ONLINE APPENDIX

A Model Details

A.1 Financial Intermediaries We first describe in detail the financial intermediaries and their relationship with consumers. We assume there is a mass of competitive financial intermediaries. Consumers can make one period nominal deposits d with the intermediaries. The period after the deposit is made, it pays Rd if the agent is alive and 0 otherwise, where R is determined on the competitive market. The deposit d can be positive or negative. The financial intermediaries are either risk-neutral or perfectly diversified over their customers' mortality risk.

On the asset side, the intermediaries invest in location and sector-specific physical capital. In addition they can sell or buy bonds b at the risk-free rate r. Then for a deposit d the intermediary's next period's profit is

$$\max_{(\{k_{io}\},b)} (1+r)b + \sum_{io} [R_{io} p^k_{io} k_{io} + (1-\delta_i) p^k_{io} k_{io}] - \pi R d$$

$$\text{subject to } k_{io} \geq 0$$

$$b + \sum_{io} p^k_{io} k_{io} = d$$

with $R_{io} p^k_{io}$ the rental rate of capital of type io; the rest of the return is the resale value of the capital stock. Clearly all kinds of capital must have the same rate of return:

$$R_{io} + 1 - \delta_i = \bar{R} \qquad \forall i.$$

Also in equilibrium perfect competition implies

$$\bar{R} = \pi R = 1 + r.$$

So we obtain that $R_{io} = \bar{R} + \delta_i - 1 = 1 + r + \delta_i - 1 = r + \delta_i$ and hence the price of capital services is $(r + \delta_i) p^k_{io}$. Similarly, $R = (1+r)/\pi > 1 + r$.

A.1.1 Agent's constraints and decisions

Here we elaborate on the derivations presented in section 3.1. Even though agents can invest in capital directly, deposits at the financial intermediaries dominate because their returns, conditional on survival, are $R = (1+r)/\pi > 1+r$. Hence the budget constraint for a live consumer in location o at age a is

$$d_{a+1} + P_o c_a = R d_a + w_o = \frac{1+r}{\pi} d_a + w_o$$

with $d_0 = 0$. Then standard arguments by iterating the equation forward, imposing No-Ponzi Game constraint and taking limits implies the constraint (9).

The consolidated budget constraint can be rewritten as follows in real terms:

$$\sum_{a=0}^{\infty} \frac{\pi^a}{(1+r)^a} c_a = \frac{1+r}{1+r-\pi} w^*.$$

Then the Lagrangian for the agent's optimization problem is:

$$\mathcal{L} = \sum_{a=0}^{\infty} (\pi\beta)^a \ln c_a + \zeta \left(\frac{1+r}{1+r-\pi} w^* - \sum_{a=0}^{\infty} \frac{\pi^a}{(1+r)^a} c_a \right),$$

with ζ being the Lagrangian multiplier. The first-order conditions are:

$$(\pi\beta)^a \frac{1}{c_a} = \zeta \frac{\pi^a}{(1+r)^a}$$

$$c_a = \zeta^{-1} (\beta(1+r))^a.$$

Plugging the expression above in the budget constraint in real terms implies

$$\zeta^{-1} = \frac{(1-\beta\pi)(1+r)}{1+r-\pi} w^*,$$

which implies the expression for c_a in section 3.1.

A.1.2 Capital market equilibrium

The deposits (in nominal terms) of surviving agents in location o evolves according to:

$$d_{a+1}^o = R d_a^o + w_o - P_o c_a,$$

with $d_0 = 0$. Let $g = \beta(1+r)$ and $K \equiv \frac{(1-\beta\pi)(1+r)}{1+r-\pi}$. Then $c_a = K g^a w^*$ and $P_o c_a = K g^a w_o$. So we have that:

$$
\begin{aligned}
d_a^o &= w_o(1+R+\cdots R^{a-1}) - K(R^{a-1}+R^{a-2}g+\cdots Rg^{a-2}+g^{a-1})w_o \\
&= w_o\frac{1-R^a}{1-R} - Kw_o\frac{R^a-g^a}{R-g} \\
&= w_o\frac{1-R^a}{1-R} - \frac{\pi}{1+r-\pi}(R^a-g^a)w_o \\
&= \frac{\pi}{1+r-\pi}(g^a-1)w_o
\end{aligned}
$$

