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Productivity differences and inter-state migration in the U.S.: A multilateral gravity approach

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ABSTRACT

In this paper, we study the quantitative role of productivity differences in explaining migration in presence of multiple destination choices. We construct a dynamic general equilibrium model with multi-region, multi-sector set-up where labor is a mobile input, which adjusts to regional and sectoral productivity shocks, resulting in migration across regions. The proposed model generates a migration network where the flow of migrants between any two regions follows a gravity equation. We calibrate the model to the U.S. data and we find that variation in industrial and regional total factor productivity shocks explains about 63% of the interstate migration in the U.S. Finally, we perform comparative statics to estimate the effects of long-run structural changes on migration. We find that capital intensity of the production process and the demand for services over manufactured goods negatively impact aggregate level of migration whereas asymmetries in trade patterns do not appear to have substantial effects.

1. Introduction

The gross flow of people across a pair of regions is typically seen to be proportional to the respective populations and inversely proportional to the geographic distance, an empirical regularity known as the gravity model of migration (Anderson, 2011). In this paper, we consider three questions based on this observation. First, what is the quantitative role of productivity differences across regions in explaining region to region yearly migration? Second, when people decide to migrate in presence of multiple destinations, why does a gravity equation hold across each pair of regions, i.e. can we explain the empirically found multi-lateral gravity equations via productivity differences across multiple regions? Finally, in the long run, what are the effects of the industry structure and trade patterns on the aggregate level of migration? We address these questions by providing a theoretical foundation to the empirical studies that use the gravity equation to analyze region to region migration flows. In particular, we quantitatively explain the magnitude of interstate migration in the U.S. by productivity differences in presence of multiple destinations.

We model an economy comprising smaller regions sharing largely similar economic background (identical labor laws, integrated financial markets, etc.), connected to each other by linkages though trade and migration. If the constituent regions receive asymmetric productivity shocks, we would expect workers to migrate from the low-productivity regions to the high productivity regions, in a friction-less world. Therefore, the process of migration would manifest itself in two forms. First, there would be flow of workers between all pairs of regions. Second, the total mass of migrants, i.e. the workers that were displaced due to the realization of the productivity shocks, will pin down the aggregate level of migration.

In the following, we construct an *N*-region, two-sector model augmented with sector and region specific idiosyncratic productivity shocks. The basic inputs are capital and labor which are respectively assumed to be fixed and movable in the short-run. Capital and labor are used to produce intermediate goods. Producers produce the final goods in the two sectors (service and manufacturing) by combining the intermediate goods and both the final goods are consumed within the regions. The intermediates used in the manufacturing sector are traded across states. Labor being the only movable input (capital is fixed), in face of different cross-sectional realization of shocks, would adjust across states according to the relative attractiveness based on productivity. For each year, we treat initial distribution of population across states as a set of labor allocation. After realization of shocks, from one set of labor allocation, we reach another set such that utilities are

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equalized across the states restoring equilibrium. The underlying logic is that migratory responses are ultimately utility enhancing[1] (Ashby, 2007).

Fig. 1 shows the distribution of population within U.S. in 2007 and Fig. 2 shows the network formed from migration across states within one year. As can be seen comparing these two figures, there are hubs of migrants (e.g. California – abbreviated as CA, see Fig. 2) which also have a large mass of population (Fig. 1) indicating that pair-wise flow of migrants depends on the relative population across states. The model described below, captures exactly this feature. For modeling purpose, we borrow from the recently blooming literature in international trade theory in the tradition of the Eaton and Kortum (2002) model (and its subsequent modifications by Alvarez and Lucas, 2007) that combines a rich description of the production processes in a multi-region set-up, capturing the propagation of shocks across regions through adjustable, i.e. movable productive inputs. The analytical structure provided by Caliendo et al. (2014) helps us to explicitly pin down the effects on labor allocation. We show that a similarly specified model can serve as a benchmark case for a frictionless world. With repeated productivity shocks, the model generates a network of migration. The basic parameters describing the model are given by the trade network structure, preferences of the households and the production functions.

The driving mechanisms in the model are two-folds. The first one is a pure general equilibrium channel which captures the labor flow as an outcome of sectoral reallocation process due to productivity differences across sectors. The second one is the trade channel through which we quantify the inter-region labor flow due to spill-over of productivity shocks due to the trade process. In general, the essential mechanism can be thought of as a planner's problem where the planner treats (perfectly divisible) labor as a movable productive input and allocates it across regions according to productivity shocks realized in different regions (see also Kennan and Walker, 2011; Bertoli et al., 2013).

We calibrate the model to the U.S. using standard parameter values to produce quantitative results. The model generates a migration network which is reasonably consistent with the U.S. data in terms of state-to-state migration as well as the total mass of migrants. In particular, the model predictions of state-to-state migration accounts for about 63% of the actual state-to-state migration. Finally, we perform comparative statics to understand the impact of changes in the macroeconomic fundamentals on the aggregate migration. We show that capital intensity has a large impact on migration, household preferences over manufactured goods vs. services have a smaller impact on migration whereas the impacts of asymmetries in trade linkages are not very significant.

The theoretical and empirical justifications for modeling factor flows (labor in the present context) using gravity equations come from Anderson (2011), who derives a gravity equation for migration in a small-scale general equilibrium framework. In particular, the derived gravity equation embeds the inward and outward resistance to migration (as proposed by Anderson and van Wincoop, 2003 in the context of trade) and it is analogous to Eaton–Kortum type trade gravity equations. Our model generalizes the structure significantly in its ability to handle trade flow as well as migration across multiple destinations. Within a fully structural set-up, this allows us to understand the directions of long-run changes in migration. Albeit different in scope, Michaels et al. (2012) provide a theory of structural change which can be interpreted as bilateral migration, based on a similar trade theoretic structure. An expanded framework was used by Redding (2016) to study the welfare gains from trade. As such the present contribution is an attempt to provide a dynamic general equilibrium model that builds on trade theoretic literature to explain the labor migration (Goston and Nelson, 2013).

There is a huge empirical literature on migration and various factors that magnifies or lessens it. Serrano-Domingo and Requena-Silvente (2013) empirically studied migration–trade linkage and related ethnic diversity to external trade. In our theoretical model, we explicitly address the linkage by providing a fully specified trading structure across the states. However, we assume labor to be homogeneous and hence, inherent diversity (for example, ethnicity) does not enter our model. Treyz et al. (1993) were an early attempt that considered a behavioral model of migration and using time-series data showed that migration is affected, among others, by relative employment opportunities, relative wages, industry composition and local amenities. In our theoretical model, the first three effects have been explicitly taken care of. Klein and Ventura (2009) construct a growth model to study the welfare gains from removing barriers to migration as there exists substantial productivity differences between the countries (see also Klein and Ventura, 2007 for the theoretical analysis of the dynamic model). However, they focus on the historical evolution of the migration pattern and study aggregated data. In the recent literature, researchers have focused on the migration-FDI nexus (see Section 5 for a detailed discussion). In the current structure of the model, we assume fixed capital stock for the sake of simplicity. Potential effects of various types of frictions on migration have been studied in details. For example, Kaplan and Schulhofer-Wohl (2013) study the reason behind the secular decline in the U.S. interstate migration over the last two decades and find reduced geographic specificity and higher information about the states to be important factors. See Molloy et al. (2011) and Coen-Pirani (2010) for a detailed overview of the interstate migration in the U.S. Magee et al. (2015) discuss an interesting approach to study the relationship between migration and consumption patterns with social factors. In the following section, we propose a model to capture annual bilateral migration between different pairs of states.

2. A model of migration

We consider an economy where each year N states experience idiosyncratic shocks T times and the workers can move across the states depending on the relative intensities of the shocks. Each state is populated by a continuum of homogeneous households. There are tradable intermediate inputs and non-tradable final goods produced by firms in each state for the consumption of the households. For fixing the notion, we assume that manufacturing industry constitutes the tradables and the service industry produces the non-tradables. Each of the final goods producing industries also produces a continuum of intermediate goods using local labor and a local fixed capital stock. This stock might be interpreted as the structures and land which does not grow over time or at least grows at a much slower pace than labor movement. The states trade on intermediate inputs. The final goods are only for consumption. The household supplies its labor to both sectors in the home region. Since the states have their idiosyncratic productivity shock processes and labor is the only mobile factor, sector and state-specific productivity shocks will lead to multi-lateral flow of labor across sectors and states. This feature is obtained from the model proposed by Caliendo et al. (2014). The flow of workers from one state to another is interpreted as migration.

