The Impact of Trade on Labor Market Dynamics*

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Abstract

We develop a dynamic labor search model where production and consumption take place in spatially distinct labor markets with varying exposure to domestic and international trade. The model recognizes the role of labor mobility frictions, goods mobility frictions, geographic factors, and input-output linkages in determining equilibrium allocations. We show how to solve the equilibrium of the model without estimating productivities, reallocation frictions, or trade frictions, which are usually difficult to identify. We use the model to study the dynamic labor market outcomes of aggregate trade shocks. We calibrate the model to 38 countries, 50 U.S. states and 22 sectors and use the rise in China's import competition to quantify the aggregate and disaggregate employment and welfare effects on the U.S. economy. We find that China's import competition growth resulted in 0.6 percentage point reduction in the share of manufacturing employment, approximately 1 million jobs lost, or about 60% of the change in the manufacturing employment share not explained by a secular trend. Overall, China's shock increases U.S. welfare by 6.7% in the long-run and by 0.2% in the short-run with very heterogeneous effects across labor markets.

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1. INTRODUCTION

Aggregate trade shocks can have heterogeneous effects across different labor markets. One source of variation is the exposure to foreign trade, measured by the degree of import competition across labor markets. Another source of variation is the extent to which trade shocks impact the exchange of goods and the reallocation of labor across and within locations. Moreover, since labor movement across markets takes time, and mobility frictions depend on local characteristics, labor market outcomes adjust differently across industries, space, and over time to the same aggregate shock. In this paper we develop a dynamic and spatial labor search model to understand and quantify the disaggregate labor market effects resulting from changes in the economic environment. The model explicitly recognizes the role of labor mobility frictions, goods mobility frictions, geographic factors, input-output linkages and international trade in shaping the effects of shocks across different labor markets.

In our economy, production takes place in spatially distinct markets. A market is a sector located in a particular region in a given country.[1] In each market there is a continuum of heterogeneous firms producing intermediate goods. Firms are competitive, have a constant returns to scale technology, demand labor, local factors, and materials from all other markets in the economy. In each market there is also a final good producer that demands intermediate goods from the lowest-cost supplier in the world. Final goods are then used as materials and consumed by households. Hence, our model has intersectoral, interregional, and international trade.[2]

Time is discrete and agents are infinitely lived. There is a constant measure of households in the world which at the beginning of the period is distributed across markets in a given manner. Households can be either employed or unemployed. Employed households supply a unit of labor and receive the local competitive market wage. Given their income, households allocate consumption across their region's final goods. Unemployed households obtain consumption in terms of home production, or what we call unemployment "benefit." We model the decision on where to supply labor across markets as a dynamic discrete choice problem. In particular, we assume that households are forward looking and that at each moment in time, conditional on their location, the state of the economy, and an i.i.d. taste shock, they decide whether to be employed in the next period and

[1] Our setup can accommodate an arbitrary number of sectors located over an arbitrary number of regions across countries.

[2] The production structure of the model builds on multi-country international trade models a la Eaton and Kortum (2002). We incorporate multiple sectors and input-output linkages as in Caliendo and Parro (2015) and local factors and interregional trade as in Caliendo, et al. (2014).

in which labor market to supply labor. Moving across labor markets is costly, and we allow for an arbitrary distribution of mobility costs. As a result, we present a novel dynamic labor search model with international, interregional, and intersectoral trade.

Solving a dynamic labor search model is typically a difficult task since it requires characterizing the evolution of employment across labor markets together with the distribution of wages governing workers' decision problem. Moreover, it also requires estimating a large set of structural parameters that are usually difficult to identify.[3] We show that by expressing the equilibrium conditions of the model in relative time differences we are able to solve the model's transition path with no need to estimate productivity levels, mobility costs across labor markets, or international and domestic trade costs. Aside from data for the initial period that directly maps into the model's conditions, the only parameters needed to solve the full transition of the dynamic model are the intertemporal discount factor, the trade elasticity, and the variance of idiosyncratic taste shocks. The method holds irrespective of the number of markets and relies on conditioning on the observed initial period allocation. The intuition is that the observed production data combined with the cross-sectional variation in trade flows across markets and the cross-sectional variation in mobility flows across labor markets are sufficient statistics for the implied levels of productivity and the distribution of trade and mobility costs. Dekle, Eaton, and Kortum (2008, hereafter DEK), have shown this result in the context of a static trade model.[4] We are the first to show this result in the context of a dynamic discrete choice model.[5]

Our study is complementary to a large body of empirical research aimed at identifying the disaggregate effects of changes in the economic environment. We contribute by introducing a framework that can be used to perform large-scale quantitative analysis and yet not lose track of the main economic insights that deliver the results. Equally important, our model can speak about effects that are usually difficult to quantify or identify in reduced form empirical research. For instance, we can study how the *levels* of aggregate employment for different countries and for specific labor markets respond to a change in policy.[6] Furthermore, we contribute to this strand of

[3] For more details see Rust (1987, 1994).

[4] Caliendo and Parro (2015) also show that DEK's technique holds with multiple sectors and input-output linkages. DEK's methodology is also referred as the "exact hat algebra," following Costinot and Rodriguez-Clare (2014).

[5] Our solution method applies to a large class of dynamic discrete choice models. It relies on obtaining a closed form analytical expression for the transition of the state variable of the economy, which is typically the case in dynamic discrete choice models with extreme value distribution assumptions.

[6] More broadly, through the lens of our model, we can study the effects of changes in many economic conditions. For instance, how changes in trade costs, labor migration costs, local structures, productivity, unemployment benefits, and local policies, affect the rest of the economy. In addition, we can analyze how aggregate changes in economic circumstances can have heterogeneous disaggregate effects.

the literature by explaining how additional channels account for the change in welfare and many other economic outcomes at the aggregate and disaggregate levels and over time.

Recent studies have analyzed the impact of trade shocks on labor market dynamics (see, e.g. Artuç and McLaren, 2010, Artuç Chaudhuri and McLaren, 2010 [hereafter ACM], Dix-Carneiro, 2014, and Dix-Carneiro and Novak, 2015)[7]. We build on this fast growing strand of the literature and apply our model and solution method to study the effects of the rise in China's import competition on U.S. labor markets.

U.S. imports from China almost doubled from 2000 to 2007. During the same period manufacturing employment fell considerably while employment in other sectors, such as construction and services, grew. Several studies (e.g. Autor, Dorn and Hanson, 2013 [hereafter ADH], Acemoglu et al., 2014, Pierce and Schott, 2012) document that an important part of the employment loss in manufactures was a consequence of China's trade expansion, either as a consequence of technological improvements in the Chinese economy or due to reductions in trade costs.[8] In most of these studies the main reason why U.S. labor markets are differentially exposed to Chinese goods is their different degree of import competition. We use our model to quantify how additional channels can also explain the employment loss in the manufacturing sector and how other sectors of the economy, such as construction and services, were also exposed to the Chinese shock. More importantly, we use our model to compute the welfare effects across labor markets over time.

We calibrate our model to 38 countries, 50 U.S. states, and 22 sectors.[9] We take the initial distribution of labor across markets in the U.S. economy and match the initial conditions of our model to those in the year 2000. We rely on the identification restriction suggested by ADH to identify China's shock; namely, we use the predicted changes in U.S. imports from China using as instrument the change in imports from China by other high-income countries for the period 2000 to 2007. Using our model, we compute the change in sectoral productivities in China between 2000 and 2007 that exactly matches the predicted changes in imports in the model. These changes in productivity is what we call the China shock and refer to it as such in the rest of the paper.

We find that increased Chinese competition reduced the share of manufacturing employment by

[7] Other papers that study the effect of trade on labor market dynamics are Cosar (2013), Cosar, Guner, and Tybout (2014), Kondo (2013), and Menezes-Filho, and Muendler (2011).

[8] ADH argue that structural reforms in the Chinese economy resulted in large technological improvements in export-led sectors. As a result, China's import penetration to the Unites States increased. Handley and Limao (2014) and Pierce and Schott (2012) argue that the U.S.' elimination of uncertainty about tariff increases on Chinese goods was another important reason why U.S. imports from China grew.

[9] It is worth noting that for an application of this dimension not using our solution method will require estimating: $N \times R \times J$ productivity levels, $N^2 \times R^2 \times J$ asymmetric bilateral trade costs, $N^2 \times R^2 \times J^2$ labor mobility costs, $N \times R \times J$ stocks of local factors. Where N, R and J are countries, regions and sectors, respectively.

0.6 percentage point in the long run, which is equivalent to a loss of about 1 million manufacturing jobs, or about 60% of the change in the share of manufacturing employment that is not explained by a secular trend. We also find that workers reallocate to the services sector as it benefits from the access to cheaper intermediate inputs from China.

Our quantitative framework also allows us to quantify the relative contribution of different sectors, regions and labor markets to the decline in manufacturing employment. We find that sectors with a higher exposure to import competition from China lost more manufacturing jobs. The computer and electronics, and furniture industries contributed to about half of the decline in manufacturing employment, followed by metal and textiles industries that together contributed to about one-fourth of the total decline. Some sectors, such as food, beverage and tobacco, gained employment, as they were less exposed to China and benefited from cheaper intermediate goods. The fact that U.S. economic activity is not equally distributed across space plus the differential sectoral exposure to China, imply that the impact of China's import competition varies across regions. We find that U.S. states that have a larger concentration of sectors that were more exposed to China lose more manufacturing jobs. California, which by far accounts for the largest share of employment in computer and electronics (the sector most exposed to China's import competition), contributed to about 12% of the decline.

Our framework also allows us to quantify the welfare effects of the increased competition from China on the U.S. economy. Our results indicate that the China shock increases U.S. welfare by 6.7% in the long run and by 0.2% in the short run. Therefore, even when U.S. exposure to China decreases employment in the manufacturing sector, the U.S. economy is better off. Moreover, the welfare effect is larger in the long run than in the short run as workers reallocate from depressed industries. We find that the non manufacturing sectors gain the most, since they are not directly exposed to competition from China and at the same time benefit from cheaper intermediate manufacturing inputs used in their production and from increased inflow of workers from other sectors. We also find that welfare gains are more uniform in the long run due to workers' reallocation.

In addition, we quantify the welfare effects across regions and find that all U.S. states fare better in the short run and in the long run. Regions benefit directly from the access to cheaper intermediate goods from China and indirectly from the effect of cheaper Chinese goods on the cost of inputs purchased from other U.S. regions. We find that the regional welfare distribution is more uniform in the long run than in the short run as, over time, workers reallocate from regions with lower real income. Across individual labor markets, we find that some labor markets, such as wood and paper manufacturing in Nevada, transport equipment manufacturing in Louisiana, and wholesale and retail Trade in Alaska, are worse off with the increased competition from China.

In summary, we are able to account for the short- and long-run distribution of winners and losers across sectors and regions of the U.S. economy caused by the increase in Chinese competition.

The paper is organized as follows. In Section 2 we present our dynamic model of costly labor reallocation and trade. Operating over the set of equilibrium conditions, we are able to write the model in a more tractable way. In Section 3 we show how this transformation reduces the burden of the quantitative application. In Section 4 we use our model to quantify the effects of increased Chinese competition on different U.S. labor markets. Finally, we conclude in Section 5. All proofs are relegated to Appendix 2.

2. A SPATIAL DYNAMIC LABOR SEARCH MODEL

Time is discrete, and we denote it by $t = 0, 1, 2, ...$ We consider a world with N countries, R regions, and J sectors. We use the indexes n or i as unique identifiers of a particular region irrespective of the country and index sectors by j or k. In each region-sector combination there is a competitive labor market. In each market there is a continuum of perfectly competitive firms producing intermediate goods using a technology with time-invariant heterogeneous idiosyncratic productivity.

We follow Eaton and Kortum (2002, hereafter EK) and assume that productivities are distributed Fréchet with a sector-specific productivity dispersion parameter θ^j. Firms have a Cobb-Douglas constant returns to scale technology, demand labor, a composite local factor that we refer to as structures, and materials from all sectors.

At the beginning of the period there is an initial distribution of labor across markets. We abstract from labor force participation decisions; thus, workers can be either employed or unemployed in a region. Workers face costs to move across markets and experience an idiosyncratic shock that affects their moving decision. The households' problem is closely related to the sectoral reallocation problem in ACM and to the competitive labor search model of Lucas and Prescott (1974).[10] Agents are forward looking and optimally decide where to move. We first characterize the dynamic problem of a household deciding where to move conditional on a path of real wages across time and labor

[10] A related model of reallocation and unemployment is developed in Dvorkin (2014). See also, Coen-Pirani (2010). Preference shocks are widely used in the literature on worker reallocation. See, for example, Kennan and Walker (2011), ACM, Dix-Carneiro (2014), and Monte (2015).

markets. We then characterize the static subproblem to solve for prices and wages conditional on the supply of labor in a given market.

2.1 Problem of the households

At $t = 0$ there is a mass $L_0^{n,j}$ of households in each location n and sector j. Households can be either *employed* or *unemployed.* An *employed* household in location n and sector j supplies a unit of labor inelastically and receives a competitive market wage $w_t^{n,j}$. Given her income she decides how to allocate consumption over local final goods from all sectors with a Cobb-Douglas aggregator. We assume that preferences are over the basket of final local goods, in particular

$$U(C_t^{n,j}), \text{ where } C_t^{n,j} = \prod\nolimits_{k=1}^{J} \left(c_t^{n,k}\right)^{\alpha^k}, \tag{1}$$

where $c_t^{n,k}$ is the consumption of sector goods k in region n at time t, and α^k is the final consumption share, with $\sum_{k=1}^{J} \alpha^k = 1$. We denote the ideal price index by $P_t^n = \prod_{k=1}^{J} \left(P_t^{n,k}/\alpha^k\right)^{\alpha^k}$. *Unemployed* households in region n obtain consumption in terms of home production, or an unemployed "benefit," $b^n > 0$. To simplify the notation, we represent sector zero in each region as unemployment; hence, $C_t^{n,0} = b^n$.[11]

Assumption 1 *Agents have logarithmic preferences, that is,* $U(C_t^{n,j}) \equiv \log(C_t^{n,j})$.