If location o has population of L_o, then there are $(1-\pi)\pi^a L_o$ agents of age a there. Noting that deposits d_{a+1} are done by agents of age a, we find that

$$
Assets_o = \sum_{a=1}^{\infty}(1-\pi)\pi^{a-1}L_o d_a^o = \frac{\pi(\beta(1+r)-1)}{(1+r-\pi)(1-\pi\beta(1+r))}L_o w_o \tag{A.1}
$$

Then tedious but straightforward algebra implies that for every location (and hence for the economy of the whole),

$$
r\ Assets_0 + L_o w_o = L_o c^* P_o = \lambda(r) L_o w_o, \tag{A.2}
$$

where $c^* = \lambda(r)w^*$ and $\lambda(r)$ is given by (13). The equation above is the aggregated budget constraint at the steady state.

The consolidated assets of all financial intermediaries, must equal the value of the capital stock, the only asset in the economy in positive net supply:

$$
\sum_o Assets_o = \sum_o \left[\sum_i p_{io}^k K_{io} + p_{To}^k K_{To}\right] \tag{A.3}
$$

So finally, combining (A.2) and (A.3) implies (26).

A.2 CES price indices

Standard CES cost minimization implies that the optimal minimized cost for the intermediate goods bundle is

$$
P_{X,io} = \left[\sum_{j=1}^{n} \upsilon_{ij}\tilde{p}_{jo}^{-\frac{\rho}{1-\rho}}\right]^{-\frac{1-\rho}{\rho}}. \tag{A.4}
$$

In the same way, cost minimization and the Cobb-Douglas production function implies that the cost of the labor-capital composite for commodity i in location o is

$$q_{io} = [(r + \delta_i)p^k_{io}]^{\theta_i} w_o^{1-\theta_i}. \tag{A.5}$$

In a similar fashion, the price of investment bundle (and also capital) is

$$p^k_{io} = \prod_{j=1}^{n} \tilde{p}_{jo}^{\eta_{ij}}, \tag{A.6}$$

A.3 Matrices M and J

Our convention is that in a generic matrix D, buyers are in rows and sellers are by columns, so $D'Q$ is the column vector of purchased intermediate goods or capital. Producers optimally demand local goods to create composite goods according to (15). Hence we have

$$M_{\tilde{id},io} = \frac{1}{\ell}\ \phi_{io,d}\ \tilde{p}_{id}^{\frac{1}{1-\gamma}} (p_{io} + t_{iod}P_{To})^{-\frac{1}{1-\gamma}} \text{ if } i \in \mathcal{P}_{\mathcal{T}},$$

$$M_{\tilde{id},id} = 1 \text{ if } i \in \mathcal{P}_{\mathcal{NT}}$$

In addition, $t_{iod}Z_{iod}$ of To transportation services are required, so

$$M_{\tilde{id},To} = t_{iod}M_{\tilde{id},io}.$$

All the other elements of the row $M_{\tilde{id},\cdot}$ are zeros.

Producer optimization implies that demand for intermediate goods is given by (17), hence:

$$M_{io,\tilde{jo}} = \frac{\tilde{X}_{jo}}{Q_{io}} = A_{io}^{\frac{\sigma}{1-\sigma}} \alpha_i v_{ij} P_{int,io}^{\frac{1}{1-\rho}} \tilde{p}_{jo}^{-\frac{1}{1-\rho}} P_{int,io}^{-\frac{1}{1-\sigma}} p_{io}^{\frac{1}{1-\sigma}}$$

with $M_{To,\tilde{jo}}$ given by the same expression and all the other elements of the row being 0.

Let's denote $\hat{I}$ to be the vector of investment in sector- and location-specific capital; let I be the vector of investment use of the local and composite commodities. Define the $(2n + 1)\ell \times (2n + 1)\ell$ matrix Δ by $\Delta_{io,io} = \delta_i$ and 0 otherwise. Then the stationarity of the capital stock implies that the vector of investment in sector specific capital:

$$\hat{I} = \Delta K.$$

Let S be a $(2n + 1)\ell \times (2n + 1)\ell$ matrix such that $S'Q$ denotes the demand for sector-specific capital stocks. $S_{io,io}$ is given by equation (19) (and similarly for $S_{To,To}$) while all the other elements are zero (including zero rows for all the composite products). So $K = S'Q$

and $\hat{I} = \Delta S' Q$.