2.1. Households' problem

In each state a continuum of households constitutes the demand side. They are the sole suppliers of labor which is used in the local production processes. There are two final goods, tradables (M) and non-tradables (S).[2] The instantaneous utility function of households in

[1] Tiebout (1956) makes an interesting observation that with low rigidities in labor market and no asymmetries in information or externalities induced by government, the consumers would reveal their preference through migration. This idea of 'voting with feet' is found to have significant empirical support (Banzhaf and Walsh, 2008).

[2] We follow the convention that manufacturing industries constitute the tradable sector and the service producing industries constitute the non-tradable sector. Note that neither of the final goods is traded. Only the intermediate inputs in the manufacturing sector can be traded.

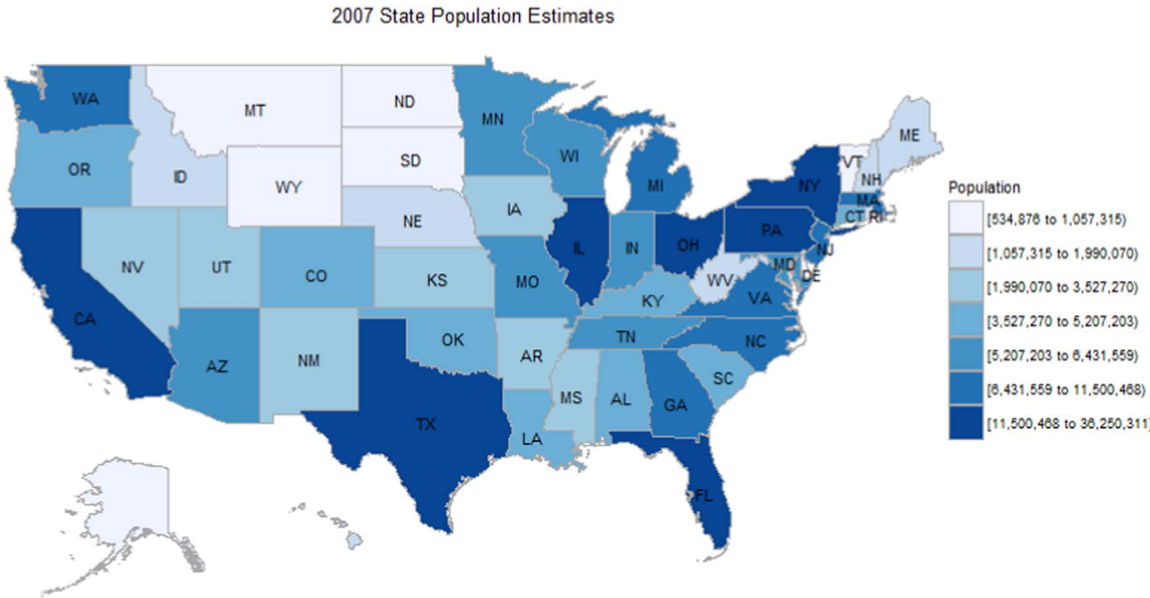


Fig. 1. Distribution of population across the states of the U.S.

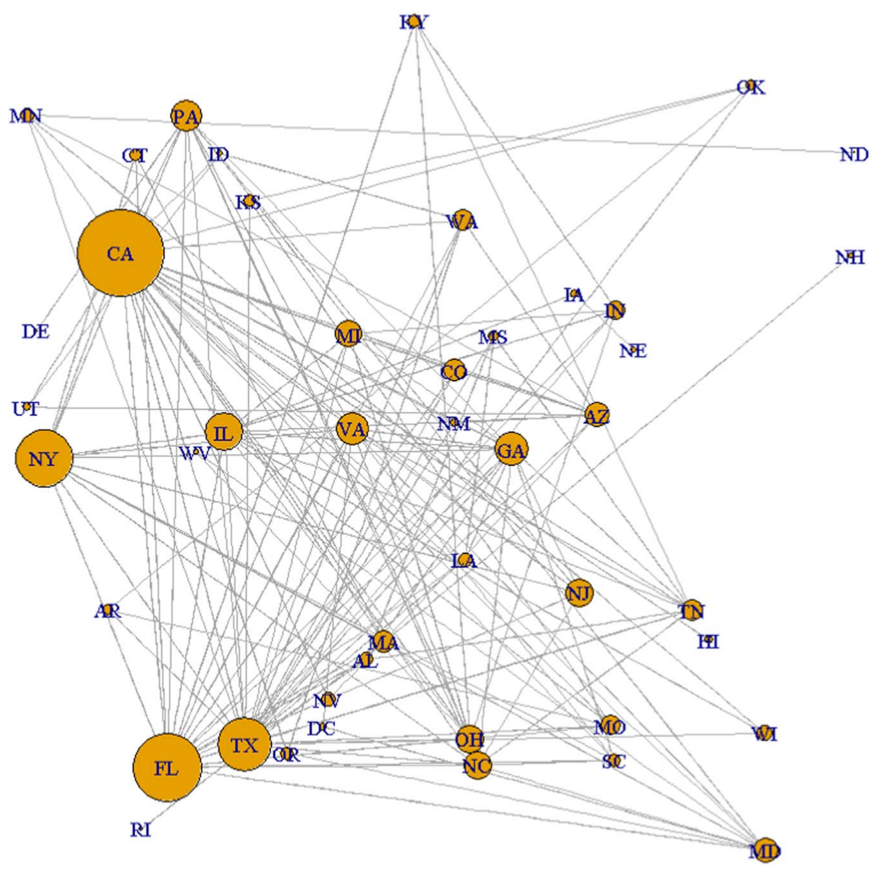


Fig. 2. Migration network across states of the U.S. in 2007. Node sizes are proportional to sum of inflow and outflow of migrants of the corresponding state. Edges represent both way flow of migrants between pairs of states, plotted only when the flow is at least 0.1% of the total number of migrants within the U.S.

the n-th state at a generic time-point t is defined over consumption of the manufactured goods (C^M) and service (C^S):

$$U_{nt} = (C_{nt}^M)^{\alpha}(C_{nt}^S)^{(1-\alpha)}, \tag{1}$$

where α is the relative weight attached to manufactured goods. The budget constraint simply states that the total expenditure of the manufactured goods and services has to be less than equal to income. This can be written as

$$P_{nt}^M C_{nt}^M + P_{nt}^S C_{nt}^S \leq I_{nt}, \tag{2}$$

where the term on the right hand side denotes per-capita income which is the sum of rental income earned from fixed capital stock (or structures and land as has been described in Caliendo et al., 2014) and wage. Let us denote the interest rate by r, the state-specific fixed capital stock by K, labor by L and wage rate by w. Thus we have the income equation:

$$I_{nt} = r_{nt}\frac{K_{nt}}{L_{nt}} + w_{nt}. \tag{3}$$

The expected lifetime utility of an agent who over time migrates to a sequence of states $\{n\}_{1,\ldots,T}$, is

$$U^T = \mathbb{E}\left(\sum_{t=1}^{T} U_{nt}\right) \text{ where } U_{nt} \text{ is given by Eq. (1).} \tag{4}$$

In order to solve the model, we will assume that there is no uncertainty in the economy in the sense that at every period, the agents first see the realized values of the factor productivity and then decide where to move. However, given diminishing productivity of labor, the utility is equalized across all states to restore equilibrium ensuring an interior solution. This allows us to solve each period separately as there is no dynamic trade-off. Therefore, we will drop the time index in the later calculations with the implicit understanding that the solution holds true for every period. Clearly the consumption choice of the static optimization problem is given by

$$C_{nt}^M = \alpha\frac{I_{nt}}{P_{nt}^M} \quad \text{and} \quad C_{nt}^S = (1-\alpha)\frac{I_{nt}}{P_{nt}^S}. \tag{5}$$

By substituting the demand functions in the utility function, we can find out the indirect utility function of households in one state as

$$U_{nt} = \left(\frac{\alpha}{P_{nt}^M}\right)^{\alpha}\left(\frac{1-\alpha}{P_{nt}^S}\right)^{1-\alpha} I_{nt}, \qquad = \frac{I_{nt}}{P_{nt}}, \tag{6}$$

where P_{nt} is the standard ideal price index defined over the prices of sectoral goods as

$$P_{nt} = \left(\frac{P_{nt}^M}{\alpha}\right)^{\alpha}\left(\frac{P_{nt}^S}{1-\alpha}\right)^{1-\alpha}. \tag{7}$$

Since the agents are free to move across the states, in equilibrium we would have utility equalized across the states and hence,

$$U_{nt} = \overline{U}_t. \tag{8}$$

Note that utility has to be equalized across states at every point of time, but not necessarily across time. In other words, in general $\overline{U}_t \neq \overline{U}_{t'}$ for any $t, t' \le T$ such that $t \neq t'$. The lifetime utility of an agent is

$$U^T = \sum_{t=1}^{T} \overline{U}_t \tag{9}$$

whatever be the sequence of states she migrated to in her lifetime.