Assumption 1 specifies the preference structure of the agents in the economy. In Section 3 we show how the equilibrium conditions of the model change if we relax this assumption. The household's problem is dynamic, and agents are forward looking and discount the future at rate $\rho \geq 0$.

Assumption 2 *Labor reallocation costs* $\tau^{n,j;i,k} \geq 0$ *depend on the origin* (n, j) *and destination* (i, k), *and are (i) time invariant, (ii) additive, and (iii) in terms of utility. We further assume that there is no international migration by imposing that (iv)* $\tau^{n,j;i,k} = \infty$ *for all* j, k *such that regions* n *and* i *belong to different countries.*

Assumption 2 describes the mobility costs in the model. As we can see, condition (iv) in the assumption states explicitly that there is no international migration in the model.[12] In addition,

[11] To simplify the notation, we abstract from local amenities, which can vary both by sectors and regions. As it will become clear later, our exercise and results are unaltered to the existence of these amenities under the assumption that they enter the period utility additively and are constant over time.

[12] This assumption is convenient for our quantitative application in Section 4, but the model can accommodate international migration.

agents have additive idiosyncratic preference (or cost) shocks for each choice and we denote them by $\epsilon_t^{i,k}$.

The timing for the workers' problem and decisions is as follows. Workers observe the economic conditions in all labor markets and the realizations of their own idiosyncratic shocks. If they begin the period in a labor market, they work and earn the market wage. If they are unemployed in a region, they get home production. Then, both employed and unemployed workers have the option to reallocate. Formally,

$$v_t^{n,j} = u(C_t^{n,j}) + \max_{\{i,k\}_{i=1,k=0}^{N,J}} \left\{ \rho E\left[v_{t+1}^{i,k}\right] - \tau^{nj,ik} + \sigma\, \epsilon_t^{i,k} \right\},$$

$$s.t.\ u(C_t^{n,j}) \equiv \begin{cases} \log(b^n) & if\, j=0, \\ \log(w_t^{n,j}/P_t^n) & \text{otherwise}; \end{cases}$$

where $v_t^{n,j}$ is the lifetime utility of a worker in region n and sector j at time t and the expectation is taken over future realizations of the preference shock. Note that workers choose to reallocate to the labor market that delivers the highest utility net of costs.

Assumption 3 *The idiosyncratic preference shock (or reallocation cost shock) ϵ has the following properties: It (i) is i.i.d. over time, (ii) follows a Type-I Extreme Value distribution, (iii) has zero mean.*

Assumption 3 is a standard assumption made in dynamic discrete choice models.[13] It allows for a simple aggregation of the idiosyncratic decisions made by households as we now show.

Denote by $V_t^{n,j} \equiv E\left[v_t^{i,k}\right]$ the expected lifetime utility of a worker, where the expectation is taken over the preference shocks. $V_t^{n,j}$ can be interpreted as the expected lifetime utility of a worker before the realization of her preference shocks or, alternatively, as the average utility of workers in that market under a pure utilitarian welfare. Then, by Assumption 2,

$$V_t^{n,j} = u(C_t^{n,j}) + \sigma \log\left[\sum_{i=1}^{N}\sum_{k=0}^{J} \exp\left(\rho V_{t+1}^{i,k} - \tau^{n,j;i,k}\right)^{1/\sigma}\right]. \tag{2}$$

Equation (2) reflects that the value of being in a particular labor market depends on the current-period utility and the option value to move into any other market in the next period.[14]

Assumption 3 also implies that the share of labor that transitions across markets has a closed-form analytical expression. In particular, denote by $\mu_t^{n,j;i,k}$ the fraction of workers that reallocate

[13] For a survey on this literature, see Aguirregabiria and Mira (2010).

[14] For an example of a model that delivers a similar expression refer to Artuç and McLaren (2010), ACM, and Dix-Carneiro (2014). ACM also provides an economic interpretation of the different components of the option value to migrate across sectors.

from market n, j to i, k (with $\mu_t^{n,j;n,j}$ the fraction who choose to remain in their original location), then,

$$\mu_t^{n,j;i,k} = \frac{\exp\left(\rho V_{t+1}^{i,k} - \tau^{n,j;i,k}\right)^{1/\sigma}}{\sum_{m=1}^{N}\sum_{h=0}^{J}\exp\left(\rho V_{t+1}^{m,h} - \tau^{n,j;m,h}\right)^{1/\sigma}}. \tag{3}$$

Equation (3) has a very intuitive interpretation. Other things equal, it reflects that markets with a higher lifetime utility (net of mobility costs) are the ones that attract more labor. From this expression we can also see that $1/\sigma$ has the interpretation of a labor mobility cost elasticity.[15] Equation (3) is a key equilibrium condition in this model because it conveys all information needed to determine how the distribution of labor evolves over time. In particular, the dynamics of the distribution of labor over markets are described by,

$$L_{t+1}^{n,j} = \sum_{i=1}^{N}\sum_{k=0}^{J} \mu_t^{i,k;n,j}\, L_t^{i,k}. \tag{4}$$

We now proceed to outline the production structure of the economy.

2.2 Production

Technology follows closely EK, particularly the multisector version in Caliendo and Parro (2015). Goods are of two types: intermediate, denoted by q, and final, denoted by Q. Firms in each sector and region are able to produce many varieties of intermediate goods and a final good. The technology to produce these intermediate goods requires labor and structures, which are the primary factors of production, and materials, which consists of final goods from all sectors. Total factor productivity (TFP) of an intermediate good is composed of two terms, a sectoral-regional component ($A^{n,j}$), which is common to all varieties in a region and sector, and a variety-specific component ($z^{n,j}$). We assume that $A^{i,j}$ is exogenous and deterministic. Since one intermediate variety is identified by $z^{n,j}$, we use it to index a variety.

[15] Note that if we were to assume that mobility costs are multiplicative and that idiosyncratic taste shocks are distributed Fréchet, then similar analytical expressions are obtained. In this case, the expected value in equation (2) and the fraction of workers who move in equation (3) will be given by

$$V_t^{n,j} = u\left(C_t^n\right) + \left(\sum_{i=1}^{N}\sum_{k=0}^{J}\left(\rho V_{t+1}^{i,k}\tau^{n,j;i,k}\right)^{1/\sigma}\right)^{\sigma},$$

and,

$$\mu_t^{n,j;i,k} = \frac{\left(\rho V_{t+1}^{i,k}\tau^{n,j;i,k}\right)^{1/\sigma}}{\sum_{m=1}^{N}\sum_{h=0}^{J}\left(\rho V_{t+1}^{m,h}\tau^{n,j;m,h}\right)^{1/\sigma}}.$$

Intermediate Goods Producers.—

The technology for intermediate goods is described by,

$$q_t^{n,j}(z^{n,j}) = z^{n,j}\left[A^{n,j}\left[l_t^{n,j}(z^{n,j})\right]^{\beta^n}\left[h_t^{n,j}(z^{n,j})\right]^{1-\beta^n}\right]^{\gamma^{n,j}}\prod_{k=1}^{J}[M_t^{n,jk}(z^{n,j})]^{\gamma^{n,jk}},$$

where $l_t^{n,j}(z^{n,j})$, $h_t^{n,j}(z^{n,j})$ are the demands for labor and structures by firms in sector j and region n, and $M_t^{n,jk}(z^{n,j})$ is the demand for material inputs from sector k by firms in sector j and region n. Material inputs are final goods from sector k produced in the same region n. The parameter $\gamma^{n,j} \geq 0$ is the share of value added in the production of sector j and region n, and $\gamma^{n,jk} \geq 0$ is the share of materials from sector k in the production of sector j and region n. We assume that the production function exhibits constant returns to scale such that $\sum_{k=1}^{J}\gamma^{n,jk} = 1 - \gamma^{n,j}$. The parameter β^n is the share of structures in value added. Structures are in fixed supply in each labor market.

We denote by $P_t^{n,j}$ the price of materials, and by $r_t^{n,j}$ the rental price of structures in region n and sector j. We define the unit price of an input bundle as

$$x_t^{n,j} = B^{n,j}\left[\left(r_t^{n,j}\right)^{\beta^n}\left(w_t^{n,j}\right)^{1-\beta^n}\right]^{\gamma^{n,j}}\prod_{k=1}^{J}[P_t^{n,k}]^{\gamma^{n,jk}}, \tag{5}$$

where $B^{n,j}$ is a constant. Then, the unit cost of an intermediate good $z^{n,j}$ at time t is

$$\frac{x_t^{n,j}}{z^{n,j}\,[A^{n,j}]^{\gamma^{n,j}}}.$$

Trade costs are represented by parameter $\kappa^{ni,j}$ and are of the "iceberg" type. One unit of any variety of intermediate good j shipped from region i to n requires producing $\kappa^{ni,j} \geq 1$ units in region i. If a good is nontradable, then $\kappa^{ni,j} = \infty$. Competition implies that the price paid for a particular variety of good j in region n is given by the minimum unit costs across regions, taking into account trade costs. That is,

$$p_t^{n,j}(z^j) = \min_i\left\{\frac{\kappa^{ni,j}\,x_t^{i,j}}{z^{i,j}[A^{i,j}]^{\gamma^{i,j}}}\right\}.$$

Final Goods Producers.—

Final goods in region n and sector j are produced by combining intermediate goods from sector j across all other regions. Let $Q_t^{n,j}$ be the quantity of final goods in region n and sector j and $\tilde{q}_t^{n,j}(z^j)$ the quantity demanded of an intermediate good of a given variety such that, for that variety, the vector of productivity draws received by the different regions is $z^j = (z^{1,j}, z^{2,j}, \ldots, z^{N,j})$. The production of final goods is given by

$$Q_t^{n,j} = \left[\int [\tilde{q}_t^{n,j}(z^j)]^{1-1/\eta^{n,j}} \phi^j(z^j) dz^j\right]^{\eta^{n,j}/(\eta^{n,j}-1)},$$

where $\phi^j(z^j) = \exp\left\{-\sum_{n=1}^{N}(z^{n,j})^{-\theta^j}\right\}$ is the joint density function over the vector z^j, with marginal densities given by $\phi^{n,j}(z^{n,j}) = \exp\left\{-(z^{n,j})^{-\theta^j}\right\}$ and the integral is over R_+^N. For nontradable sectors the only relevant density is $\phi^{n,j}(z^{n,j})$ since final good producers use only locally produced goods. There are no fixed costs or barriers to entry and exit in the production of intermediate and final goods. Competitive behavior implies zero profits at all times. Because of constant returns to scale in production, the number of firms in the economy is undetermined, but this is inconsequential for equilibrium allocations.

Given the properties of the Fréchet distribution, the price of the final good j in region n at time t is

$$P_t^{n,j} = \Gamma(\xi^{n,j})^{1/(1-\eta^{n,j})} \left[\sum_{i=1}^{N} [x_t^{i,j}\kappa^{ni,j}]^{-\theta^j} [A^{i,j}]^{\theta^j \gamma^{i,j}}\right]^{-1/\theta_j}, \tag{6}$$

where $\Gamma(\xi^{n,j})$ is the Gamma function evaluated at $\xi^{n,j} = 1 + \left(1 - \eta^{n,j}/\theta^j\right)$ [16]. Following similar steps as earlier, from the problem of the final good producer we can solve for the share of total expenditure in market (n,j) on goods j from market i. In particular,

$$\pi_t^{ni,j} = \frac{[x_t^{i,j}\kappa^{ni,j}]^{-\theta^j} [A^{i,j}]^{\theta^j \gamma^{i,j}}}{\sum_{m=1}^{N} [x_t^{m,j}\kappa^{nm,j}]^{-\theta^j} [A^{m,j}]^{\theta^j \gamma^{m,j}}}. \tag{7}$$

This equilibrium condition reflects that the more productive market i,j is, the cheaper is the costs of production in market i,j, and therefore, the more region n purchases sector j goods from region i. In addition, the easier is to ship sector j goods from region i to n (lower $\kappa^{ni,j}$), the more region n purchases sector j goods from region i. This equilibrium condition is sometimes referred to as the gravity equation.

Market Clearing.—

In order to accommodate observed trade imbalances, we assume there is a mass 1 of rentiers in each market. Rentiers cannot reallocate to other regions. They own the local structures and rent them to local firms. The rentiers of a particular region n remit all the proceeds to a world pool of rents, of which they own a share ι^n. The difference between the remittances and the income rentiers

[16] We assume that $1 + \theta^j > \eta^{n,j}$.

receive will generate trade imbalances, which change in magnitude as the rental prices change. The rentier uses her income to buy goods produced in her own region using equation (1).

Let $X_t^{n,j}$ the total expenditure on final good j in region n. Then, regional market clearing in final goods implies

$$X_t^{n,j} = \sum\nolimits_{k=1}^{J} \gamma^{n,kj} \sum\nolimits_{i=1}^{N} \pi_t^{in,k} X_t^{i,k} + \alpha^j \left[\sum\nolimits_{k=1}^{J} w_t^{n,k} L_t^{n,k} + \iota^n \chi_t \right], \tag{8}$$

where $\pi_t^{in,k}$ denotes the share of region n's total expenditures on sector j's intermediate goods purchased from region i, and $\sum_{k=1}^{J}(w_t^{n,k} L_t^{n,k} + \iota^n \chi_t)$ is the total income in region n, where $\chi_t = \sum_{i=1}^{N} \sum_{k=1}^{J} r_t^{i,k} H^{i,k}$. We refer to equilibrium condition (8) as the goods market equilibrium condition. Given prices and wages, workers and rentiers exhaust their income in final goods (the last term in the equation), and producers supply exactly these final goods for consumption plus the materials needed for intermediate goods production.