Next, let the $(2n+1)\ell \times (2n+1)\ell$ matrix N denote the optimal construction of the location and sector-specific capital stock. $N_{io,\tilde{j}o}$ is given by equation (20) while all the other elements are 0. Also this notation and (A.6) imply

$$P^k = NP,$$

where P^k and P are the vectors of prices for capital and other commodities.

Finally the optimal construction of the investment good implies:

$$I = N'\hat{I} = N'\Delta S' Q$$

Defining $J = S\Delta N$, we have $I = J'Q$.

A.4 Proofs

Proof of Lemma 1. Before we proceed with the proof, we establish a necessary property of the generalized Leontief inverse. Let $F = M + J$. We have that $\Omega(I - F) = I$, which rearranges to $\Omega = I + \Omega F$. Then by iteration:

$$\Omega = I + F + F^2 + \cdots F^s + \Omega F^{s+1} \geq I + F^2 + \cdots F^s$$

for any s, where we used the fact that $M \geq \mathbf{0}$, $J \geq \mathbf{0}$, hence $F \geq \mathbf{0}$ and $\Omega \geq \mathbf{0}$. This implies that if $F^s_{a1,a2} > 0$ or if $(F\Omega)_{a1,a2} > 0$, then $\Omega_{a1,a2} > 0$. Also since Ω exists and is nonnegative, it follows that $\lim_{s\to\infty} F^s = \mathbf{0}$.

Let's define a good i to be nontrivial if there exist some indices $s_1, s_2, \cdots s_m$ such that

$$\xi_{s_1}(\alpha_{s_1} v_{s_1,s_2} + \theta_{s_1}\eta_{s_1,s_2})(\alpha_{s_2} v_{s_2,s_3} + \theta_{s_2}\eta_{s_2,s_3})\cdots(\alpha_{s_m} v_{s_m,i} + \theta_{s_m}\eta_{s_m,i}) > 0.$$

Given the discussion above and the form of the matrices G and F, a good i is produced in positive amounts if and only if it is nontrivial.

Let p be the number of nontrivial local goods that use labor directly ($1 \leq p \leq n$) with P being the corresponding set of commodities. If the transportation sector does not use labor set $q = 0$; otherwise define q to be the number of locations o such that $t_{io,d} > 0$ for some i, d with i nontrivial and tradable. So we have $p\ell + q$ industry-location pairs that are nontrivial and use labor directly. Let P_{total} be the set of all these industry-location pairs.

We can adopt any ordering scheme for the $(2n+1)\ell$ commodities in the vectors and matrices used in Section 3.4. The ordering convention we adopt here is that we list first industry 1 in the set P and all its locations, industry 2 and so on till industry p; then we list all q transportation-location pairs and then in a similar way we list all the remaining industries (including the aggregated ones). This numbering scheme implies that the last $(2n+1)\ell - p\ell - q$ rows of the matrix z are only zeros. Then for any L, $z\Omega' G' L$ has only zeros for the last $(2n+1)\ell - p\ell - q$ elements. Let

$$R = \left[I_{p\ell+q\times p\ell+q} \quad \mathbf{0}_{p\ell+q\times(2n+1)\ell-p\ell-gq} \right].$$

Then the matrices $D = z\Omega' G'$ and $E = Rz\Omega' G' R'$ have the same nonzero eigenvalues; moreover L is an eigenvector of D if and only if RL is an eigenvector of E and the last $(2n+1)\ell - p$ elements of L are zeros. So we will focus on the matrix E.

In order to apply the Perron-Frobenius theorem[22] we need to show that the matrix E is irreducible, that is for any indices x_1, x_2 there exists $m(x_1, x_2)$ such that $\left(E^{m(x_1,x_2)}\right)_{x_1,x_2} > 0$. Most of the rest of the proof is devoted to this step.

Case 1 $x1 = ea$, $x2 \in P_{total}$, where $e \in P$ is a tradable good and a is some arbitrary location.