2.2. Supply side

The final goods (both manufactured goods and the service products) are used for consumption. However, in each sector these goods (M and S) are produced by a bundling technology which uses a continuum of intermediate goods. These intermediates are in turn produced by combining local labor and capital stock. Note that as in Caliendo et al. (2014), we keep the trade channel open as the final goods producing firms can buy intermediate goods from any state. We can clearly identify the source of fluctuation in labor allocation through this channel.

2.2.1. Intermediates

Firms of both sectors $j \in \{M, S\}$ in each state n produces a continuum of varieties of intermediate goods following an i.i.d. shock process, ξ_n^j and a deterministic productivity level Z_n^j. As in Caliendo et al. (2014), the shock process ξ_n^j follows a Frechet distribution with shape parameter θ^j. The production functions for both sectors ($j \in \{M, S\}$) are defined as

$$q_n^j = \xi_n^j Z_n^j (k_n^j)^{\beta}(l_n^j)^{1-\beta}, \tag{10}$$

where lowercase letters l and k denote the demand for labor and capital respectively by a representative firm, β being the relative weight assigned to capital. The shock process Z^j_n is assumed to follow a random walk in logarithm that is, we assume that

$$Z_n^j(t+1) = \psi_{it} Z_n^j(t) \quad \text{where } \psi_i \sim N(1, \sigma_i) \text{ and } i \in \{M, S\}. \tag{11}$$

The unit cost of production in each sector in state n can be found by minimizing

$$w_n^j l_n^j + r_n^j k_n^j, \tag{12}$$

subject to

$$\xi_n^j Z_n^j (k_n^j)^{\beta}(l_n^j)^{1-\beta} = 1. \tag{13}$$

We can derive the unit cost as a function of the productivity levels and the input prices- wage and rental rate:

$$c_n^j = \frac{1}{\xi_n^j Z_n^j}[\beta^{-\beta}(1-\beta)^{(1-\beta)}] r_n^{\beta} w_n^{(1-\beta)}. \tag{14}$$

The firms would produce the variety as long as the price equals to or more than the unit cost c_n^j. Price would be equal to the unit cost because of competition in the intermediate goods market. For notational convenience, we lump the terms in the unit cost function and denote them by

$$B = \beta^{-\beta}(1-\beta)^{(1-\beta)} \quad \text{and} \quad \omega_n^j = B r_n^{\beta} w_n^{(1-\beta)}. \tag{15}$$

Let p_n^j denote the equilibrium price of two sectors ($j \in \{M, S\}$) in the n-th state. Therefore, profit η of a firm producing intermediate goods in the j-th sector is simply given by total revenue minus wage bill and rental payment:

$$\eta_{intermediates}^j = p_n^j q_n^j - w_n l_n^j - r_n k_n^j. \tag{16}$$

At the optimal level the expenditures on labor and capital are (see Eq. (10); profit would be zero in this market)

$$w_n l_n^j = (1-\beta) p_n^j q_n^j, \tag{17}$$

$$r_n k_n^j = \beta p_n^j q_n^j. \tag{18}$$

2.2.2. Final goods

As has been described above, the final goods production in both sectors ($j \in \{M, S\}$) is carried out competitively using a bundling technology:

$$Q_n^j = \left[\int (\tilde{q}_n^j(\xi^j))^{\gamma_n^j} \phi^j(\xi^j) d\xi^j\right]^{1/\gamma_n^j}, \tag{19}$$

where the i.i.d. productivity shocks on intermediate goods are distributed as

$$\phi^M(\xi^M) = \exp\left(-\sum_{n=1}^{N} (\xi_n^M)^{-\theta^M}\right), \tag{20}$$

$$\phi^S(\xi^S) = \exp(-(\xi_n^S)^{-\theta^S}), \tag{21}$$

and $\tilde{q}$ is the optimally chosen level of production of the intermediate goods. Since intermediates for manufactured goods are traded, the shocks are jointly distributed, whereas for non-tradable service sector that is not the case. Thus the pattern of trade between the states is incorporated in the above production functions in terms of intermediates.

Therefore in the n-th state, the profit of the final goods producers in both sectors ($j \in M, S$) is defined as total revenue from selling the final goods minus the cost of procuring and using the intermediates:

$$\eta_{n,final}^j = P_n^j Q_n^j - \int p_n^j(\xi^j)\tilde{q}_n^j(\xi^j)\phi_n^j(\xi^j)d\xi^j, \tag{22}$$

where the final goods production function is given above (Eq. (19)). Clearly the optimal demand for a particular type of intermediate good is given by

$$\tilde{q}_n^j = \left(\frac{p_n^j(\xi^j)}{P_n^j}\right)^{-\frac{1}{1-\gamma_n^j}} Q_n^j, \tag{23}$$

which on substitution in the production function gives us the aggregate price level for the final good as a function of prices of intermediates used in the production process:

$$P_n^j = \left[\int (p_n^j(\xi^j))^{\frac{\gamma_n^j}{\gamma_n^j-1}}\phi^j(\xi^j)d\xi^j\right]^{\frac{\gamma_n^j-1}{\gamma_n^j}}. \tag{24}$$

Intuitively, this functional form of the aggregate pricing equation reflects the particular bundling technology assumed in Eq. (19).

2.2.3. Closing the model

Final goods are non-tradable in all sectors. Only the intermediates in the manufacturing sector M are tradables. The cost of transportation from location n to i (in units of good produced in location n) is given as

$$\tau_{ni}^M \geq 1,\ \tau_{ni}^S = \infty. \tag{25}$$

For obvious reasons, we define $\tau_{nn}^M = 1$. Such a structure imposes an ice-berg cost on transportation. Therefore, due to cost minimization the pricing equations for intermediates are given as

$$p_n^M = \min_i\left(\frac{\kappa_{in}^M \omega_i^M}{\xi_i^M Z_i^M}\right). \tag{26}$$

Following Eaton and Kortum (2002), such a specification gives us

$$P_n^M = \Gamma(f_n^M)^{\gamma_n^M/(\gamma_n^M-1)}\left[\sum_{i=1}^N [\omega_i^M \kappa_{in}^M]^{-\theta^M}(Z_i^M)^{\theta^M}\right]^{-1/\theta^M}, \tag{27}$$

where $\Gamma(\cdot)$ denotes a gamma function and $f_n^M = 1 + (\gamma_n^M)/(\theta^M(\gamma_n^M - 1))$ where $\gamma_n{}^M$ is the measure of substitutability of intermediates in the production function of the final goods (see Eq. (19)). On the other hand, the price index of the non-tradables is given as

$$P_n^S = \Gamma(f_n^S)^{\gamma_n^M/(\gamma_n^M-1)}\omega_n^S(Z_n^S)^{-1}, \tag{28}$$

where $f^S{}_n$ is defined analogously in terms of the measure of substitutability ($\gamma_n{}^S$) in the production of the service good. The labor market clearing holds at two levels. Within each state, total labor must be equal to the sum of the sectoral allocation:

$$L_n^M + L_n^S = L_n \quad \forall\ n \leq N \tag{29}$$

and at the aggregate level, total labor endowment must be equal to the sum of the geographical distribution across states:

$$\sum_n L_n = 1. \tag{30}$$

Similarly for capital stock, we have regional market clearing

$$K_n^M + K_n^S = K_n \quad \forall\ n \leq N. \tag{31}$$

Note that since capital is immobile, we do not have market clearing condition for capital at the aggregate level. Solving for labor allocation we get

$$L_n = \frac{\left[\frac{\omega_n}{P_n\overline{U}}\right]^{1/\beta} K_n}{\sum_i \left[\frac{\omega_i}{P_i\overline{U}}\right]^{1/\beta} K_i}, \tag{32}$$

where ω_n is described in Eq. (15).

2.2.4. Regional market clearing

Since final goods are only consumed (no investment opportunity), total consumption (C_n) by whole population (L_n) must be equal to production (Q_n) in both sectors $j \in \{M, S\}$:

$$L_n C_n^j = Q_n^j. \tag{33}$$

In terms of expenditure $X^j{}_n$ on the final goods in sector j in state n, we find

$$X_n^M = \alpha I_n L_n \quad \text{and} \quad X_n^S = (1-\alpha)I_n L_n, \tag{34}$$

where $I_n L_n$ is the total income and α is the weight on manufactured goods in the utility function (see Eq. (1)). The intuition of this result is that due to the Cobb–Douglas structure of the utility function, the resultant expenditure is linear in aggregate nominal income (follows directly from Eq. (5)).