Labor market clearing in region n and sector j is

$$L_t^{n,j} = \frac{\gamma^{n,j} \left(1 - \beta^n\right)}{w_t^{n,j}} \sum\nolimits_{i=1}^{N} \pi_t^{in,j} X_t^{i,j}, \tag{9}$$

while the market clearing for structures in region n and sector j must satisfy

$$H^{n,j} = \frac{\gamma^{n,j} \beta^n}{r_t^{n,j}} \sum\nolimits_{i=1}^{N} \pi_t^{in,j} X_t^{i,j}. \tag{10}$$

We now proceed to formally define an equilibrium of the economy.

2.3 Equilibrium

The state of the economy at any given moment in time is determined by the distribution of labor across all markets $s_t = \{L_t^{n,j}\}_{n=1,j=0}^{N,J}$. The sectoral-regional productivities are $A = \{A^{n,j}\}_{n=1,j=1}^{N,J}$, iceberg transportation costs are described by $K = \{\kappa^{ni,j}\}_{n=1,i=1,j=1}^{N,N,J}$, the labor mobility costs by $\Upsilon = \{\tau^{n,j;i,k}\}_{n=1,j=0,i=1,k=0}^{N,J,J,N}$, the distribution of structures across markets by $H = \left\{H^{n,j}\right\}_{n=1,j=1}^{N,J}$, the distribution of regional unemployment benefits by $b = \{b^n\}_{n=1}^{N}$, and we define $\Theta \equiv (A, K, \Upsilon, H, b)$. We seek to find equilibrium prices $P_t = \{P_t^{n,j}\}_{n=1,j=1}^{N,J}$, wages $w_t = \{w_t^{n,j}\}_{n=1,j=1}^{N,J}$, and rental prices $r_t = \{r_t^{n,j}\}_{n=1,j=1}^{N,J}$ given (s_t, Θ). We refer to this equilibrium as a *temporary* equilibrium. Formally,

Definition 1 *Given* (s_t, Θ), *a* ***temporary equilibrium*** *is a vector of* w, r, *and* P *that satisfies equilibrium conditions* (5) *to* (10). *We denote by* $\omega(s_t, \Theta)$ *the* ***temporary equilibrium*** *of the economy given* (s_t, Θ).

Suppose it can be shown that for any (s_t, Θ) there is a unique temporary equilibrium. Then the wage rate can be expressed as $w_t = w(s_t, \Theta)$, rental prices as $r_t = r(s_t, \Theta)$, and prices as $P_t = P(s_t, \Theta)$.[17] After defining the temporary equilibrium, we can now define the sequential competitive equilibrium of the model. Let $\mu_t = \{\mu_t^{n,j;i,k}\}_{n=1,j=0,i=1,k=0}^{N,J,J,N}$, and $V_t = \{V_t^{n,j}\}_{n=1,j=0}^{N,J}$. The definition of a sequential competitive equilibrium is given below.

Definition 2 *Given (s_0, Θ), a* ***sequential competitive equilibrium*** *of the model is a sequence of $\{s_t, \mu_t, V_t, \omega(s_t, \Theta)\}_{t=0}^{\infty}$ that solves equilibrium conditions (2) to (4), and the temporary equilibrium at each t.*

Finally, we define a stationary equilibrium of the model.

Definition 3 *A* ***stationary equilibrium*** *of the model is a sequential competitive equilibrium such that $\{s_t, \mu_t, V_t, \omega(s_t, \Theta)\}_{t=0}^{\infty}$ are constant for all t.*

A stationary equilibrium in this economy is a situation in which all aggregate variables do not change over time. In a stationary equilibrium, workers flow from one market to another, but on net inflows and outflows cancel exactly.

3. QUANTITATIVE ANALYSIS

The main challenge in solving for all the transitional dynamics in a dynamic discrete choice model with a rich spatial structure is that it requires a large number of unknown parameters. Note from definitions (1) to (3) that to solve for an equilibrium of the model it is necessary to condition on Θ; namely, almost the entire set of parameters of the model (productivity, endowments of local structures, labor mobility costs, unemployment benefits, and trade costs). As we increase the dimension of the problem —adding countries, regions, or sectors— the number of parameters grows exponentially. We now show that one can solve this problem and compute the equilibrium dynamics of the model without knowing Θ.

[17] Note that given (s_t, Θ), a temporary equilibrium is the solution to a multi-country interregional trade model as in Caliendo, et al. (2014). The existence and uniqueness of that model has not been proven so far; however, numerical simulations indicate that there is one. Yet, we know from Alvarez and Lucas (2007) that there exists a unique equilibrium of a one-sector version of the model. More recently, Allen and Arkolakis (2014) provide a sharp characterization of the equilibrium conditions of a more general model than that of Alvarez and Lucas (2007).

3.1 Solution Method

Our solution method exploits the multiplicative properties of the equilibrium conditions. We start by first showing that one can characterize how the temporary equilibrium changes from one state to another without knowing Θ. This result is presented in the following proposition.

Proposition 1 *Consider the temporary equilibrium at state s and a temporary equilibrium at state s'. Denote the change in the temporary equilibrium from one state to the other by $\hat{\omega}(\hat{s}, \Theta)$ where $\hat{s} = s'/s$. The solution to the change in the temporary equilibrium from state s to s' is independent of Θ; namely, $\hat{\omega}(\hat{s}, \Theta) = \hat{\omega}(\hat{s})$.*

Proposition 1 is very important since it shows that given a sequence of states s_t, one can solve for the sequence of temporary equilibria without requiring information on productivities, transportation costs, labor mobility costs, unemployment benefits and structures. In a different context, this "trick" is used in international trade models to evaluate the change in the equilibrium conditions to a change in policy.[18] The solution method in trade was first introduced by DEK. Proposition 1 is also important because it shows that one can solve for the change of a temporary equilibrium to a given arbitrary change in technologies, trade costs, migration costs, or any other element of Θ, which hereafter we refer to as a change in policy. We state this last observation without proof with Corollary 1.

Corollary 1 *Consider the temporary equilibrium at state s and given policy $\top$. Solving for a change in the temporary equilibrium given a change in policy, $\hat{\top} = \top'/\top$ does not require Θ.*

We now characterize the solution of the dynamic model. We want to understand how the sequential equilibrium of the model changes after a change in policy. We assume that agents at $t = -1$ are not expecting the change in policy and that at $t = 0$ agents learn about the change in the economic environment. This timing assumption allows us to use information about agents' actions at $t = -1$ to solve for the sequential equilibrium, under a new policy, in relative time differences. Let the new policy sequence be given by $\top = \{\top_t\}_{t=0}^{\infty}$, and denote by $\hat{\top} = \{\hat{\top}_t\}_{t=1}^{\infty}$ the relative time difference of policy $\top$, where $\hat{\top}_t = \top_t/\top_{t-1}$. The next proposition shows that one can compute the sequential equilibrium in relative time differences, without knowing Θ.

[18] It is important to emphasize that the temporal equilibrium described in Definition 1 is not specific to a multisector EK model, but it can also be the equilibrium of other trade models such as Melitz (2003). In other words, our solution method requires that the temporary equilibrium solves for equilibrium prices given the distribution of employment irrespective of the model's structure or microfoundations that determine those prices.

Proposition 2 *Conditional on* $\left(s_0, \mu_{-1}\right)$ *and given* $\hat{\top} = \{\hat{\top}_t\}_{t=1}^{\infty}$, *the solution to the sequential equilibrium in relative time differences does not require* Θ, *and solves the following system of equations*

$$\mu_{t+1}^{n,j;i,k} = \frac{\mu_t^{n,j;i,k} \left[Y_{t+2}^{i,k}\right]^{\rho}}{\sum_{m=1}^{N} \sum_{h=0}^{J} \mu_t^{n,j;m,h} \left[Y_{t+2}^{m,h}\right]^{\rho}}, \tag{11}$$

$$Y_{t+1}^{n,j} = \sum_{i=1}^{N} \sum_{k=0}^{J} \lambda_{t+1}^{n,j;i,k} \left[Y_{t+2}^{i,k}\right]^{\rho}, \tag{12}$$

$$L_{t+1}^{n,j} = \sum_{i=1}^{N} \sum_{k=0}^{J} \mu_t^{i,k;n,j} L_t^{i,k},$$

where $Y_{t+1}^{i,k} \equiv \exp\left(V_{t+1}^{i,k} - V_t^{i,k}\right)^{1/\sigma}$, $\lambda_{t+1}^{n,j;i,k} = \left(\hat{w}_{t+1}^{n,j} / \hat{P}_{t+1}^{n}\right)^{1/\sigma} \mu_t^{n,j;i,k}$, *and* $\hat{w}_{t+1}^{n,j}\left(\hat{s}_{t+1}, \hat{\top}_{t+1}\right)$, *and* $\hat{P}_{t+1}^{n}\left(\hat{s}_{t+1}, \hat{\top}_{t+1}\right)$ *are the solution to the temporary equilibrium at state* $\hat{s}_{t+1}$ *and policy* $\hat{\top}_{t+1}$.

Proposition 2 is one of the key results of this paper. This transformation reduces the burden of calibration and allows solving for the transitional dynamics of the model using only a few parameters and data for the initial period i.e., the initial value of the labor transition matrix and the initial distribution of workers across labor markets.[19] Moreover, one can apply this solution method to evaluate any sequence of policy changes. For instance, quantify the effects of an arbitrary change in TFP, $A^{n,j}$, trade costs $\kappa^{ni,j}$, labor mobility costs $\tau^{n,j;i,k}$, structures H, and unemployment benefits b^n across markets and over time. In the quantitative exercise in Section 4, we consider how a change in sectoral TFP in China affects U.S. labor market outcomes.

3.2 Taking the model to the data

Our initial period is the year 2000. Our solution method requires the initial values of the bilateral trade shares $\pi_0^{ni,j}$, value added $w_0^{n,j} L_0^{n,j} + r_0^{n,j} H_0^{n,j}$, the distribution of employment $L_0^{n,j}$, and the initial matrix of mobility across regions and sectors, μ_{-1}. We also need to compute the share of value added in gross output $\gamma^{n,j}$, the share of structures in value added β^n, and the material shares $\gamma^{n,jk}$. Finally, we need to input the dispersion of productivities θ^j, the variance of the preference shock σ, and the discount factor ρ. This section provides a summary of the data sources and measurement to calibrate the model, with further data details provided in Appendix 1.

[19] It is worth noting that given Assumption 2, we do not require information on the level of wages and local prices across markets in the initial period to solve the model. If instead we had linear utility, then the equation for $\lambda_1^{n,j;i,k}$ will given by

$$\lambda_1^{n,j;i,k} = \left(\hat{w}_1^{n,j} / \hat{P}_1^{n} - 1\right) \frac{w_0^{n,j}}{P_0^n} \mu_0^{n,j;i,k},$$

which, as we can see, will require conditioning on observed $\frac{w_0^{n,j}}{P_0^n}$.

Regions, sectors, and labor markets. We calibrate the model to the 50 U.S. states, 37 other countries, including China and a constructed rest of the world, and 22 sectors. The 22 sectors are classified according the North American Industry Classification System (NAICS), 12 of which are manufacturing sectors, 8 are service sectors, and we also include construction and wholesale and trade.[20] Our definition of a labor market in the U.S. economy is thus a state-sector pair, including unemployment, leading to 1150 markets. In the other countries, there is a single labor market despite having many productive sectors.

Discount factor We take the time period to be a quarter and calibrate the discount factor ρ to 0.99, implying a yearly interest rate of roughly 4%.

Trade across labor markets We construct the bilateral trade shares $\pi_0^{ni,j}$ for the year 2000 for the 38 countries in our sample, including the aggregate United States, from the World Input Output Database (WIOD). The WIOD database presents national input-output tables of major countries in the world and a constructed rest of the world that are linked through international trade statistics for 35 sectors, which we are able to map to our 22 NAICS sectors.

The sectoral bilateral trade flows across the 50 U.S. states were constructed by combining information from the WIOD database and the 2002 Commodity Flow Survey (CFS), which is the closest available year to 2000. From the WIOD database we compute the total U.S. domestic sales for the year 2000 for our 22 sectors. From the 2002 CFS we compute the bilateral expenditure shares across regions and sectors. These two pieces of information allow us to construct the bilateral trade flows matrix for the 50 U.S. states across sectors, where the total U.S. domestic sales match the WIOD data for the year 2000.

Bilateral trade flows between the 50 U.S. states and the rest of the countries in the world were constructed by combining information from the WIOD database and regional employment data from the Bureau of Economic Analysis (BEA). In our paper, local labor markets have different exposures to international trade shocks because there is substantial geographic variation in industry specialization. Regions that have a high concentration of production in a given industry should react more to international trade shocks to that industry. Therefore, our measure for the exposure of local labor markets to international trade combines trade data with local industry employment. Specifically, we split the bilateral trade flows at the country level computed from WIOD into bilateral trade flows between the U.S. states and other countries by assuming that the share of each

[20] Agriculture, mining, utilities, and the public sector are excluded from the analysis.

state in total U.S. trade with any country in the world in each sector is determined by the regional share of total employment in that industry as in ADH.

Input shares We obtain data on gross output, value added, and intermediate consumption across sectors and countries from the WIOD and across U.S. states from the BEA. We use these data to calibrate the share of value added in gross output ($\gamma^{n,j}$) and the share of materials in gross output ($\gamma^{n,jk}$).

To calibrate $(1-\beta^n)$, the share of labor in value added for the 50 U.S. states, we use the share of labor compensation in value added (less taxes and subsidies) using data from the BEA. For the rest of the countries in the world, we use labor compensation and value added data from the OECD Input-Output database.

The share of final good expenditure is calculated as $\alpha^j = \frac{\sum_{n=1}^{N}\sum_{k=1}^{J}\gamma^{n,kj}\sum_{n=1}^{N}\sum_{i=1}^{N}\pi^{in,k}X^{i,k}}{\sum_{n=1}^{N} w^{n,k}L^{n,k}+\iota^n\chi}$.

