the HS-6 digit level tariffs. We do this for the MFN rate and the applied rate. Note that in the case of MFN, each importer and for each sector will impose the same tariff across all the exporters. However, there might be some discrepancies across exporters when using the applied rate owing to the existence of FTA agreements between the importer and the exporter. In our sample, we find that the average applied rate is always less or equal to the MFN rate.

[16]We are missing data on Taiwan in the BACI database for imports.