Let us denote the total expenditure on intermediates bought by the n-th state from the i-th state for producing j type final good ($j \in \{M, S\}$) by $X_{ni}{}^j$. Similarly, we denote the share of that expenditure in the total revenue in the n-th state by π_{ni}^j. Since the zero-profit condition holds, total cost must exhaust total revenue which in turn implies that the share

$$\pi_{ni}^M = \frac{X_{ni}^M}{X_n^M} = \left(\Gamma(f_n^M)^{\gamma/(1-\gamma)}\frac{\tau_{ni}^M \omega_i^M}{P_n^M Z_n^M}\right)^{-\theta^M}. \tag{35}$$

Recall that for the non-tradables the transportation cost is infinite ($\tau^S = \infty$) and hence, for the non-tradables,

$$\pi_{nn}^S = 1, \tag{36}$$

which is almost tautological in the sense that the share of local production is unity in the production of final goods in the non-tradables sector.

Let us introduce a hat notation here which simplifies the exposition of considerably. Define

$$\hat{x} = \frac{x_{new}}{x_{old}}, \tag{37}$$

which says that the ratio of the new and the old values of any variable x is denoted by $\hat{x}$. This trick is useful because as Caliendo et al. (2014) show that the whole model can be solved in ratios of the old and the new values of all variables rather than actually deriving the old and the new values separately.

2.3. Equilibrium

Now we can define the equilibrium of this model.

2.3.1. Static economy

First, we define it for a static model which is equivalent to assuming the time horizon T=1. Given labor endowments $\{L_n\}$ (we normalize it so that L=1) and the capital endowment $\{K_n\}_n$, a competitive equilibrium is an utility level $\overline{U}$, factor prices $\{r_n, w_n\}_n$, labor allocation $\{L_n\}_n$, final goods expenditure $\{X_n^M, X_n^S\}_n$, consumption vector $\{c_n^M, c_n^S\}_n$, prices of final goods $\{P_n^M, P_n^S\}_n$ and pairwise regional intermediate expenditure share in every sector $\{\pi_n^M, \pi_n^S\}_n$ such that all markets clear in all states $n \in N$.

Proposition 1. *Given an initial labor endowment vector $\{L_n\}$ and a vector of productivity shocks in two sectors ($\{Z_n^j\}$ for $j \in \{M, S\}$) across a set of N states, there exists a new labor allocation vector such that the utility is equalized across all states.*

See Caliendo et al. (2014) for a detailed discussion. We adapt their algorithm for our purpose and present it in Appendix A.3.

2.3.2. Dynamic economy

Since the labor response in the static model can be solved explicitly following the above technique, we now discuss the dynamic counterpart of it.

Proposition 2. *In the dynamic case with $T \geq 1$, under an equilibrium configuration, the above defined static equilibrium would hold for each and every time period $t \leq T$.*

To see why that is true, we can use backward induction. There are two crucial assumptions in the whole model that delivers this result. One, there is no cost involved in migration and two, the workers decide to move after they see the realized shocks. Now consider the penultimate period $T - 1$. When the productivity shocks occur in the period T, depending on the relative intensities of the shocks the workers would migrate. Therefore from the perspective of period $T - 1$, there is no state dependence of the decision that will be made in period T. In other words, it does not matter which state the worker belongs to to make a decision about period T. Therefore from the perspective of period $T - 2$, the state where a particular worker is does not matter for the decision that will be made on period $T - 1$. Extending the same argument, we see that right from period 1 the sequence of states that a worker travels, does not matter. Utilities are always equalized across states in every period.

This is very helpful in solving the model as we can essentially solve for the labor allocation in each period separately after realization of the productivity shocks specific to the state and the sectors. Another implicit assumption plays an important role here. Note that we did not define capital ownership explicitly. The underlying idea is that the government is the owner of all capital stock within each state. The firms rent capital from the government who in turn distributes the proceeds to the workers. Hence even if we do have repeated migration within these T periods, i.e. the same worker can come back to one particular state over and over again depending on productivity shocks, we have no problem allowing that since the workers are not capital owners. In reality, we do see a large amount of repeat migration which might relate to the issue of capital holding. For example, Thom (2014) documents a large amount of repeat migration among workers and links it to their savings behavior (see also Martins, 2008). In the present context, we chose to ignore it as it lies out of scope of our work.

2.4. The effects of shocks

The above system of equations can be solved at every time point t after realization of the sequence of sector and state specific shocks $\widehat{Z}_{nt}^{j}$. Given a set of parameters $\{\theta^j, \alpha, \beta\}_{n,j=\{S,M\}}^{N}$ and data for $\{I_n, L_n, \pi_{ni}^{j}, \widehat{Z}_n^{j}\}_{n,i,j=\{S,M\}}^{N,N}$ the system yields solution for $\{\widehat{w}_n, \widehat{L}_n, \widehat{X}_n^{j}, \widehat{P}_n^{j}, X_{n'}^{j}, \pi_{ni'}^{j}\}_{n,i,j=\{M,S\}}^{N,N}$ with the hat notation denoting the ratio of the new value of a variable to that of the old value. From these we can find out the changes in real prices and output along with utility $\{\widehat{r}_n, \widehat{\pi}_{nn}^{j}, \widehat{I}_n^{j}, \widehat{\widehat{U}}\}_{n,j=\{M,S\}}^{N}$.

2.5. The network of migration

Given the labor dynamics across regions, we are in a position to construct the labor mobility network based on Propositions 1 and 2. The basic idea is that due to any productivity shock, all states will face a fluctuation in the efficient level of employment. Some states will lose workers whereas others will gain.

Fig. 3 shows the basic idea of constructing the migration matrix ($[m_{ij}]$) for a single realization of sectoral and regional shocks. A set of workers will leave the source states (let us denote it by S), i.e. the ones receiving relatively bad productivity draws. We assume that they form a pool of workers from which they go to the destination states, i.e. the ones with relatively higher productivity draws (the complementary set, $D = N - S$). So at point of time t, there would be unilateral migration from the source states (S^t) to the destination states (D^t). Since productivity draws are i.i.d., multiple realizations of productivity shocks over time t, would generate a sequence of such unilateral migration matrices ($[m_{ij}]_t$). Due to the i.i.d. assumption, each state will sometimes belong to the set of source states S^t and sometimes to the set of destination states D^t. By integrating over time (i.e. by summing up over t), we generate full migration matrix with bilateral migration. Propositions 1 and 2 provide the theoretical support for such a construction. Below we describe the exact details of the process.

Since workers are assumed to be homogeneous both in terms of consumption pattern and labor supply, they would show no particular preference for any region under the no-friction regime that is when there is no friction opposing labor mobility. Recall that for the n-th region, the total change is $\widehat{L}_n$. Therefore, total change for the n-th region is $(\widehat{L}_n - 1)L_n$. Therefore, one can write the labor flow from the j-th region to the i-th region at time t as

$$F_{ji}^{t} = \left(\frac{(\widehat{L}_j - 1)L_j}{\sum_{n\in\mathcal{N}^{out}}(\widehat{L}_n - 1)L_n}\right)(\widehat{L}_i - 1)L_i, \tag{38}$$

where $\mathcal{N}^{out}$ is the set of states from which labor migrates to other states and $j \in \mathcal{N}^{out}$. The above flow equation uses the fact that the labor is homogeneous in that the inflow from a region j to region i will be proportional to the contribution of region j relative to the total mass of displaced workers. Note

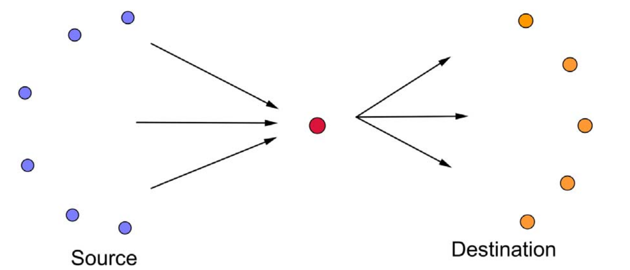


Fig. 3. An illustration of flow of workers after realization of productivity shocks. Some states are donor and others are receivers. Workers from the states receiving comparatively worse productivity shocks are assumed to form a pool of migrants (red) and then they go to the states receiving higher productivity shocks. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

that one could alternatively write it as

$$F_{ji}^{t} = -\left(\frac{(\widehat{L}_i - 1)L_i}{\sum_{n\in\mathcal{N}^{in}}(\widehat{L}_n - 1)L_n}\right)(\widehat{L}_j - 1)L_j, \tag{39}$$

where $\mathcal{N}^{in}$ is the set of states to which labor migrates from other states. Evidently in absence of links to the rest of the world,

$$\sum_{i\in\mathcal{N}^{in}}(\widehat{L}_i - 1)L_i = -\sum_{j\in\mathcal{N}^{out}}(\widehat{L}_j - 1)L_j, \tag{40}$$

that is total inflow must be equal to total outflow.