Trade elasticities The dispersion of productivities θ^j is obtained from Caliendo and Parro (2015).

The initial labor mobility matrix and the initial distribution of labor To determine the initial distribution of workers in the year 2000 by U.S. states and sectors (and unemployment), we use the 5 percent Public Use Microdata Sample (PUMS) of the decennial U.S. Census for the year 2000. Information on industry is classified according to the NAICS which we aggregate to our 22 sectors and unemployment.[21] We restrict the sample to people between 25 and 65 years of age who are either unemployed or employed in one of the sectors included in the analysis. Our sample contains over 5 million observations.

We combine information from the PUMS of the American Community Survey (ACS) and the Current Population Survey (CPS) to construct the initial matrix of quarterly mobility across our regions and sectors (μ_{-1}).[22] Our goal is to construct a transition matrix describing how individuals move between state-sector pairs from one quarter to the next (from t to $t+1$). The ACS has partial information on this; in particular, the ACS asks people about their current state and industry (or unemployment) and the state in which they lived during the previous year. We use the year

[21] While unemployment in the Census is defined similarly to the Current Population Survey (CPS), design and methodological differences in the Census tend to overestimate the number of unemployed workers relative to the CPS.

[22] The ACS interviews provide a representative sample of the U.S. population for every year since 2000. For the year 2001, the sample consists of 0.5 percent of the U.S. population. The survey is mandatory and is a complement to the decennial Census.

2001 since this is the first year for which data on interstate mobility at a yearly frequency are available.[23] We find that around 2% of the U.S. population moves across states in a year in this time period. We assume that people face equal probabilities of moving in any given quarter. Under this assumption we can recover a quarterly interstate mobility rate. Unfortunately, the ACS does not have information on workers' past employment status or the industry in which people worked during the previous period.

We use the PUMS from the monthly CPS to obtain information on past industry of employment (or unemployment) at the quarterly frequency. The main advantages of the CPS is that it is the source of official labor market statistics and has a relatively large sample size at a monthly frequency. In the CPS, individuals living at the same address can be followed month to month for a small number of periods.[24] We match individuals surveyed three months apart and compute their employment or unemployment status and work industry, accounting for any change between interviews as a transition.[25] The main limitation with the CPS is that individuals who move to a different residence, which of course includes interstate moves, cannot be matched. Our 3-month match rate is close to 90%.[26] As the monthly CPS does not have information on interstate moves, we use this information to compute the industry and unemployment transitions within each state —that is, a set of 50 transition matrices, each with 23×23 elements.[27] Table 2 in Appendix 1 helps visualize the information provided by these two datasets in terms of transition probabilities.

The information missing from the above discussion is the past industry history of interstate movers. To have a full transition matrix, we assume that workers who move across states and are in the second period in state i and sector j have a past industry history similar to workers who did not switch states and are in the second period in state i and sector j.[28]

Table 1 shows some moments of worker mobility across labor markets computed from our estimated transition matrix for the year 2000. Our numbers are consistent with the estimates by Molloy et al. (2011) and Kaplan and Schulhofer-Wohl (2012) for interstate moves and Kambourov

[23] The 2000 Census asked people about the state in which they lived 5 years before but not the previous year; thus, we do not use the Census data despite the much larger sample.

[24] In particular, the CPS collects information on all individuals at the same address for four consecutive months, stops for eight months, and then surveys them again for another four months.

[25] We observe individuals three months apart using, on the one hand, their first and fourth interviews, and on the other, their fifth and eighth interviews.

[26] Mortality, residence change, and nonresponse rates are the main drivers of the 10% mismatch rate.

[27] After restricting the sample as discussed earlier, in any given month we have around 12,000 observations for the entire United States. To more precisely estimate the transitions, we use all months from October 1998 to September 2001, leading to a sample of over 400,000 matched records.

[28] Mechanically, we distribute the interstate movers according to the intersectoral mobility matrix for the state in which they currently live.

and Manovskii (2008) for intersectoral mobility.[29]

Table 1. U.S. interstate and intersectoral labor mobility

Probability	p25	p50	p75
Changing j in same n	3.74%	5.77%	8.19%
Changing n but not j	0.04%	0.42%	0.73%
Changing j and n	0.03%	0.04%	0.06%
Staying in same j and n	91.1%	93.6%	95.2%

Note: Quarterly transitions. Data sources: ACS and CPS

One important observation from Table 1 is that there is a large amount of heterogeneity in transition probabilities across labor markets, which indicates that workers in some industries and states are more likely to switch to a different labor market than other workers. In particular, the 25th and 75th percentiles of the distribution of sectoral mobility probabilities by labor market are 40% lower and higher than the median, respectively. This dispersion is even larger for interstate moves. We interpret the observed low transition probabilities and their heterogeneity as evidence of substantial and heterogeneous costs of moving across labor markets, both spatially and sectorally.

Variance of preference shocks Finally, we calibrate σ, the scale parameter for the variance of reallocation preference shocks, to be 1.8, which is the baseline estimate in ACM. Dix-Carneiro (2014) estimates a value of 2.15. In our model, we assume logarithmic utility for workers while ACM and Dix-Carneiro (2014) assume linear utility. We have re-estimated parameter σ in ACM using their data but under logarithmic utility, and the values are largely unaffected. Therefore, we chose to use their baseline estimates. Still, we conduct robustness checks on our results to alternative values of this parameter.

3.3 Identifying the Trade Shocks

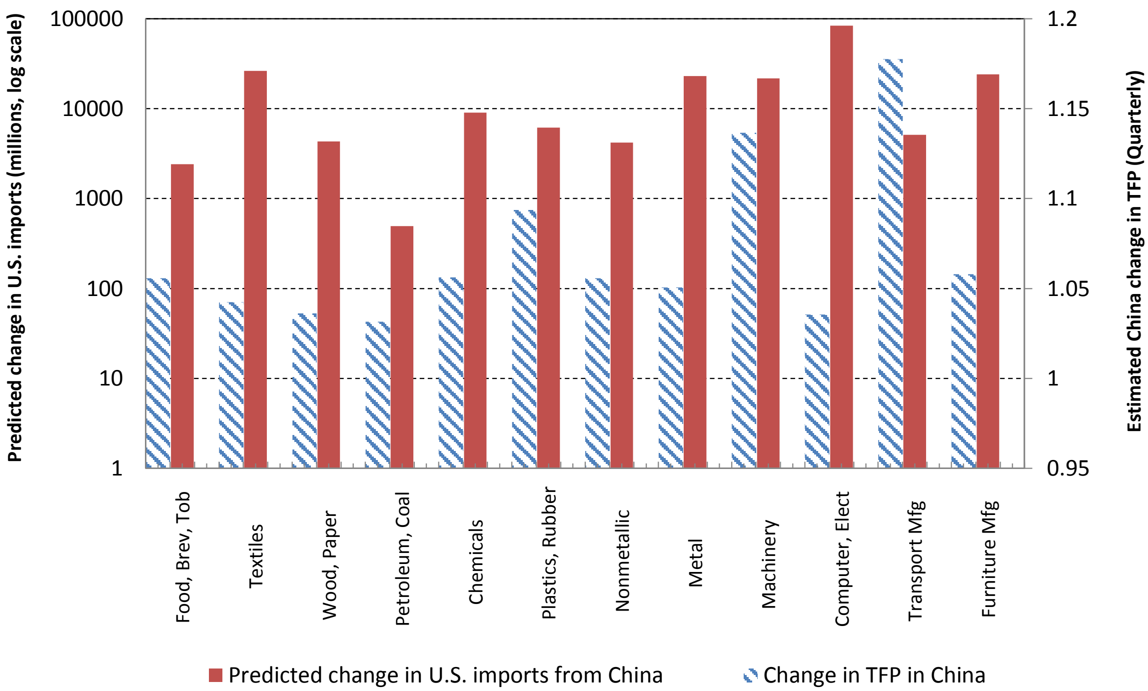
In previous work, ADH and Acemoglu et al. (2014) argue that the increase in U.S. imports from China had asymmetric impacts across regions and sectors. In particular, labor markets with greater exposure to the increase in import competition from China saw a larger decrease in manufacturing

[29] Since our period is a quarter, our rates are not directly comparable with the yearly mobility rates for state and industry switches in these works. Moreover, our sample selects workers from ages 25 to 65, who tend to have lower mobility rates than younger workers.

employment.

We calibrate a series of TFP changes to our 12 manufacturing sectors of the Chinese economy $\left\{\hat{A}^{China,j}\right\}_{j=1}^{12}$ to match exactly, within our model, the change in U.S. manufacturing imports from China from 2000 to 2007. Since not all of the observed changes in U.S. imports from China are necessarily the result of a change in Chinese TFP, we replicate the procedure of ADH and compute the predicted changes in U.S. imports from China using the change in imports of other advanced economies from China as an instrument. In other words, this is similar to the first-stage regression of the two-stage least squares estimation in ADH.

FIG. 1. Predicted change (2000-2007) change in imports vs. model-based Chinese TFP change



Concretely, we estimate the following regression

$$\Delta M_{USA,j} = a_1 + a_2 \Delta M_{other,j} + u_j,$$

where j is one of our manufacturing sectors. $\Delta M_{USA,j}$ and $\Delta M_{other,j}$ are the changes in U.S. imports from China and imports of other advanced economies from China between 2000 and 2007.[30] We then use the predicted changes in U.S. imports according to this regression to calibrate the size of

[30] In particular, the coutries are Australia, Denmark, Finland, Germany, Japan, New Zealand, Spain, and Switzerland.

the TFP changes for each of the manufacturing sectors in China that will deliver the same change in imports in the model as in the data. As the changes in imports of other advanced economies from China are an extremely good predictor of the change in U.S. imports from China, the results of the exercise presented here remain largely unaltered if instead we use the actual change in U.S. imports from China rather than the predicted change. Finally, since the change in U.S. imports from China is quite evenly distributed over this period, we smoothed the estimated TFP over 2000-2007 across all quarters.

Figure 1 shows the predicted change in U.S. manufacturing imports from China computed as in ADH and the implied sectoral productivity changes in China. Computer and electronics is the sector most exposed to import competition from China, accounting for about 40% of the predicted total change in U.S. imports from China, followed by the textiles and furniture industries with about 12% each, and metal and machinery with 10% of the total import penetration growth each. On the other hand, the food, beverage and tobacco, and the petroleum industries are the ones least exposed, accounting for less than 1.5% of the predicted total change in U.S. imports from China.

Our model estimates that TFP increased in all manufacturing industries in China. While our estimated changes in Chinese TFP are correlated with the changes in U.S. imports from China by sector, this correlation is not perfect.

4. THE EFFECTS OF INCREASED IMPORT COMPETITION FROM CHINA

In this section, we quantify the dynamic effects of China's import penetration growth on the U.S. economy. We first compute the dynamic model, holding productivities in China constant. After doing so, we input the estimated quarterly change in productivities across the Chinese manufacturing sectors over the period 2000-2007; then compute the changes in equilibrium allocations due to the China shock. We first discuss the effects on aggregate, sectoral, and regional employment and then analyze the effects on welfare.

Employment Effects

Starting with sectoral employment, the upper-left panel in Figure 2 presents the dynamic response of the manufacturing share of employment with and without the China shock. As the figure shows, there are transitional dynamics toward a steady state equilibrium even in the absence of any change in Chinese productivity. These dynamics occur since the economy is not in a steady state in the year

2000. In other words, the observed employment in manufacturing in 2000 is the equilibrium result of a series of shocks and structural changes that hit the economy before that year, and the economy is transitioning to a new steady state as a result. For instance, U.S. manufacturing employment has experienced a secular decline over the past several decades, and in 2000 the economy was still adjusting to this structural change. Thus we observe a decline in manufacturing employment even in the absence of productivity changes in China.[31] The implication of this observation is that calibrating the model by assuming that the economy is in steady state would overestimate the impact of the increased import competition from China since part of the observed decline in manufacturing employment is not related to Chinese competition.

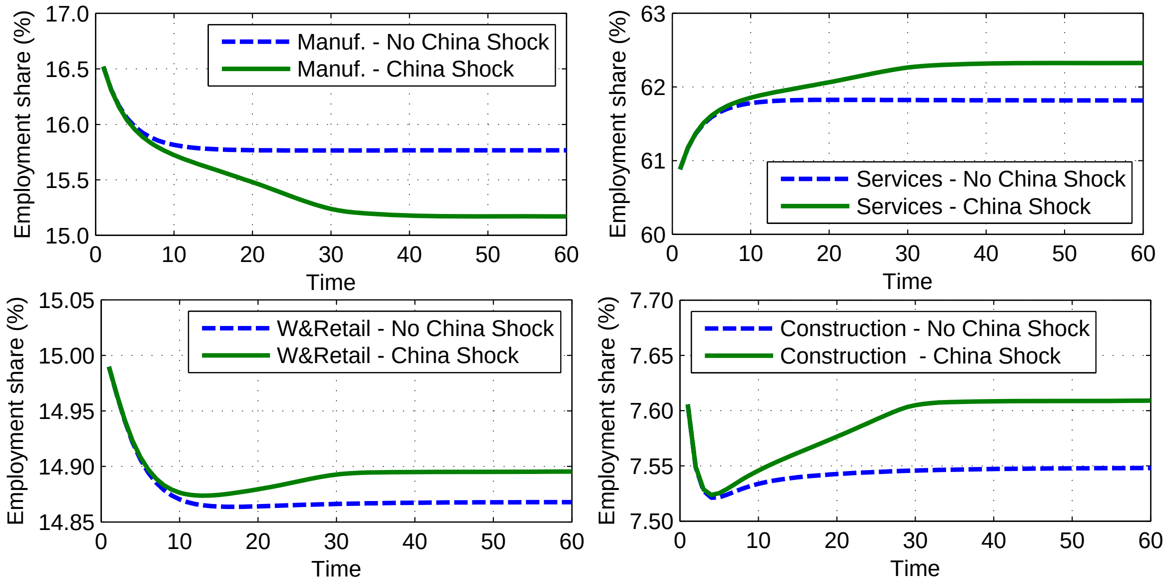
Therefore, the upper-left panel in Figure 2 shows the transitional dynamics of manufacturing employment with and without the China shock. The difference between the two is our account of the effect of China's import penetration growth on U.S. manufacturing employment. The figure shows that import competition from China contributed to a substantial decline in the share of manufacturing employment, a result that is in line with ADH. Our results indicate that increased competition from China reduced the share of manufacturing employment by 0.6 percentage point after 10 years, which is equivalent to about 1 million jobs, or about 60% of the change in manufacturing employment that is not explained by a secular trend.[32]

As shown in the other three panels of Figure 2, increased import competition from China makes workers reallocate to other sectors; thus, the share of employment in services, wholesale and retail, and construction increases. Moreover, as Figure 3 shows, Chinese competition reduced the U.S. unemployment rate slightly. The role of intermediate inputs and sectoral linkages is crucial to understanding these reallocation effects. Import competition from China leads to decreased production among U.S. manufacturing sectors that compete with China, but it also affords the U.S. economy access to cheaper intermediate goods from China that are used as inputs in the non-manufacturing sectors. Therefore, production and employment increase in the non-manufacturing sectors as a result. Moreover, the increase in employment in these sectors slightly more than offsets the decline in manufacturing employment so that the unemployment rate declines. Finally, the

[31] If we were to include long-run trends or structural changes in our model, our economy could fully account for the continuous fall in manufacturing employment.