First, $x_2 = fb$ for some industry f and location b. The expressions for M, J imply that if $(\alpha_{s_1} V_{s_1,s_2} + \theta_{s_1}\eta_{s_1,s_2}) > 0$, then $F_{a_1o,\widetilde{a_2o}} > 0$. Also, we know that $F_{\widetilde{io},io} = M_{\widetilde{io},io} > 0$ for all io and $F_{\widetilde{io},id} = M_{\widetilde{io},id} > 0$ for all d if i is tradable. Then the fact that i is nontrivial and the discussion above imply that for some indices

$$\xi_{s1} F_{\widetilde{s_1b},s_1b} F_{s_1b,\widetilde{s_2b}} F_{\widetilde{s_2b},s_2b} \cdots F_{s_kb,\widetilde{eb}} > 0. \tag{A.7}$$

Since e is tradable, $F_{\widetilde{eb},ea} > 0$. This and equation (A.7) imply that $F^m_{\widetilde{s_1b},ea} > 0$ for some m hence $\Omega_{\widetilde{s_1b},ea} > 0$. Since $\xi_{s_1} > 0$, the expressions for G implies $G_{fb,\widetilde{s_1b}} > 0$. Finally, since e is in P, $z_{ea,ea} > 0$. Then we have that $z_{ea,ea}\Omega'_{ea,\widetilde{s_1b}} G'_{\widetilde{s_1b},fb} > 0$, so $E_{ea,fb} > 0$.

Case 2 $x1 = ea$, $x2 \in P_{total}$, where $e \in P$ a nontradable good and a is some arbitrary location.

If the locations coincide ($a = b$), then the construction above can be repeated. If $a \neq b$, we need a few additional steps. Let s_2 be an arbitrary tradable good. By the same construction as above, $\xi_{s_1} F^{m_1}_{\widetilde{s_1b},\widetilde{s_2b}} > 0$ for some integer m_1 and industry s_1. Since s_2 is tradable, $F_{\widetilde{s_2b},s_2a} > 0$, so $\xi_{s_1} F^{m_1+1}_{\widetilde{s_1b},s_2b} > 0$. The second part of assumption 1 and a similar construction as before implies that $F^{m_2}_{s_2a,s_3a} > 0$ for some $s_3 \in P$. Therefore, $F^{m_1+m_2+1}_{\widetilde{s_1b},s_3a} > 0$, so $\Omega_{s_1b,s_3a} > 0$. Also, since $G_{fb,\widetilde{s_1b}} > 0$ and $z_{s_3a,s_3a} > 0$, it follows that $G_{fb,\widetilde{s_1b}}\Omega_{\widetilde{s_1b},s_3a} z_{s_3a,s_3a} > 0$, which is equivalent to $E_{s_3a,fb} > 0$.

[22]See Meyer (2010), chapter 8 for details on the Perron-Frobenius theorem.

We already established that $E_{ia,ja} > 0$ for any industries $i, j \in P$, so $E_{ea,s_3a} > 0$ and hence $(E^2)_{ea,fb} > 0$.

Case III $q > 0$ and the good $ea = To$ with $t_{iod} > 0$ for some d and some nontrivial tradable i.

By the same construction as used before we establish that for some s_1, $G_{fb,\widetilde{s_1 b}} \Omega_{\widetilde{s_1 b},id} > 0$. But we have that $M_{\tilde{id},To} = t_{iod} M_{\tilde{id},io} > 0$. So we have that $z_{To,To} \Omega'_{To,\widetilde{s_1 b}} G'_{\widetilde{s_1 b},fb} > 0$ and hence $E_{To,fb} > 0$.

This implies that the matrix E is irreducible and nonnegative. Then the Perron-Frobenius theorem directly implies all the results of the lemma. □

Proof of Theorem 1. We prove the four statements of the theorem.

1. If an equilibrium allocation exists given wages and prices, it is unique.

   Suppose that there exists an equilibrium allocation for the given wages and prices. Then as we show in section 3.4, consumer and producers optimization, goods and labor market clearing implies $L = \lambda(r) z \Omega' G' L$. Lemma 1 shows that there exists a unique nonnegative eigenvector of the matrix $\lambda(r) z \Omega' G'$. Since $C = G'L, Q = \Omega' C; K = S'Q$, $I = J'Q$, it follows that the equilibrium allocation is unique.