With a single realization of a set of shocks across the sectors and the states, there will be some donor states and some receiver states for that period. Those states that experienced relatively better shocks will be ranked higher in relative attractiveness and workers will migrate to such receivers from the donor states (which have experienced relatively bad shocks). Therefore, at every point of time such a set of shocks would generate a directed and weighted network of migrants. But this network would be unidirectional in the sense that labor flow is always one-way between any pair. However, with repeated shocks in the steady state, a state that was a net donor in one period may turn out to be a net receiver in the next period. In general over sufficient number of time points (with large enough T), we will generate bilateral flow for each and every possible pairs of states. Evidently the net flow (inflow−outflow) would be much smaller than the gross flow (inflow+outflow). This is another characteristic of model that matches the data well, for example in case of U.S. the gross flow is about 10 times larger than the net flow as has been documented in Kaplan and Schulhofer-Wohl (2013).

3. Results and analysis

We use standard parameter values to simulate the model and compare the resultant migration network to U.S. data.

3.1. Parameter values

We list the parameter values used to simulate the model in Table 1. The weight assigned to manufactured goods in the utility function is 0.4 and capital's share in the production cost is 0.3. Both are within range considered in the literature.[3] Parameter θ describes competitiveness in production process which is difficult to estimate. However, the values considered here are within the range used in the literature.[4] While generating the shocks to the productivity (Z), we divided each shock by the length of the

[3] See also Section 4 for comparative statics exercises when these parameters change.

4See for example, Eaton and Kortum (2002) for a range of estimated values of θ. Smaller values of θ indicate higher ranges of heterogeneity. The estimated values of the parameter show wide fluctuations across samples. So we have checked for multiple combinations of the dispersion parameter for both the manufacturing sector and the service sector. Our results are reasonably robust to changes in the dispersion parameter.

Table 1
Parameter values used for simulation (U.S.).

Description	Parameter	Value
Service goods' weight in consumption	$1-\alpha$	0.6
Capital's share in cost	β	0.3
Dispersion of shocks: manufacturing	θ_m	8
Dispersion of shocks: service	θ_s	2
Std. dev. of shocks: manufacturing	σ_M	0.0380
Std. dev. of shocks: service	σ_S	0.0057
Length of simulation	T	200
# simulations averaged	–	10

time horizon T for reasons explained below. For any i-th sector ($i \in \{m, s\}$)

$$\psi_{it} = \frac{\widetilde{\psi}_{it}}{T} \quad \text{where } \widetilde{\psi} \sim N(1, \sigma_i), \tag{41}$$

so that

$$\sum_t^T \psi_{it} = \sum_t^T \frac{\widetilde{\psi}_{it}}{T} \to 1 \quad \text{for } T \to \infty. \tag{42}$$

The interpretation is that, T is the equivalent to the number of shocks received by each region, within one year. For simulation purpose, we assume T=200 and we checked that the results are not sensitive to the choice for sufficiently large T. Note that repeated shocks are required to generate both-way flow of workers within one year. But we also need to make sure that such shocks when aggregated should not explode with increasing T. Eq. (42) shows that even with larger values of T, the aggregate effect for each state would be close to zero keeping the system in the steady state. But at each $t \le T$, there will be non-negligible effects through realization of shocks ψ across states (see Eq. (11)). Productivity dispersions are computed by taking the standard deviations of measured TFP in the respective sectors across years.

3.2. The migration network for the U.S.

To test the model on a frictionless case, we calibrate the model on the U.S. data. We plug in data of population, per capita GDP, bilateral trade and TFP distribution for 51 states in the model to generate a migration network. The American Community Survey Data (2007) provides data of interstate migration for 2007. Data for other years are not available. To simulate productivity shocks-driven bilateral migration from the theoretical model, we use a block recursive algorithm (see Appendices A.2 and A.3). We use the parameter values described in Table 1, and provide the population data for the countries (L_i; we normalize it so that $\sum_i L_i = 1$), the per-capita GDP and the bilateral trade relationship between countries (π_m and π_s) as inputs of the model (see Appendices A.2 and A.3).

We compare the theoretical results (referred to as TFP driven migration henceforth) with the actual data of migration. In order to compare meaningfully, we consider the dyads for which actual migration data is available (both m_{ij} and m_{ji}) and sum up ($m_{ij} + m_{ji}$) to get the gross flow of migration and regress this on its theoretical counterpart, the TFP driven migration (theoretical $m_{ij} + m_{ji}$). Table 2 shows the results of regressing actual data (at level values – nominal as well as normalized – relative) on theoretical model results with robust errors.

For the purpose of regression with nominal values, we construct the dependent variable as

$$y_k = \frac{m_{ij}^{data} + m_{ji}^{data}}{\sum_{nt} L_{nt}^{data}}. \tag{43}$$

We divide the migration flow by the total population so that we can talk about total flow of migration in percentage terms. Similarly, we construct the explanatory variable as

Table 2
Regression results with robust errors for the U.S. (2007).

Variable	TFP driven migration	Contiguity	Intercept	R^2
Nominal	0.82695***	0.00006***	0.00000	0.6305
	(0.06435)	(0.00001)	(0.00000)	
Relative	0.68521***	0.00243***	0.00004	0.6305
	(0.05332)	(0.00023)	(0.00003)	

Note: *$p < .1$, **$p < .05$, and N=1275.
*** $p < 0.01$.

$$x_k = \frac{m_{ij}^{model} + m_{ji}^{model}}{\sum_{nt} L_{nt}^{model}}. \tag{44}$$

Note that we already normalized the total labor in the model so that the denominator for x_k is 1. In the regression we control for contiguity which is a dummy variable showing whether two countries in a dyad share a border or not. Accordingly, the specification is

$$y_k = \alpha_0 + \alpha_1 x_k + \alpha_2 D_{cont.} + \epsilon_k \tag{45}$$

where $D_{cont.}$ is a dummy for contiguity and ϵ_k is an $i.i.d.$ error term. A good fit of the model would imply $\widehat{\alpha_0} = 0$ and $\hat{\alpha}_1 = 1$. At the nominal level the table shows that TFP changes can explain most of the migration seen in real data. These regressions are on dyads and do not consider the direction of flow of migration.

Given that we are considering multiple states as possible destinations of migrants at every point in time, we also characterize the relative flows of migrants across pairs. For example, assume that there are three states A, B and C. We also want to make a comparison between the flow from A to B and back, and from B to C and back. For relative strength of edges between pairs of states, we divide the relevant variables on both sides of the regression by the sum of the all values of weights that is the new dependent variable is $\tilde{y}_k = y_k / \sum_k y_k$ and the explanatory variable is $\tilde{x}_k = x_k / \sum_k x_k$. The control variable remains as is. The result is presented in Table 2.

We note that there are problems with econometric modeling of source–destination dependence through spatial autoregressive models (LeSage and Pace, 2008). In the present exercise, we avoid that problem in two ways. One, the source–destination effect is fully endogenized through a general equilibrium structure and hence, the dependence on the *third* state has been taken care of through the market-clearing mechanism. Second, we define the migration across a pair of states as the sum of the bilateral flow and hence, the direction is not important (see Eqs. (43) and (44)). Also, note that we are not econometrically modeling pairwise migration (y_k in Eq. (43)). Since by construction, the model produces migration responses to productivity differences across N states, the variable x_k in Eq. (44) is taken to capture the extent of productivity-driven pair-wise migration after controlling for the third destination effect. From Table 2 we can say that the productivity-driven migration (as explained by the theoretical model) explains about 63% of actual migration.

Specifically, Table 2 shows the results of regressing actual data (at level values – nominal and normalized – relative) on theoretical model results (Eq. (45)). Even at the nominal level the table shows that TFP changes can explain most of the migration seen in real data. These regressions are also on dyad observations and do not consider the direction of flow of migration. The interesting result is that the predicted total mass of migrants match pretty well with the data. Calibrating the model we see that the total flow should be around 2%. Average interstate migration in the U.S. in the last 20 years is also close to 2%. This rate actually shows a secular decline over the same period as in 1990 the rate was about 3% and in 2011, the rate is about 1.5% of the whole population (Kaplan and Schulhofer-Wohl, 2013). Even with such a decline, the orders of the variable are reasonably comparable.