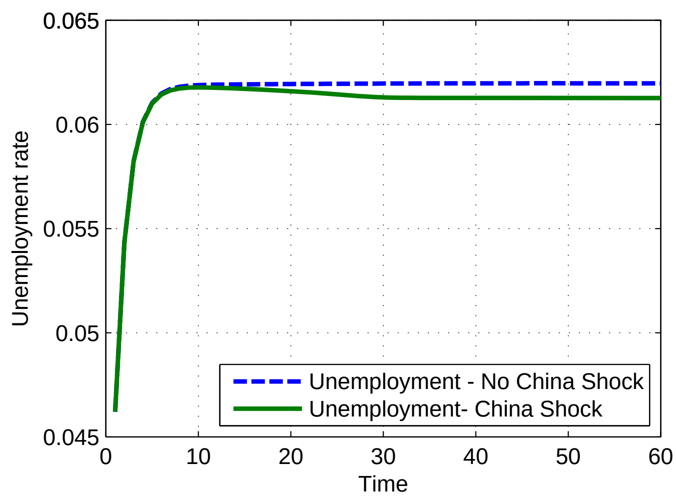
[32] The difference between the observed share of manufacturing employment in the U.S. economy in 2007 and its predicted value using a simple linear trend on this share between 1965 and 2000 is 1%. In other words, the change in the U.S. manufacturing share that is unexplained by a linear trend is 1%. To compute the implied levels of manufacturing employment loss in 2007, we take data on total employment from the Bureau of Economic Analysis for the year 2007 (Table SA25N: Total Full-Time and Part-Time Employment by NAICS Industries) and in order to match the sectors in our model we substract employment in farming, mining, utilities and the public sector. That yields a level of employment of 151.4 million. We multiply by our model's implied change in manufacturing employment share and get 0.91 million jobs.

Fig. 2. The Evolution of Employment Shares



employment in construction overshoots a bit in the short run, which is explained, as mentioned earlier, by the fact that the economy was transitioning to a steady state when the change in Chinese productivity hit the U.S. economy. As a result, in the initial year the relative benefits of working in the construction sector are too low and people move more quickly to other sectors than in the long run.

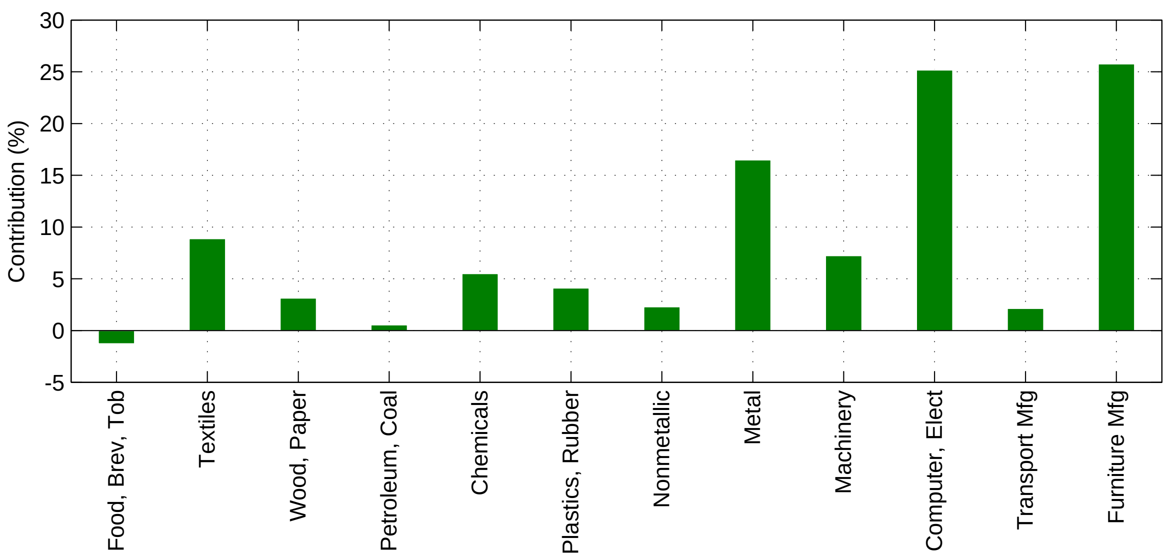
Fig. 3. The Evolution of the Unemployment Rate



Our quantitative framework also allows us to further explore the decline in manufacturing employment caused by the China shock by explaining the sources of this decline. To do so, we quantify the relative contribution of different sectors, regions, and local labor markets to the decline in the manufacturing share of employment.

Figure 4 shows the contribution of each manufacturing sector to the total decline in manufacturing employment. The figure shows that employment in some industries was affected more than in others. Specifically, sectors with higher exposure to import competition from China lost more manufacturing employment. The computer and electronics, and furniture industries contributed to about half of the decline in manufacturing employment, followed by the metal and textiles industries, which together contributed to about one-fourth of the total decline. Sectors less exposed to import competition from China explain a smaller portion of the decline in manufacturing employment. In fact, these sectors also benefit from the access to cheaper intermediate goods from sectors that experienced a substantial productivity increase in China. In some cases, such as food beverage and tobacco, the increased production from the access to cheaper intermediate goods more than offsets the negative effects from increased import competition, and employment increased as a result.

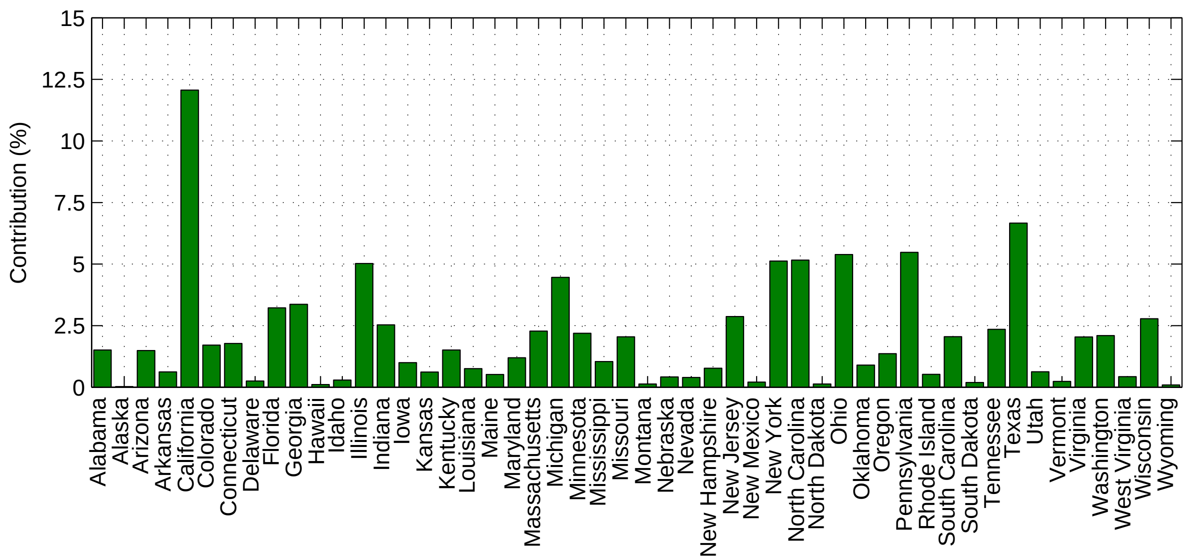
FIG. 4. Sectoral contribution to the change in manuf. employment due to China shock



The fact that U.S. economic activity is not equally distributed across space combined with the differential sectoral exposure to China, also imply that the impact of import competition from China on manufacturing employment varies across regions.

Figure 5 presents the regional contribution to the total decline in manufacturing employment. States with a comparative advantage in sectors more exposed to import competition from China lose more employment in manufacturing. For instance, California alone accounted for 20%, or essentially one-fifth of all employment in the computer and electronics industry in the year 2000. For comparison, the state with the next-largest share of employment in this sector is Texas with 8%, while all other states had shares of employment in computer and electronics of less than 2%. As a result, California is the state that contributed the most to the decline in manufacturing employment (about 12%) followed by Texas. States with a comparative advantage in goods less affected by import competition from China and that benefited from the access to cheaper intermediate goods had a smaller impact on employment.

Fig. 5. Regional contribution to the change in manuf. employment due to China shock



The contribution of each labor market to the total decline in manufacturing employment varies considerably across regions and sectors. We find that most manufacturing labor markets lost jobs, although employment increased in some of them. Computer and electronics in California was the labor market that contributed the most to the decline in manufacturing employment, accounting for 4.6% of the total decline. Employment increased in labor markets such as food, beverage, and tobacco in Wisconsin, California, and Arkansas; and transportation equipment in New Hampshire, among others. Notice that even when California experienced a decline in manufacturing employment due to import competition from China, some labor markets in California such as food, beverage and tobacco gained in employment, highlighting the importance of taking into account the spatial and sectoral distribution of economic activity.[33]

[33] ADH show evidence that higher exposure to Chinese imports in a labor market causes a larger increase in unemployment in that market. In our model, unemployment falls due to the China shock, but we constructed a

Welfare effects

We now turn to the aggregate and disaggregate welfare effects of increased import competition from China on the U.S. economy. Similar to the quantification of employment effects, we compute the change in welfare with and without the China shock. For each welfare computation we normalize the lifetime utility in the fourth quarter of 2000 to one.[34] We present two set of results, one denoted "short-run welfare effects" and the other "long-run welfare effects." The short-run welfare effect refers to the percent change in lifetime utility of a representative worker in each labor market in the first period after the shock starts hitting the economy. Given that agents are forward looking in our economy, in the short run, their decisions interiorize the future path of Chinese productivity changes. Therefore, the short-run welfare effects are economically meaningful. The long-run welfare effect refers to the percent change in lifetime utility once the economy has reached the new stationary equilibrium.[35]

We first estimate the aggregate welfare effect on the U.S. economy. Our results indicate that China's import penetration growth increases U.S. welfare by 6.7% in the long run and by 0.2% in the short run.[36] Even when increased import competition from China reduces employment in the manufacturing sector, the U.S. economy is better off due to the access to cheaper intermediate goods used as inputs across sectors. Moreover, the welfare effect is larger in the long run than in the short run as workers reallocate from industries and regions that are more depressed due to the increased competition with China.

We also use our quantitative framework to compute the winners and losers across regions, sectors, and local labor markets. We use a utilitarian approach to aggregate utility across heterogeneous workers. Figure 6 presents the percentage change in welfare across sectors in the long run and short run. The bigger winners from the increased competition from China are the non-manufacturing sectors. These sectors are not directly exposed to competition from China and at the same time

measure of import changes per worker in a each U.S. state over the period 2000-2007 and find that states with a lower import penetration experience a larger fall in unemployment. Similarly, in states with higher import penetration unemployment does not fall as much. Therefore, our model also accounts for the positive relation between import penetration and unemployment in a labor market.

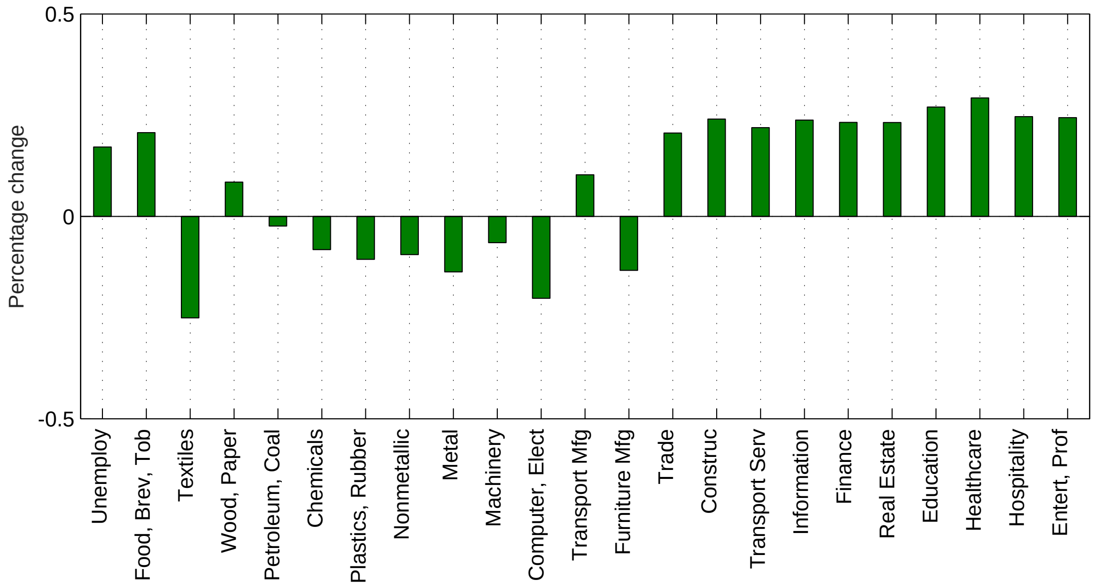
[34] For instance, when we calculate sectoral welfare effects, we set $\sum_{n=1}^{N} L_0^{n,j} V_0^{n,j} = 1$, and when we compute regional welfare effects, we set $\sum_{j=0}^{J} L_0^{n,j} V_0^{n,j} = 1$.