2. A necessary condition for existence of equilibrium, given wages and prices is that $\lambda(r) sp(z\Omega' G') = 1$.

   Since $L = \lambda(r) z \Omega' G' L$, then 1 is an eigenvalue of $\lambda(r) z \Omega' G'$; since $L \geq \mathbf{0}$, lemma 1 also implies that $1 = sp(\lambda(r) z \Omega' G' L) = \lambda(r) sp(z \Omega' G' L)$.

3. A sufficient condition for existence of equilibrium, given wages and prices is that $\lambda(r) sp(z\Omega' G') = 1$.

   We use the notations introduced in Appendix A.3. The proof is by construction. As lemma 1 implies, there exists a (unique) nonnegative eigenvector L given by $L = \lambda(r) z \Omega' G' L$. Then define $C = G'L; Q = \Omega' C; K = S'Q; I = J'Q$. As shown in section 3.4, by construction we have goods and labor market clearing, and firms and households optimize. The household's budget constraint holds by the construction of the matrix G and the fact that $C = \lambda(r) G' L$; the stationarity of capital stocks is built into the construction of J'. Finally, we need to show that the asset market clears. Let W be the vector of nominal wages. The price minimization conditions (10), (14), (A.4), (16), (A.5) and (A.6) can be rewritten as

$$\begin{aligned}
P &= MP + S(rI + \Delta)P^k + zW \\
&= MP + rSP^k + S\Delta NP + zW \\
&= MP + rSP^k + JP + zW,
\end{aligned}$$

which implies that

$$\begin{aligned}
P &= (I - M - J)^{-1}(rSP^k + zW) \\
&= \Omega(rSP^k + zW)
\end{aligned}$$

Using the equation above and the fact that $z\Omega' G' L\lambda(r) = L$:

$$\begin{aligned}
P'C &= rP^{k'} S'\Omega' C + W' z\Omega' C \\
&= rP^{k'} S' Q + W' z\Omega' G' L\lambda(r) \\
&= rP^{k'} K + W' L,
\end{aligned}$$

which is equivalent to (26).

4. If $\theta = \mathbf{0}$, then $sp(z\Omega' G') = 1$ and the equilibrium $r = \frac{1}{\beta} - 1$.

   Lemma 1 implies that $\mu = sp(z\Omega' G') > 0$ and that there is a unique $L \geq \mathbf{0}$ such that $z\Omega' G' L = \mu L$. By construction, $S = \mathbf{0}$, so by the same derivation as above $P' G' L = \mu W' L$. By construction, $P' G' = W'$, so we obtain

$$\mu = \frac{P' G' L}{W' L} = \frac{W' L}{W' L} = 1,$$

   which proves the first subclaim. Note that z, Ω, G, W do not depend on r.

   Finally, we know that a necessary condition for equilibrium is that $\lambda(r) sp(z\Omega' G') = 1$, so the fact that $sp(z\Omega' G') = 1$, implies $\lambda(r) = 1$. Then since $\lambda(\beta^{-1} - 1) = 1$ and $\lambda(.)$ is strictly increasing we have that $r = \beta^{-1} - 1$.

$\square$

B Derivations from the Simplified Model in Section 4

Proof of Proposition 1. The proof is organized in a number of claims that we prove.

Claim 1. *Let $p_{od} = p_o \bar{t} t_{od}$ be the user price of variety o in region d. Then:*

$$\frac{p'_{od}}{p_{od}} = \frac{p'_o}{p_o} + \frac{t_{od} p_{To}}{p_o} = \frac{p'_o}{p_o} + t_{od} A_o. \tag{B.1}$$

Proof of Claim *Using the definition,*

$$\frac{dp_{od}}{d\bar{t}} = \frac{d(p_o + \bar{t} t_{od} p_{To})}{d\bar{t}} = \frac{dp_o}{d\bar{t}} + t_{od} p_{To} + \bar{t} t_{md} \frac{dp_m}{d\bar{t}}$$

Then evaluating at $\bar{t} = 0$, and using the fact that for $\bar{t} = 0$, $p_{od} = p_o$,

$$\frac{p'_{od}}{p_{od}} = \frac{p'_o}{p_o} + t_{od} \frac{p_{To}}{p_o}.$$

Finally, since the transportation good and the regular good have the same production function up to multiplicative productivity, $\frac{p_{To}}{p_o} = \frac{1/A_T}{1/A_o} = A_o$, which implies (B.1).