Fig. 4 plots the normalized actual interstate migration on the normalized values of migration predicted. In the right panel we take natural log – showing a very clear clustering around the fitted line. Evidently, the bulk of the labor flow is captured by the theoretical model which emphasizes the productivity-driven migration in line of Klein and Ventura (2009) and Kennan and Walker (2011). That is, in case of U.S. which was taken as the closest approximation to a frictionless place (in terms of social and political dimensions) is actually described well by a model emphasizing only economic incentives behind migration.

3.3. Working of the model: multilateral gravity equations

From the tables presented above, the model explains about 63% of the fluctuations in edge weight of the migration network in case of the U.S. (see Table 2) controlling for contiguity. The coefficient assigned to the TFP-driven migration is sufficiently high (about 0.8 on an average). The reason the model fits well with the data is that it effectively creates a network that describes a multilateral gravity equation between all pairs of states.

The basic descriptive equation of gross flow of labor between any dyad, i.e. any pair $(\{i, j\})$ of states is

$$\mathbb{F}_{i,j} = C_{i,j}\left(\frac{L_i \cdot L_j}{d_{i,j}^{\eta}}\right), \tag{46}$$

where $\mathbb{F}_{i,j}$ is the weight of the edge of the network between the i-th and the j-th state (representing trade flow or migration) and C is a constant. The equation shows that the labor flow is proportional to the product of the two states' population and inversely proportional to some power of the distance $(d_{i,j}^{\eta})$ between these two states. Usually, η is found to be very close to 1. The emergence of such a pattern has been subject to a huge number of empirical studies in the trade theoretic literature. Chaney (2014) in particular gives a framework to understand why η is close to one. Lin (2013) shows that the effect of distance on trade is gradually diminishing over time. In the present context, we do not attempt to embed distance in the model. Therefore, in all empirical analysis we have controlled for it by using contiguity data. For the same reason, a reduced form description of our model is

$$\mathbb{F}_{i,j} = C_{i,j}(L_i \cdot L_j). \tag{47}$$

Fig. 5 describes the relationship generated by the model, between weights of the dyads in terms of labor flow and products of populations of the corresponding states. Evidently it has a good fit with the idea of multilateral gravity approach except that there is no counterpart of distance in our model (following Eq. (47)).

Since the distances between the states do not have particularly large variations, the weights of the dyads capturing the migration flow depend almost linearly on the product of population. This is precisely what our model generates in terms of labor flow. Therefore, the relationship can be further simplified to

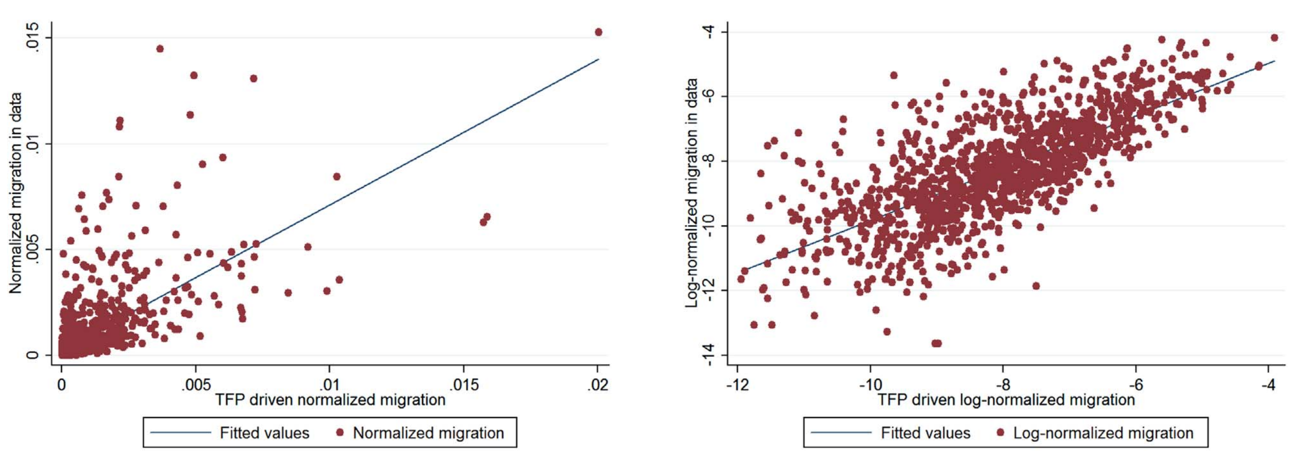
$$\mathbb{F}_{i,j} = C(L_i \cdot L_j). \tag{48}$$

Thus the model captures the broad description of the migration network at the macro-level as well as region-pair specific level. An interesting feature of the model is that $C_{i,j} = C$ as is shown in Fig. 5. This constant parameter C embodies the structure of the economy in the sense that it captures the structural parameters of the whole economy (in our case, the U.S.) including the preferences, production technology and the trade patterns. When we make any changes in such structural parameters that will be reflected in the magnitude of that constant and will have corresponding effects on the level of migration. We study such cases in Section 4.

The main implication is that the model provides a theoretical foundation to the empirical studies on gravity equations in the context of internal migration. Here we discuss a few features of the above results. The gravity equation derived from the model is ‘multilateral’ in the sense that migration between a pair of states depends not only on the population of the states but also that of the alternative destination states. In fact, through the general equilibrium mechanism, population distribution along with the production structure, incomes, consumption bundles, etc. for all states, contribute to the final allocation of labor after realization of productivity shocks. Hence, the alternative destinations matter for migration across states, through wage differentials which can be ultimately traced to productivity differences. In this sense, it can be argued that the model implicitly shows ‘multilateral resistance’ to migration as relative alternative wages decide which destination a worker will migrate to. However, our model ignores the differences in relative migration costs as labor is assumed to be freely movable without any cost. Such a cost appears to play an important role in the multilateral resistance (Bertoli and Moraga, 2013 includes such costs in the utility specification; but not as a general equilibrium mechanism). For this reason, we do not estimate the model *per se.* Through Eq. (45) we check validity of the model only as all third destination effects are already theoretically incorporated in the model predicted pair-wise migration flow. Finally, we provide a broad characterization in terms of Eq. (47) to elucidate the linear response of the general equilibrium model that a more populated state would generate bigger migration responses as opposed to a smaller state, in response to proportional productivity differences. Hence, Eq. (47) represents an overall summary of the effects of the underlying mechanism and not an estimation.

4. Counterfactual experiments

The model that we have presented above captures the economy in a very short horizon of time. But it is well known that over a considerable amount of time several economic variables do change substantially. The empirical observation of structural shift is probably the most



(a) Relative - normalized values (b) Log relative - log of normalized values

Fig. 4. Scatter plots showing the normalized interstate migration data on the simulation results for the U.S. for year 2007, in level and in log.

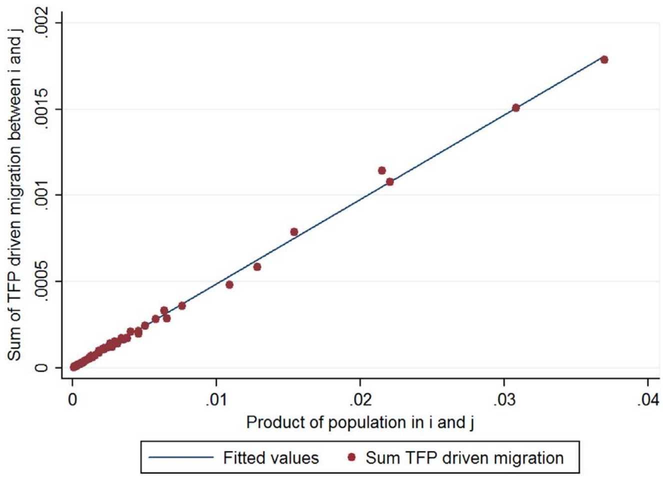


Fig. 5. The model captures the multilateral gravity relation between donor and receiver states (regions). We have plotted the weight of dyads ($\mathbb{F}_{i,j} = m_{ij} + m_{ji}$) as a function of the product of populations ($L_i \cdot L_j$) for all dyads $i, j \in N$.

prominent example of it which states that over time the service sector tends to dominate the manufacturing sector (Acemoglu, 2007). Another interesting observation is that the level of migration itself shows time-varying properties, for example even in the U.S. there exists a secular decline in the aggregate level of interstate migration. It has shown about 50% fall over the period of last two decades (Kaplan and Schulhofer-Wohl, 2013). Similarly in a growing economy, any particular sector taken in isolation, shows a secular increase in per-capita capital stock. In the context of the present model, we can use parametric variations to understand the changes in the behavior of economic incentive-driven migration process in face of these long-run changes in the 'deep parameters' of the economy.