[35] We calculate the welfare effect of the China shock in a given market n, j as $V_t^{n,j(\text{china shock})} - V_t^{n,j(no\text{ china shock})}$, where $t = 1$ for the short run and $t = 200$ for the long run calculations. To compute regional welfare effects and sectoral welfare effects we aggregate markets using the initial allocation of labor, $L_0^{n,j}$.

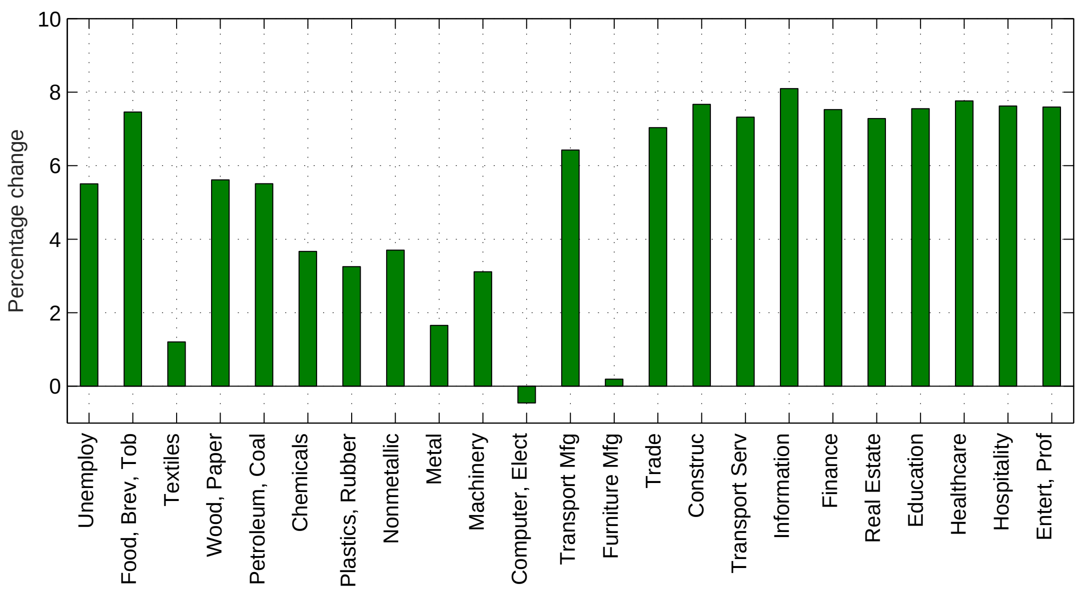
[36] According to equation (2) welfare of the average worker in a given labor market has two components; the first one is the real wage earned in that labor market, and the second one is the option value of staying in that market or moving to a different labor market. In static trade models, there is not such option value, thus the real wages perceived in a region or country is a sufficient statistic to compute welfare.

Fig. 6. Welfare effects across sectors

a: Short-run effects



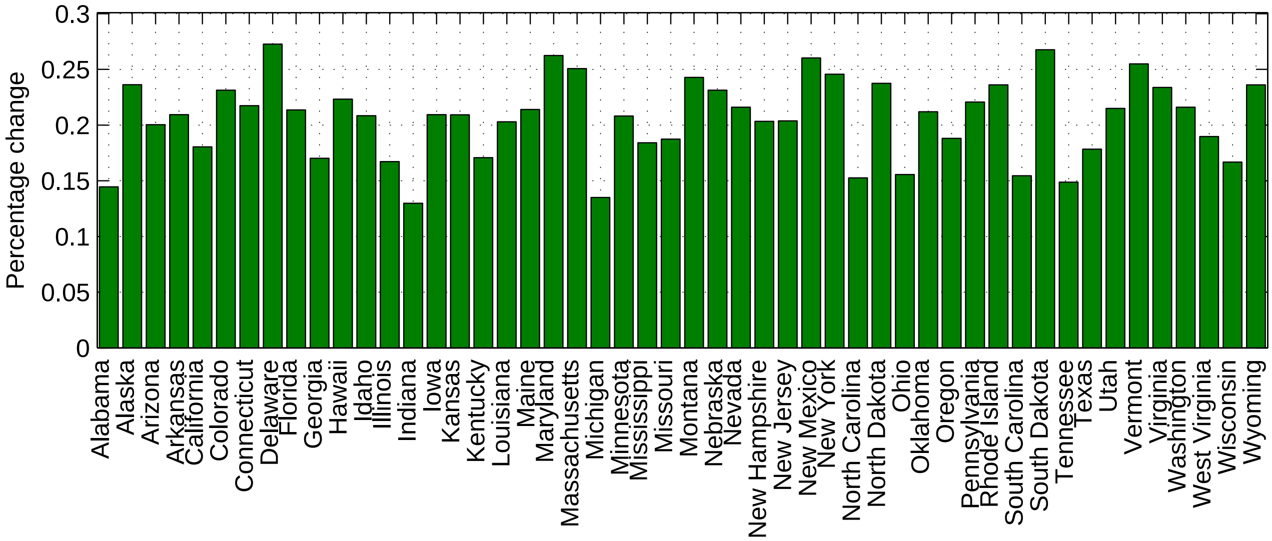
b: Long-run effects



benefit from access to cheaper intermediate manufacturing inputs from China used in the production of non-manufacturing goods. In addition, welfare gains are more uniform in the long run than in the short run as workers reallocate from the depressed industries.

FIG. 7. Welfare effects across regions

a: Short-run effects



b: Long-run effects

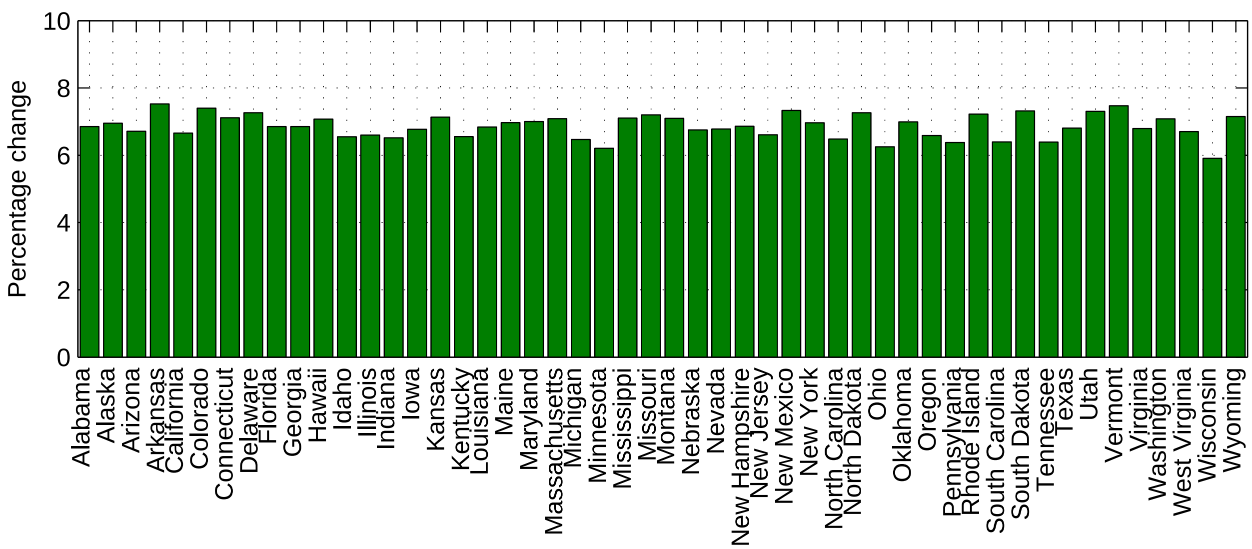
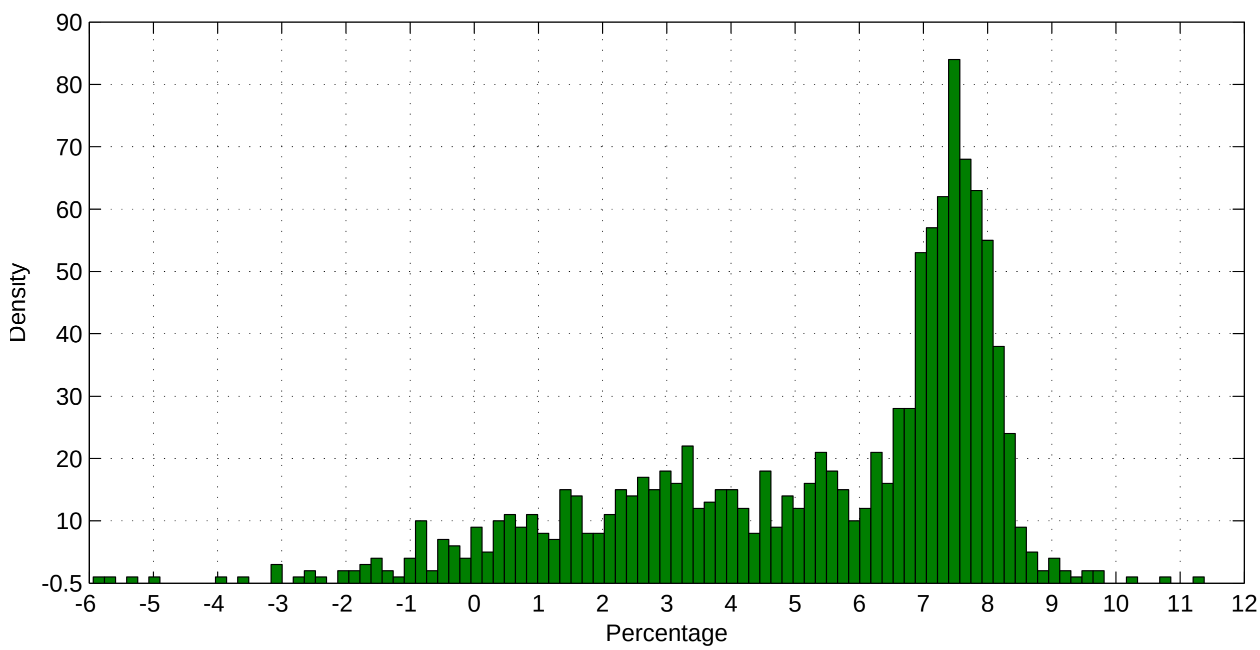


Figure 7 shows the welfare effects across regions in the long run and short run. All U.S. states are better off both in the short run and the long run. Regions benefit from the access to cheaper intermediate goods from China. In addition, since regions can produce with cheaper intermediate inputs, they can also trade cheaper goods with other U.S. states. Therefore, regions with a comparative advantage in sectors less exposed to import competition from China, regions that purchase materials from sectors where productivity in China increased more, and regions that trade more with the rest of the U.S. economy benefit more from the increased productivity in China. As an example, California, the state most exposed to competition from China, still gains more relative to other states since it trades more with the rest of the U.S. economy. The regional distribution of welfare is also more uniform in the long run than in the short run as workers reallocate from regions with lower real income. Across individual labor markets (Figure 8), some labor markets are worse off with the increased competition from China —for example, wood and paper in Nevada, transportation equipment in Louisiana, and wholesale and retail trade in Alaska, among others.

An important takeaway from Figure 8 is that there is a very heterogeneous response to the same aggregate shock across labor markets . The distribution of welfare gains (and losses) has a long left tail. We find that welfare loses are concentrated in a few labor markets, but most labor markets gain as a consequence of cheaper imports from China.

Fig. 8. Long run welfare changes across labor markets



5. CONCLUSION

In this paper, we build on Artuc, Chaudhuri, and McLaren (2010) and Eaton and Kortum (2002), to develop a dynamic and spatial labor search model. The model explicitly recognizes the role of labor mobility frictions, goods mobility frictions, geographic factors, input-output linkages, and international trade in determining allocations. We calibrate the model to 38 countries, 50 U.S. states and 22 sectors to quantify the impact of increased import competition from China over the period 2000-2007 on employment and welfare across spatially different labor markets. Our results indicate that although exposure to import competition from China reduces manufacturing employment, aggregate U.S. welfare increases. Disaggregate effects on employment and welfare across regions, sectors, and labor markets, and over time are shaped by all the mechanisms and ingredients mentioned previously.

We emphasize that our quantitative framework can be applied to an arbitrary number of sectors, regions, and countries and can be used to address a broader set of questions, generating a fruitful future research agenda. For instance, with our framework we can study the impact of changes in trade costs, or productivity, in any region in any country in the world. It can also be used to explore the effects of capital mobility across regions, to study the economic effects of different changes in government policies, such as changes in taxes, subsidies or unemployment benefits, or to study policies that reduce mobility frictions.[37] Other interesting topics to apply this framework are the quantification of the effects of trade agreements and other changes in trade policy on internal labor markets, and the impact of migration across countries. In addition, we can study the transmission of regional and sectoral shocks across a production network when trade and factor reallocation is subject to frictions.[38] The model can also be computed at a more disaggregated level to study migration across metropolitan areas, or commuting zones, although the challenge here is to collect the relevant trade and production data at these levels of disaggregation. Quantitative answers to some of these questions using dynamic models of the type developed here present, at least for us, an exciting avenue for future research.