Claim 2.

$$\frac{\tilde{P}'_m}{\tilde{P}_m} = \sum_o s_o^Z \frac{p'_{om}}{p_{om}} = \sum_o s_o^Z \frac{p'_o}{p_o} + \kappa_{m\leftarrow} \tag{B.2}$$

where $s_o^Z = Z_{om} p_{om} / (\tilde{P}_m \tilde{Q}_m)$ and $\kappa_{m\leftarrow} \equiv \sum_o s_o^Z \kappa_{om}$.

Proof of Claim *The prices are minimized costs of producing one unit, so the envelope theorem implies:*

$$\frac{d\tilde{P}_m}{d\bar{t}} = \sum_o \frac{Z_{om}}{\tilde{Q}_m} \frac{dp_{md}}{d\bar{t}} = \tilde{P}_m \sum_o \frac{p_{om} Z_{om}}{\tilde{P}_m \tilde{Q}_m} \frac{dp_{om}/d\bar{t}}{p_{om}}$$

Evaluating at $\bar{t} = 0$, $p_{om} = p_{od}, \forall m, d$ so $\frac{p_{om} Z_{om}}{\tilde{P}_m \tilde{Q}_m} = S_o^Z \quad \forall m$. Then plugging equation (B.1) in the expression above implies (B.2).

Claim 3. *If $\bar{t} = 0$, $\tilde{P}_m X_m / (p_m Q_m) = \tilde{P}_o X_o / (p_o Q_o) \forall m, o$. We denote $\tilde{P}_m X_m / (p_m Q_m) = S^X$.*

Proof of Claim *Real wage equalization implies that*

$$\frac{w_i}{\tilde{P}_i} = \frac{w_j}{\tilde{P}_j} = \omega \quad \forall i, j.$$

Then since all locations have the same constant returns to scale production function up to productivity, it follows that $\tilde{X}_o^* / L_o^* = z$ for all locations o. Then the cost share of intermediate goods is

$$\frac{\tilde{P}_o \tilde{X}_o}{p_o Q_o} = \frac{\tilde{P}_o \tilde{X}_o}{w_o L_o + \tilde{P}_o \tilde{X}_o} = \frac{z}{\omega + z} \equiv S^X,$$

a term common for all locations (and goods).

Claim 4.
$$\frac{p'_m}{p_m} = S^X \frac{\tilde{P}'_m}{\tilde{P}_m} + (1 - S^X)\frac{w'_m}{w_m} = \frac{\tilde{P}'_m}{\tilde{P}_m} + (1 - S^X)\frac{\omega'}{\omega}. \tag{B.3}$$

Proof of Claim *In the same fashion as above,*

$$\frac{dp_m}{d\bar{t}} = \frac{X_m}{Q_m}\frac{d\tilde{P}_m}{d\bar{t}} + \frac{L_m}{Q_m}\frac{dw_m}{d\bar{t}} = p_m \frac{\tilde{P}_m X_m}{p_m Q_m}\frac{d\tilde{P}_m/d\bar{t}}{\tilde{P}_m} + p_m \frac{w_m L_m}{p_m Q_m}\frac{dw_m/d\bar{t}}{w_m}.$$

Evaluating at $\bar{t} = 0$, $\frac{\tilde{P}_m X_m}{p_m Q_m} = S^X$ $\forall m$, *so*

$$\frac{p'_m}{p_m} = S^X \frac{\tilde{P}'_m}{\tilde{P}_m} + (1 - S^X)\frac{w'_m}{w_m}$$

Substituting $w'_m/w_m = \omega'/\omega + \tilde{P}'_m/\tilde{P}_m$ *finishes the derivation.*