The general prediction of the model in all of the following exercises remains valid in the sense labor flow network essentially captures the multilateral gravity equation type behavior. By making parametric variations, we can study how total mass of labor migration alters when subjected to productivity shocks. One can think of such exercises as reflecting changes the coefficient of the gravity equation (the term multiplying the labor mass, C in Eq. (48)). We have listed all parameter values used for the following exercises in Table 4 (see Appendix).

4.1. Structural change

The shift of employment from agriculture to manufacturing and then eventually to service sector is referred to as structural change (Acemoglu, 2007). In the context of the present paper, we focus on the second stage of this transformation which entails a gradual shift of employment from manufacturing to service, accompanying the growth process of modern economies almost without any exception. There is a large literature making connections between economic growth and structural change (see Acemoglu, 2007 for a detailed analysis) which also entails changes in labor and capital endowments over time. Serrano-Domingo et al. (2011) documents that regional patterns of industry formation can be related to the labor endowments. Here we study the effects of structural change on the aggregate level of migration assuming that the industrial configuration is given for the migration decision as each household is extremely small compared to the whole economy. This assumption is in line with the standard macroeconomic approach. Since the process of structural change refers to an ever-increasing share of service goods in the consumption basket (demand-driven structural change; see e.g. Echevarria, 1997), we see an increase in size of the non-tradable sector. This will impact labor migration pattern at the aggregate level. Michaels et al. (2012) build a model of structural change on a framework similar to ours and explains the movement of labor away from agriculture resulting in urbanization over a century. Instead we take the phenomena of structural change as given and by parametric variation of preference, we seek to determine the effects on migratory responses.

There are broadly two ways to capture the structural change. One interpretation is that it is demand-driven that is over time people demand more service goods than manufactured goods (see for example Echevarria, 1997 for a preference-driven mechanism). The simplest way to address this issue in the current context is to do comparative statics between economies with different preference for manufactured goods. For comparison, we assume a symmetric economy consisting of N=10 states where all states have equal share in initial population ($L_n = 1/N \ \forall \ n$) and then trade matrix is perfectly symmetric in the sense that all elements are $1/N$ indicating equal weights attached to all states by all states and per-capita GDP is normalized at 1 for every state. In Fig. 6, we plot the how gross migration changes with changes in the weight assigned to manufactured good in the utility function α (see Eq. (1)). As α increases, total migration decreases. The interpretation is that with higher weight attached to service goods, that sector becomes more important which is non-tradable. The productivity shocks in the non-tradable sector cannot be mitigated through trade channel, by definition. Correspondingly, it shows a higher level of adjustment in terms of the only movable input, labor. The elasticity of migration with respect to changes in the preference parameter is seen to be low reflecting the idea that such changes do not have pronounced effects on migration.

4.2. Increasing asymmetries in the trade network

The trade network is extremely skewed as has been documented in several studies. For example Chaney (2014) shows regional asymmetries in trade flow. Such asymmetries in trade network also affects the migration process as that network is the medium of transmission of idiosyncratic sectoral and spatial shocks to other sectors and states. Different degree of asymmetry in the trade network would imply different levels of spill-over effects of such shocks and would eventually result in different levels of migration responses.

In the benchmark case, we assume that share of manufactured goods in the consumption bundle (α) is 0.4 and the share of capital in the production function (β) is 0.3 and a completely symmetric trade matrix with all elements $1/N$, N being the number of states. From that we make the trade matrix completely asymmetric in the sense that it is set to be equal to an identity matrix, effectively making it manufacturing non-tradable good. The mass of people migrating under this set of parameter values is about 1.8% whereas the mass of migrants in the benchmark case is 1.6%. This indicates that again a similar mechanism is at work. More emphasis on non-tradables increases the extent of adjustment process.

4.3. Capital intensity in production

With growth, the production process often evolves towards using more and more capital intensive technology (Acemoglu, 2007). In the present model, such changes in the intensity of capital usage affect the migratory responses of workers. In Fig. 6, we show how gross migration decreases with increase in β which denotes capital's share in the production function (see Eq. (10)). This is intuitive because the less labor required in the production process, the less would be the extent of adjustment. However, one should also note that in this model capital is fixed. Thus labor movement becomes much more pronounced as that is the only factor that can be adjusted, which is manifested in the high magnitude of the migration elasticity with respect to capital intensity.

5. Summary and conclusion

Dependence of migration decisions on multiple destinations has become an important topic in the migration literature (Bertoli and Moraga, 2013). We have presented a model of migration based on a

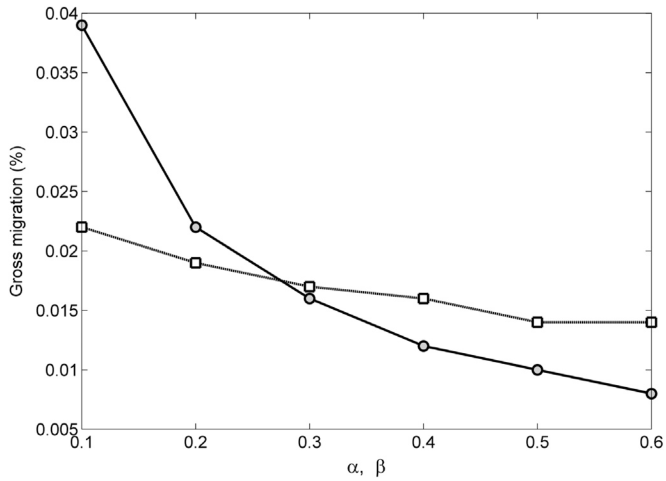


Fig. 6. Changing response of workers to productivity shocks with different parameter values α (blank squares) and β (filled circles).

richly specified structure originally developed in the trade theoretic literature following Eaton and Kortum (2002). We employ a technique originally developed by Caliendo et al. (2014) to pin down the migratory responses in a static multi-region, multi-sector economy. We convert it into a dynamic general equilibrium model. In steady state, the system is subjected to successive productivity shocks under realistic parameterization and from that we generate a *directed* and *weighted* network of migration. We use standard parameter values for U.S. economy to simulate the model, which performs well in explaining the network of labor flow across states of the U.S. and it matches the gross flow of labor with the real data reasonably well. Apart from providing a model of the multilateral gravity equations, we have also experimented with possible changes in the capital intensity, preferences as well as the trade patterns. The results show that the aggregate level of migration can be substantially affected due to such changes. In particular, increase in capital intensity significantly reduces the aggregate level of migration.

A simplifying assumption made throughout the exercise that makes the model tractable, is that people migrate for economic incentives in a frictionless set-up. While there can be multiple reasons to migrate (for example, family-related), this assumption regarding motivation behind migration is broadly consistent with the data (Kennan and Walker, 2011). The lack of frictions allows us to keep the model easily tractable. However, it excludes the case of country-to-country migration with substantial differences in economic and social structure, but for the present purpose it is a useful approximation. Another factor was considered by Molloy et al. (2011) regarding the effects of the housing sector on migration. While it is true that there are several instances of sudden increase in country-specific migration due to housing sector boom, in general that does not play an important role. In principle, the present model could be easily augmented with a housing sector. First, that would not change the resultant gravity equation in migration and second, Kaplan and Schulhofer-Wohl (2013) argue that the housing sector shows much more volatility than the process of migration which is highly inertial. Molloy et al. (2011) considered this particular channel and showed that there exists a very weak connection if any, in case of U.S.

To maintain tractability, we assume that capital is state-specific. For modeling international migration this assumption may not be very realistic as international migration may be related to FDI (Jayet and Marchal, 2016). In the present context, we assumed that the frequency with which productivity dispersion appears is quite high, i.e. we are effectively assuming that labor adjusts faster than capital. Possible causes may include institutional barriers for example. A related point is that research in this area suggests that the relationship between migration and FDI works through the mobility of the skilled workers. Jayet and Marchal (2016) for example shows that capital can substitute unskilled labor but complement skilled labor (see Kugler and Rapoport, 2007; see also Javorcik et al., 2011 for the effects of migration on capital flow). A future direction of the work would be to include capital flow with skill differences for labor and studying complementarity or lack thereof, in presence of productivity shocks.