[37] There is a rapid and growing interest to answer these type of questions; see for instance, Fajgelbaum, Morales, Suárez-Serrato, Zida (2015), Ossa (2015), and Tombe and Zhu (2015).

[38] We can therefore extend the analysis of Acemoglu et al. (2012) to a frictional economy. Moreover, we could incorporate local natural disaster shocks and quantify their effect, as recently analyzed in Carvalho et al. (2014).

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APPENDIX 1: DATA

List of Sectors and Countries We calibrate the model to the 50 U.S. states, 37 other countries including a constructed rest of world, and a total of 22 sectors classified according to the North American Industry Classification System (NAICS) for the year 2000. The list includes 12 manufacturing sectors, 8 service sectors, wholesale and retail trade, and the construction sector. Our selection of the number of sectors and countries was guided by the maximum level of disaggregation at which we were able to collect the production and trade data needed to compute our model. The twelve manufacturing sectors are Food, Beverage, and Tobacco Product (NAICS 311–312); Textile, Textile Product Mills, Apparel, Leather, and Allied Product (NAICS 313–316); Wood Product, Paper, Printing, and Related Support Activities (NAICS 321–323); Petroleum and Coal Products (NAICS 324); Chemical (NAICS 325); Plastics and Rubber Products (NAICS 326); Nonmetallic Mineral Product (NAICS 327); Primary Metal and Fabricated Metal Product (NAICS 331–332); Machinery (NAICS 333); Computer and Electronic Product, and Electrical Equipment and Appliance (NAICS 334–335); Transportation Equipment (NAICS 336); Furniture and Related Product, and Miscellaneous Manufacturing (NAICS 337– 339). The eight service sectors are: Transport Services (NAICS 481-488); Information Services (NAICS 511–518); Finance and Insurance (NAICS 521–525); Real Estate (NAICS 531-533); Education (NAICS 61); Health Care (NAICS 621–624); Accommodation and Food Services (NAICS 721–722); Other Services (NAICS 493, 541, 55, 561, 562, 711–713, 811-814). We also include the Wholesale and Retail Trade sector (NAICS 42-45), and the Construction sector, as mentioned earlier.

The countries in addition to the United States are: Australia, Austria, Belgium, Bulgaria, Brazil, Canada, China, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, India, Indonesia, Italy, Ireland, Japan, Lithuania, Mexico, the Netherlands, Poland, Portugal, Romania, Russia, Spain, Slovak Republic, Slovenia, South Korea, Sweden, Taiwan, Turkey, the United Kingdom, and the rest of the world.

International Trade, Production, and Input Shares across Countries International trade flows across sectors and the 38 countries including the United States for the year 2000 are obtained from the World Input-Output Database (WIOD). The WIOD provides world input-output tables from 1995 onward. National input-output tables of 40 major countries in the world and a constructed rest of the world are linked through international trade statistics for 35 sectors. For three countries in the database, Luxembourg, Malta, and Latvia, value added and/or gross output data were missing for some sectors; thus, we decided to aggregate these three countries with the constructed rest of the world, which gives us the 38 countries (37 countries and the United States) we used in the paper. From the world input-output table, we know total purchases made by a given country from any other country, including domestic sales, which gives us the bilateral trade flows. In a few cases (12 of 30,118 observations) the bilateral trade flows have small negative values due to negative change in inventories. Most of these observations involve bilateral trade flows between the constructed rest of the world and some other countries, and in two cases, bilateral trade flows of Indonesia. We input zero trade flows when we observe these small negative bilateral trade flows that in any way represent a negligible portion of total trade.

From the world input-output table we are also able to collect sectoral value added and gross output data, as well as the share of value added in gross output and construct the input-output coefficients for all sectors and countries.

The sectors, indexed by ci for sector i in the WIOD database, were mapped into our 22 sectors as follows: Food Product, Beverage, and Tobacco Product (c3); Textile, Textile Product Mills, Apparel, Leather, and Allied Product (c4–c5); Wood Product, Paper, Printing, and Related Support Activities (c6–c7); Petroleum and Coal Products (c8); Chemical (c9); Plastics and Rubber Products (c10); Nonmetallic Mineral Product (c11); Primary Metal and Fabricated Metal Product (c12); Machinery (c13); Computer and Electronic Product, and Electrical Equipment and Appliance (c14); Transportation Equipment (c15); Furniture and Related Product, and Miscellaneous Manufacturing (c16); Construction (c18); Wholesale and Retail Trade (c19–c21); Transport Services (c23–c26); Information Services (c27); Finance and Insurance (c28); Real Estate (c29–c30); Education (c32); Health Care (c33); Accommodation and Food Services (c22); Other Services (c34).

Regional trade, production data, and input shares

Interregional Trade Flows The sectoral bilateral trade flows across the 50 U.S. states were constructed by combining information from the WIOD database and the 2002 Commodity Flow Survey (CFS). From the WIOD database we compute the total U.S. domestic sales for the year 2000 for our 22 sectors. We use information from the CFS for the year 2002, which is the closest available year to 2000, to compute the bilateral expenditure shares across U.S. states, as well as the share of each state in sectoral total expenditure. The CFS survey for the year 2002 tracks pairwise trade flows across all 50 U.S. states for 43 commodities classified according to the Standard Classification of Transported Goods (SCTG). These commodities were mapped into our 22 NAICS sectors by using the CFS tables for the year 2007, which present such mapping. The 2007 CFS includes data tables that cross-tabulate establishments by their assigned NAICS code against commodities (SCTG) shipped by establishments within each of the NAICS codes. These tables allow for mapping of NAICS to SCTG and vice versa. Having constructed the bilateral trade flows for the NAICS sectors, we first compute how much of the total U.S. domestic sales in each sector is spent by each state. To do so, we multiply the total U.S. domestic sales in each sector by the expenditure share of each state in each sector. Then we compute how much of this sectoral expenditure by each state is spent on goods from each of the 50 U.S. states. We do so by applying the bilateral trade shares computed with the 2002 CFS to the regional total spending in each sector. The final product is a bilateral trade flows matrix for the 50 U.S. states across sectors, where the bilateral trade shares are the same as those in the 2002 CFS, and the total U.S. domestic sales perfectly match those from the WIOD for the year 2000.

Regional production data and input shares We also need to compute value added, gross outputs, the share of value added in gross output, and the material shares for each states and sector in the United States for the year 2000. Value added for each of the 50 U.S. states and 22 sectors is obtained from the Bureau of Economic Analysis (BEA) by subtracting taxes and subsidies from GDP data. Gross outputs for the U.S. states in the 12 manufacturing sectors are computed from our constructed bilateral trade flows matrix as the sum of domestic sales and total exports. In a few cases (34 observations), gross output was determined to be a bit smaller than value added (probably due to some small discrepancies between trade and production data —for instance, a few missing trade shipments in the CFS database), in these cases we constrain value added to be equal to gross output. With the value-added data and gross output data for all U.S. states and sectors, we compute the share of value added in gross output. For the eight service sectors, the wholesale and retail trade sector, and the construction sector, we have only the aggregate U.S. gross output computed from the WIOD database. To split these gross output data into the 50 U.S. states, we proceed as follows. We assume that the share of value added in gross output is constant across states and equal to the national share of value added in gross output. We then divide value added for each state in these sectors by the value-added shares computed at the national level using data from the BEA, as a result we obtain the regional gross output. Then we calculate the regional share of gross output in each of these 10 sectors, and applied this share to the gross output data from WIOD. The result is the gross output for each of the 50 U.S. states in the service sectors, wholesale and retail trade, and construction, that is consistent with the gross output data from the WIOD.

While material input shares are available by sector at the country level, they are not disaggregated by state in the WIOD database. We assume therefore that the share of material in total intermediate consumption varies across sectors but not across regions. Notice, however, that the material-input shares in gross output are still sector and region specific as the share of total material expenditure in gross output varies by sector and region.

Trade between U.S. states and the rest of the world. From the WIOD database we compute the sectoral bilateral trade flows between the United States and the rest of the countries in our sample. We also need to compute, within the United States, the bilateral trade flows between each state and the rest of the countries. In our paper, local labor markets have different exposure to international trade shocks because there is substantial geographic variation in industry specialization. Local labor markets that are more important in the production in a given industry should react more to international trade shocks in that industry. Therefore, our measure for the exposure of local labor markets to international trade combines trade data with local industry employment. Specifically, the share of each state in total U.S. trade with any country in the world in each sector is determined by the regional share of total employment in that industry. The employment shares used to compute the bilateral trade shares between the U.S. states and the rest of the countries are constructed using employment data across sectors and states from the BEA. In 22 cases, data are missing, and in these cases we search for employment data in the closest available year. Still, in three cases, Alaska in the plastics and rubber industry, and North Dakota and Vermont in the petroleum and coal industry, we could not find employment data; thus, we input zero employment. The 19 cases in which we find employment data in years different from 2000 represent in total less than 0.01% of U.S. employment in 2000.

Share of final goods expenditure The share of income spent on goods from different sectors is calculated as follows,

$$\alpha^j = \frac{\sum_{n=1}^{N} \sum_{k=1}^{J} \gamma^{n,kj} \sum_{n=1}^{N} \sum_{i=1}^{N} \pi^{in,k} X^{i,k}}{\sum_{n=1}^{N} w^{n,k} L^{n,k} + \iota^n \chi},$$

where $\sum_{n=1}^{N} \sum_{k=1}^{J} \gamma^{n,kj} \sum_{n=1}^{N} \sum_{i=1}^{N} \pi^{in,k} X^{i,k}$ denotes total spending in intermediate goods across all countries and regions, and $\sum_{n=1}^{N} w^{n,k} L^{n,k} + \iota^n \chi$ is the total world income.

Share of labor compensation in value added Disaggregated data on labor compensation are generally very incomplete. Therefore, we compute the share of labor compensation in value added at the national level and assume that it is constant across sectors. For the United States, data on labor compensation and value added for each state for the year 2000 are obtained from the BEA. For the rest of the countries, data are obtained from the OECD input-output table for 2000 or the closest year. For India, Cyprus, and the constructed rest of the world, labor compensation data were not available. In these cases we input the median share across all countries from the other 34 countries that are part of the rest of the world.

Further details on the calculation of the labor transition matrix Table 2 summarizes the information used to construct a quarterly transition matrix across state, industry, and unemployment. The letter x in the table denotes information available in the matched CPS, and the letter y denotes information available in the ACS.

Table 2. Information available on ACS and CPS

		State A				**State B**			
		Ind 1	Ind 2	...	Ind J	Ind 1	Ind 2	...	Ind J
State A	Ind 1	x	x	...	x				
	Ind 2	x	x	...	x				
	...	...	...	...	...				
	Ind J	x	x		x				
	Total	**y**	**y**	**...**	**y**	**y**	**y**	**...**	**y**
State B	Ind 1					x	x	...	x
	Ind 2					x	x	...	x
	...					...	...	...	...
	Ind J					x	x		x
	Total	**y**	**y**	**...**	**y**	**y**	**y**	**...**	**y**

As mentioned earlier, information on interstate mobility in the ACS is for moves over the year. To calculate quarterly mobility we assume that interstate moves are evenly distributed over the year and we rule out more that one interstate move per year. In this case, our adjustment consists of keeping only one-fourth of these interstate moves and imputing three-fourths as non-moves. After this correction, we impute the past industry history for people with interstate moves from state i to state n and industry j according to the intrastate sectoral transition matrix for state n conditional on industry j.

Our computed value for the initial labor transition matrix is consistent with aggregate magnitudes of interstate and industry mobility for the yearly frequency estimated in Molloy et al. (2011) and Kamborouv and Manovskii (2008).

APPENDIX 2: PROOFS

Proposition 1 *Consider the temporary equilibrium at state s and a temporary equilibrium at state s'. Denote the change in the temporary equilibrium from one state to the other by $\hat{\omega}(\hat{s},\Theta)$, where $\hat{s} = s'/s$. The solution to the change in the temporary equilibrium from state s to s' is independent of Θ. Namely, $\hat{\omega}(\hat{s},\Theta) = \hat{\omega}(\hat{s})$.*

Proof Suppose the economy is at a temporary equilibrium at s_t. Define the operator $\hat{y}$ over a variable y_t as $\hat{y}_{t+1} = \frac{y_{t+1}}{y_t}$. Applying the operator over the equilibrium conditions that define a temporary equilibrium, equations (5) to (10) result in the following set of equilibrium conditions:

$$\hat{x}^{n,j}_{t+1} = [(\hat{w}^{n,j}_{t+1})^{(1-\beta^n)} (\hat{r}^{n,j}_{t+1})^{\beta^n}]^{\gamma^{n,j}} \prod_{k=1}^{J} [\hat{P}^{n,k}_{t+1}]^{\gamma^{n,jk}}, \tag{13}$$

$$\hat{P}^{n,j}_{t+1} = \left[\sum_{i=1}^{N} \pi^{ni,j}_t \left(\hat{x}^{i,j}_{t+1}\right)^{-\theta^j}\right]^{-1/\theta^j}, \tag{14}$$

$$\pi_{t+1}^{ni,j} = \pi_t^{ni,j} \left(\frac{\hat{x}_{t+1}^{i,j}}{\hat{P}_{t+1}^{n,j}} \right)^{-\theta^j}, \tag{15}$$

$$X_{t+1}^{n,j} = \sum_{k=1}^{J} \gamma^{n,kj} \sum_{i=1}^{N} \pi_{t+1}^{in,k} X_{t+1}^{i,k} + \alpha^j \left[\sum_{k=1}^{J} \hat{w}_{t+1}^{n,j} \hat{L}_{t+1}^{n,k} w_t^{n,k} L_t^{n,k} + \iota^n \chi_{t+1} \right], \tag{16}$$

where $\chi_{t+1} = \sum_i^N \sum_k^J \hat{r}_t^{i,k} r_t^{i,k} H^{i,k}$. By inspecting equations (13) to (16), we can see that one can solve for $\hat{w}_{t+1}^{n,j}$, and $\hat{P}_{t+1}^{n,j}$, given a change in $\hat{L}_{t+1}^{n,k}$, without knowing Θ. Finally, if we denote the change in the temporary equilibrium from one state s_t to s_{t+1} by $\hat{\omega}(\hat{s}, \Theta)$, then the solution to the change in the temporary equilibrium is given by $\hat{\omega}(\hat{s})$.

Proposition 2 *Conditional on* (s_0, μ_{-1}) *and given* $\hat{\Upsilon} = \{\hat{\Upsilon}_t\}_{t=1}^{\infty}$, *the solution to the sequential equilibrium in relative time differences does not require* Θ, *and solves the following system of equations,*

$$\mu_{t+1}^{n,j;i,k} = \frac{\mu_t^{n,j;i,k} \left[Y_{t+2}^{i,k} \right]^{\rho}}{\sum_{m=1}^{N} \sum_{h=0}^{J} \mu_t^{n,j;m,h} \left[Y_{t+2}^{m,h} \right]^{\rho}}, \tag{17}$$

$$Y_{t+1}^{n,j} = \sum_{i=1}^{N} \sum_{k=0}^{J} \lambda_{t+1}^{n,j;i,k} \left[Y_{t+2}^{i,k} \right]^{\rho}, \tag{18}$$

$$\lambda_{t+1}^{n,j;i,k} = \left(\frac{\hat{w}_{t+1}^{n,j} \left(\hat{s}_{t+1}, \hat{\Upsilon}_{t+1} \right)}{\hat{P}_{t+1}^{n} \left(\hat{s}_{t+1}, \hat{\Upsilon}_{t+1} \right)} \right)^{1/\sigma} \mu_t^{n,j;i,k}, \tag{19}$$

where $Y_{t+1}^{i,k} \equiv \exp\left(V_{t+1}^{i,k} - V_t^{i,k} \right)^{1/\sigma}$, *and* $\hat{w}_{t+1}^{n,j}\left(\hat{s}_{t+1}, \hat{\Upsilon}_{t+1} \right)$ *and* $\hat{P}_{t+1}^{n}\left(\hat{s}_{t+1}, \hat{\Upsilon}_{t+1} \right)$, *is the solution to the temporary equilibrium given state* $\hat{s}_{t+1}$ *and policy* $\hat{\Upsilon}_{t+1}$. *The state of the economy evolves according to* (4).

Proof Define $Y_{t+1}^{i,k} \equiv \exp\left(V_{t+1}^{i,k} - V_t^{i,k} \right)^{1/\sigma}$. Now consider the fraction of workers who reallocate from market n, j to i, k, at $t+1$, equilibrium condition (3) at $t+1$,

$$\mu_t^{n,j;i,k} = \frac{\exp\left(\rho V_{t+1}^{i,k} - \tau^{n,j;i,k} \right)^{1/\sigma}}{\sum_{m=1}^{N} \sum_{h=0}^{J} \exp\left(\rho V_{t+1}^{m,h} - \tau^{n,j;m,h} \right)^{1/\sigma}}.$$

Taking the relative time differences of this equation, we get

$$\frac{\mu_{t+1}^{n,j;i,k}}{\mu_t^{n,j;i,k}} = \frac{\frac{\exp\left(\rho V_{t+2}^{i,k} - \tau^{n,j;i,k} \right)^{1/\sigma}}{\sum_{m=1}^{N} \sum_{h=0}^{J} \exp\left(\rho V_{t+2}^{m,h} - \tau^{n,j;m,h} \right)^{1/\sigma}}}{\frac{\exp\left(\rho V_{t+1}^{i,k} - \tau^{n,j;i,k} \right)^{1/\sigma}}{\sum_{m=1}^{N} \sum_{h=0}^{J} \exp\left(\rho V_{t+1}^{m,h} - \tau^{n,j;m,h} \right)^{1/\sigma}}}.$$

Using the fact that mobility costs do not change over time, this expression can be expressed as

$$\frac{\mu_{t+1}^{n,j;i,k}}{\mu_t^{n,j;i,k}} = \frac{\exp\left(\rho V_{t+2}^{i,k} - \rho V_{t+1}^{i,k} \right)^{1/\sigma}}{\frac{\sum_{m=1}^{N} \sum_{h=0}^{J} \exp\left(\rho V_{t+2}^{m,h} - \tau^{n,j;m,h} \right)^{1/\sigma} \frac{\exp\left(\rho V_{t+1}^{m,h} - \tau^{n,j;m,h} \right)^{1/\sigma}}{\exp\left(\rho V_{t+1}^{m,h} - \tau^{n,j;m,h} \right)^{1/\sigma}}}{\sum_{m=1}^{N} \sum_{h=0}^{J} \exp\left(\rho V_{t+1}^{m,h} - \tau^{n,j;m,h} \right)^{1/\sigma}}},$$

which is equivalent to

$$\frac{\mu_{t+1}^{n,j;i,k}}{\mu_t^{n,j;i,k}} = \frac{\exp\left(V_{t+2}^{i,k} - V_{t+1}^{i,k}\right)^{\rho/\sigma}}{\sum_{m=1}^{N}\sum_{h=0}^{J}\mu_t^{n,j;m,h}\exp\left(V_{t+2}^{m,h} - V_{t+1}^{m,h}\right)^{\rho/\sigma}}.$$

Using the definition of $Y_{t+1}^{i,k}$ we get

$$\mu_{t+1}^{n,j;i,k} = \frac{\mu_t^{n,j;i,k}\left[Y_{t+2}^{i,k}\right]^{\rho}}{\sum_{m=1}^{N}\sum_{h=0}^{J}\mu_t^{n,j;m,h}\left[Y_{t+2}^{m,h}\right]^{\rho}}, \tag{20}$$

which is equilibrium condition (11) in the main text. Now take the equilibrium condition (2) in time differences at region n and sector j,

$$V_{t+1}^{n,j} - V_t^{n,j} = u(C_{t+1}^{n,j}) - u(C_t^{n,j}) + \sigma\log\left[\frac{\sum_{m=1}^{N}\sum_{h=0}^{J}\exp\left(\rho V_{t+2}^{m,h} - \tau^{n,j;m,h}\right)^{1/\sigma}}{\sum_{m=1}^{N}\sum_{h=0}^{J}\exp\left(\rho V_{t+1}^{m,h} - \tau^{n,j;m,h}\right)^{1/\sigma}}\right].$$

Multiplying and dividing each term in the numerator by $\exp\left(\rho V_{t+1}^{m,h} - \tau^{n,j;m,h}\right)^{1/\sigma}$, and using (3) and the fact that mobility costs do not change over time, we obtain

$$V_{t+1}^{n,j} - V_t^{n,j} = u(C_{t+1}^{n,j}) - u(C_t^{n,j}) + \sigma\log\left[\sum_{m=1}^{N}\sum_{h=0}^{J}\mu_t^{n,j;m,h}\exp\left(\rho V_{t+2}^{m,h} - \rho V_{t+1}^{m,h}\right)^{1/\sigma}\right].$$

Taking exponential from both sides and use the definition of $Y_{t+1}^{i,k}$ to obtain

$$Y_{t+1}^{n,j} = \sum_{i=1}^{N}\sum_{k=0}^{J}\lambda_{t+1}^{n,j;i,k}\left[Y_{t+2}^{i,k}\right]^{\rho}, \tag{21}$$

and $\lambda_{t+1}^{n,j;i,k}$ is given by

$$\lambda_{t+1}^{n,j;i,k} = e^{\frac{u(C_{t+1}^{n,j}) - u(C_t^{n,j})}{\sigma}}\mu_t^{n,j;i,k},$$

and given Assumption 1, we obtain

$$\lambda_{t+1}^{n,j;i,k} = \left(\frac{\hat{w}_{t+1}^{n,j}}{\hat{P}_{t+1}^{n}}\right)^{1/\sigma}\mu_t^{n,j;i,k}, \tag{22}$$

where $\hat{w}_{t+1}^{n,j}$ and $\hat{P}_{t+1}^{n}$ solve the temporary equilibrium. Note that by Proposition 1, the sequence of temporary equilibriums given $\hat{\top}$ does not depend on Θ. The equilibrium conditions (20), (21), and (22) do not depend on Θ either. Therefore, given a sequence $\hat{\top} = \{\hat{\top}_t\}_{t=1}^{\infty}$, the solution to the change in the sequential equilibrium of the model given $\hat{\top}$, $W_{\infty}(\hat{\top})$, does not require Θ.

APPENDIX 3 EQUILIBRIUM CONDITIONS IN RELATIVE CHANGES

In this appendix, we present the set of equilibrium conditions of our model in relative time differences. All the equations have already been introduced earlier, but to ease the exposition and facilitate the understanding of our model, we present then again here. We report the number of equations for that economic condition given the dimension of our model in parentheses.

Cost of the input bundle (NJ equations):

$$\hat{x}^{n,j}_{t+1} = \left((\hat{w}^{n,j}_{t+1})^{(1-\beta^n)}\,(\hat{r}^{n,j}_{t+1})^{\beta^n}\right)^{\gamma^{n,j}} \prod_{k=1}^{J} \left(\hat{P}^{n,k}_{t+1}\right)^{\gamma^{n,jk}}.$$

Price index (NJ equations):

$$\hat{P}^{n,j}_{t+1} = \left[\sum_{i=1}^{N} \pi^{ni,j}_{t} \left(\hat{x}^{i,j}_{t+1}\hat{\kappa}^{ni,j}_{t+1}\right)^{-\theta^j} \left(\hat{A}^{i,j}_{t+1}\right)^{\theta^j\gamma^{i,j}}\right]^{-1/\theta^j}.$$

Trade shares ($(N)^2J$ equations):

$$\pi^{ni,j}_{t+1} = \pi^{ni,j}_{t} \left(\frac{\hat{x}^{i,j}_{t+1}\hat{\kappa}^{ni,j}_{t+1}}{\hat{P}^{n,j}_{t+1}}\right)^{-\theta^j} \left(\hat{A}^{i,j}_{t+1}\right)^{\theta^j\gamma^{i,j}}$$

Market clearing in final goods (NJ equations):

$$X^{n,j}_{t+1} = \sum\nolimits_{k=1}^{J} \gamma^{n,kj} \sum\nolimits_{i=1}^{N} \pi^{in,k}_{t+1} X^{i,k}_{t+1} + \alpha^j \left[\sum\nolimits_{k=1}^{J} \hat{w}^{n,j}_{t+1}\hat{L}^{n,k}_{t+1} w^{n,k}_{t} L^{n,k}_{t} + \iota^n \chi_{t+1}\right],$$

Labor mobility shares ($N^2(J+1)^2$ equations):

$$\mu^{n,j;i,k}_{t+1} = \frac{\mu^{n,j;i,k}_{t}\left[Y^{i,k}_{t+2}\right]^{\rho}}{\sum_{m=1}^{N}\sum_{h=0}^{J}\mu^{n,j;m,h}_{t}\left[Y^{m,h}_{t+2}\right]^{\rho}},$$

Value function changes ($N(J+1)$ equations)[39]:

$$Y^{n,j}_{t+1} = \sum\nolimits_{i=1}^{N}\sum\nolimits_{k=0}^{J} \lambda^{n,j;i,k}_{t+1}\left[Y^{i,k}_{t+2}\right]^{\rho},$$

Labor reallocation dynamics ($N(J+1)$ equations):

$$L^{n,j}_{t+1} = \sum_{i=1}^{N}\sum_{k=0}^{J} \mu^{i,k;n,j}_{t} L^{i,k}_{t}$$

Finally, labor market clearing has to hold in equilibrium (NJ equations):

$$\hat{w}^{n,j}_{t+1}\hat{L}^{n,j}_{t+1} w^{n,j}_{t} L^{n,j}_{t} = \gamma^{n,j}(1-\beta_n)\sum_{i=1}^{N}\pi^{in,j}_{t+1}X^{i,j}_{t+1},$$

where $\chi_{t+1} = \sum_{i=1}^{N}\sum_{k=1}^{J}\hat{r}^{i,k}_{t} r^{i,k}_{t} H^{i,k}$. We also have that in equilibrium $\hat{w}^{n,j}_{t} = \hat{w}^{n}_{t} = \hat{r}^{n,j}_{t} = \hat{r}^{n}_{t}$ for all n such that $\tau^{n,j;n,k} = 0$. This condition means that if there is free mobility across sectors in a given region n, factor prices will equalize across sectors in that region. In the context of our model, this happens in all countries outside the United States.

We take as given $L^{n,j}_0$, $w^{n,j}_0$, $\mu^{nj,ik}_{-1}$, $\pi^{ni,j}_0$, $r^{n,j}_0$, χ_0, for all n, j, i, k. We need to find $\hat{w}^{n,j}_{t+1}$ $((NJ)\times t)$, where the term in parenthesis denotes the number of elements, $\hat{r}^{n,j}_{t+1}$ $((NJ)\times t)$, $\hat{P}^{n,j}_{t+1}$ $((NJ)\times t)$, $\pi^{ni,j}_{t+1}$ $((N^2J)\times t)$, $X^{n,j}_{t+1}$ $((NJ)\times t)$, $\mu^{n,j;i,k}_{t+1}$ $((N^2(J+1)^2)\times t)$, $Y^{n,j}_{t+1}$ $((N(J+1))\times t)$, and $L^{n,j}_{t+1}$ $((N(J+1))\times t)$ for all $t>0$.

[39] Note that, with an abuse of notation, for $j=0$, $\left(\hat{w}^{n,j}_{t+1}/\hat{P}^{n}_{t+1}\right) = 1$.