Finally, the assumption of frictionless environment and homogeneity of labor effectively implies zero migration cost and that labor is perfectly substitutable across states and sectors. Due to this assumption, we do not have to keep track of different types of labor migrating all over the set of states considered. While this assumption restricts us from discussing other issues like skill-specific migration as discussed above, we retain it because of the tractability it provides to the model. Introducing constant migration cost would reduce the level of total migration only without impacting the relative pair-wise flows. On the other hand, introducing region-specific or household-specific migration cost would introduce pair-wise frictions, which in turn would provide a general equilibrium channel of multilateral resistance. However, even though introducing such a factor would be more realistic, it would complicate the decision making process considerably. With such an assumption, we would have to keep track of the distribution of such heterogeneous households to determine market clearing prices for wages and rental rates, which lies outside the scope of this paper. So in the present paper, we assumed cost of mobility to be zero for analytical and computational simplicity. A future direction of research would be to incorporate frictions explicitly in the general equilibrium model to estimate the effects of different types of friction on migration in presence of multiple sources and destinations.

To summarize, the present approach allows us to model the migration decision of households as a function of relative opportunities based on macroeconomic fundamentals of multiple destinations. Also, the model provides policy implications for analyzing and potentially regulating internal migration. We show that long run increases in the capital intensity in the production structure has a substitution effect on labor, reducing migration. Also, shifting consumer preferences for non-tradables like services will reduce migration. Thus the policy makers aiming to increase internal migration to have a more flexible labor market within the country need to factor in these effects which reduces the incentives for migration. On the other hand, the elasticity of migration with respect to changing trade asymmetries is fairly low implying that the changes in the relative trade flows (caused by emergence of a new trading hub, for example) across regions will have a muted effect on migration. Thus the secondary effect of trade asymmetries that the policy-makers consider in terms of affecting consumer welfare by hampering prospect of migration may be reasonably low. Hence, a country can pursue a pro-active policy for increasing internal migration by favoring production of goods that are tradable, rather than region-specific non-tradable consumption goods.

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A.1. Sources of data

Migration is defined as movement across different regions of residence in one year. More specifically, if a person was in a different state of residence (in the present context) in the previous year than this year, then we count that person as a migrant (Table 3).

A.2. Equilibrium conditions

The basic references for solving this types of models are Caliendo and Parro (2014) and Caliendo et al. (2014). Below, we list the equilibrium conditions. We normalize the total population so that L=1 in the following.

- Labor mobility conditions (N equations):

$$\widehat{L}_n = \frac{\left(\frac{\widehat{\omega}_n}{\widehat{P}_n}\right)^{1/\beta}}{\sum_n L_n\left(\frac{\widehat{\omega}_n}{\widehat{P}_n}\right)^{1/\beta}}L, \tag{49}$$

where

$$\widehat{P}_n = (\widehat{P}_n^M)^{\alpha}(\widehat{P}_n^S)^{1-\alpha}. \tag{50}$$

- Regional market clearing conditions ($2N$ equations):

$$X_n^{j'} = \alpha^j(\widehat{\omega}_n(\widehat{L}_n)^{1-\beta}I_n L_n), \tag{51}$$

where the index j refers to sectors M and S.
- Price index ($2N$ equations):

$$\widehat{P}_n^j = \left(\sum_{i=1}^{N}\pi_{ni}^j(\widehat{x}_i^j)^{-\theta^j}(\widehat{Z}_i^j)^{\theta_j}\right)^{-1/\theta^j}, \tag{52}$$

where the index j refers to sectors M and S.
- Trade shares ($2N^2$ equations):

$$\pi_{ni}^{j'} = \pi_{ni}^j\left(\frac{\widehat{x}_i^j}{\widehat{P}_n^j}\right)^{-\theta^j}(\widehat{Z}_i^j)^{\theta^j}, \tag{53}$$

where the index j refers to sectors M and S.
- Labor market clearing (N equations):

$$\widehat{\omega}_n(\widehat{L}_n)^{(1-\beta)}I_n L_n = \sum_j\sum_i \pi_{in}^{j'}X_i^{j'}, \tag{54}$$

where the index j refers to sectors M and S.

A.3. Solution algorithm

The system can be solved block recursively. We have modified the algorithm presented in Caliendo et al. (2014) for solving the labor allocation problem resulting from asymmetric productivity shocks to suit our purpose. Below we present the steps to be followed for solving the model. Consider exogenous changes in productivity $\widehat{Z}_n^M$, $\widehat{Z}_n^S$ for all n. Define a weight $f \in (0, 1)$ to be used to update the guess. In practice, f=0.99 works well.

- Guess relative change in regional factor prices $\widehat{\omega}$.
- Set $\widehat{x}_n^j = \widehat{\omega}_n$ and

$$\widehat{P}_n^j = \left(\sum_{i=1}^{N}\pi_{ni}^j(\widehat{x}_i^j)^{-\theta^j}(\widehat{Z}_i^j)^{\theta_j}\right)^{-1/\theta^j}. \tag{55}$$

Table 3
Data sources.

Data	Source
Migration	American Community Survey Data (2007)
Per capita personal income	Bureau of Economic Analysis (2007)
State population	Bureau of Economic Analysis (2007)
Trade share across states	Economic Census: Transportation Commodity Flow Survey (2007)
TFP	OECD (2007)

- Find

$$\pi_{ni}^{j'} = \pi_{ni}^{j}\left(\frac{\hat{x}_i^j}{\hat{P}_n^j}\hat{\kappa}_{ni}^j\right)^{-\theta^j}(\hat{Z}_i^j)^{\theta^j}. \quad (56)$$

- Find

$$\hat{L}_n = \frac{\left(\frac{\hat{\omega}_n}{\hat{P}_n}\right)^{1/\beta}}{\sum_n L_n\left(\frac{\hat{\omega}_n}{\hat{P}_n}\right)^{1/\beta}}L, \quad (57)$$

where

$$\hat{P}_n = (\hat{P}_n^M)^{\alpha}(\hat{P}_n^S)^{1-\alpha}. \quad (58)$$

- Find

$$X_n^{j'} = \alpha^j(\hat{\omega}_n(\hat{L}_n)^{1-\beta}I_n L_n). \quad (59)$$

- Find

$$\hat{\omega}^{new} = \frac{\sum_i \pi_{in}^{j'} X_i^{j'}}{\hat{L}_n^{(1-\beta)}(I_n L_n)} \quad (60)$$

- Update the guess by

$$\hat{\omega}^* = f\cdot\hat{\omega} + (1-f)\cdot\hat{\omega}^{new} \quad (61)$$

- Stop if $\| \hat{\omega} - \hat{\omega}^* \| \le \epsilon$, else go back to the first point above.
- Find net labor inflow,

$$F_n = (\hat{L}_n - 1)L_n. \quad (62)$$

- Construct the network of labor flow,

$$F_{ij} = -\left(\frac{(\hat{L}_j - 1)L_j}{\sum_{n\in\mathcal{N}^{out}}(\hat{L}_n - 1)L_n}\right)(\hat{L}_i - 1)L_i, \quad (63)$$

where $\mathcal{N}^{out}$ is the set of states from which labor migrates to other states and $j \in \mathcal{N}^{out}$. This process generates an directed labor flow network.
- Define a new matrix, $F = triu(abs(F + F'))$ where the operator $triu(\cdot)$ gives the upper triangular part and $abs(\cdot)$ denotes absolute value of their respective arguments.

This way one would generate the directed, weighted network between N states. With repeated shocks for T periods, one would have T networks each for each period. Summing over them one can generate the final network. We have averaged the final network thus produced over $O(10)$ realizations to arrive at a stable network free of fluctuations in the edge weights.

A.4. Parameter values

Below we list all parameter values in Table 4 used in the counterfactual experiments in Section 4 (N=10). Parameter values used in the benchmark simulations can be found Table 1.

Table 4
Parameter values used for counterfactual experiments.

Description	Parameter	Value (Section 4.1)	Value (Section 4.2)	Value (Section 4.3)
Population	L_n	0.1	0.1	0.1
Service goods' weight in consumption	$1-\alpha$	–	0.6	0.6
Trade linkages	τ_{ni}	$1/N$	–	$1/N$
Capital's share in cost	β	0.3	0.3	–
Dispersion of shocks: manufacturing	θ_m	8	8	8
Dispersion of shocks: service	θ_s	2	2	2
Std. dev. of shocks: manufacturing	σ_M	0.0380	0.0380	0.0380
Std. dev. of shocks: service	σ_S	0.0057	0.0057	0.0057
Length of simulation	T	200	200	200
# simulations averaged		10	10	10

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