With these 4 claims, we can prove the proposition (equation (28)). Add the arbitrary normalization $\sum_o S^Z_o \frac{p'_o}{p_o} = 0$. Then (B.2) implies

$$\frac{\tilde{P}'_m}{\tilde{P}_m} = \kappa_{m\leftarrow}.$$

Substituting in (B.3):
$$\frac{p'_m}{p_m} = \kappa_{m\leftarrow} + (1 - S^X)\frac{\omega'}{\omega}.$$

Then the normalization $\sum_o S^Z_o \frac{p'_o}{p_o} = 0$ implies

$$\sum_d S^Z_d \kappa_{d\leftarrow} + (1 - S^X)\frac{\omega'}{\omega} = 0$$

$$\frac{\omega'}{\omega} = -\frac{1}{1 - S^X}\sum_d S^Z_d \kappa_{d\leftarrow} = -\frac{1}{1 - S^X}\sum_d \sum_o S^Z_d S^Z_o t_{od} A_o$$

□

Proof of Corollary 1. Since $Z_{od}/\tilde{Q}_d \propto A_o^{\epsilon_\gamma}$ and $p_{od} \propto A_o^{-1}$, it follows that $S^Z_o = X A_o^{\epsilon_\gamma - 1}$ for some constant X. Since $ES^Z_o = 1$, it follows that

$$X = (EA_o^{\epsilon_\gamma - 1})^{-1} = \exp\left((1 - \epsilon_\gamma)\mu_A - \frac{\nu_a^2}{2}(\epsilon_\gamma^2 - 3\epsilon_\gamma + 2)\right),$$

where we used the distributional assumptions on A.

From Proposition 1, we know

$$\kappa = E(S_o^Z S_d^Z A_o t_o d) = X^2 E(A_o^{\epsilon_\gamma} A_d^{\epsilon_\gamma - 1} t_o d).$$

From the distributional assumptions, we know that

$$\ln(A_o^{\epsilon_\gamma} A_d^{\epsilon_\gamma - 1} t_{od}) \sim N\left((2\epsilon_\gamma - 1)\left(\mu_A - \frac{\nu_A^2}{2}\right) + \mu_t - \frac{\nu_t^2}{2}, (\epsilon_\gamma^2 + (\epsilon_\gamma - 1)^2)\nu_A^2 + \nu_t^2 + (2\epsilon_\gamma - 1)\rho_{tA}\nu_A\nu_t\right).$$

Then the expression for κ follows from the expression for X that we derived and the expectation of a lognormal variable. □

Proof of Proposition 2. The proof is in number of steps.

Step 1. ***Derivation of*** $\frac{p'_{od}}{p_{od}} - \frac{\tilde{P}'_d}{\tilde{P}_d}$

We have that

$$\begin{aligned}\frac{p'_{od}}{p_{od}} - \frac{\tilde{P}'_d}{\tilde{P}_d} &= \frac{p'_o}{p_o} + t_{od}A_o - \frac{\tilde{P}'_d}{\tilde{P}_d} \\ &= \frac{\tilde{P}'_o}{\tilde{P}_o} + (1 - S^X)\frac{\omega'}{\omega} + t_{od}A_o - \frac{\tilde{P}'_d}{\tilde{P}_d} \\ &= \kappa_{o\leftarrow} - \kappa_{d\leftarrow} - \kappa + t_{od}A_o,\end{aligned}$$

where we used in order equations (B.1)*;* (B.3)*;* (B.2) *and* (28)*.*

Step 2. ***Derivation of*** $\tilde{Q}'_{1d}/\tilde{Q}_{1d}$

The resource constraint implies:

$$\begin{aligned}\tilde{Q}_{1d} &= \tilde{C}_{1d} + \tilde{X}_{1d} + \tilde{X}_{td} \\ &= \frac{w_d L_d}{\tilde{P}_d}\left[1 + \frac{\tilde{P}_d X_{1d}}{w_d L_{1d}}\frac{L_{1d}}{L_d} + \frac{\tilde{P}_d X_{Td}}{w_d L_{Td}}\frac{L_{Td}}{L_d}\right]\end{aligned}$$

Equations (17), (18) *and the assumption that* $\alpha_T = \alpha_1$ *imply that*

$$\frac{\tilde{P}_d X_{1d}}{w_d L_{1d}} = \frac{\tilde{P}_d X_{Td}}{w_d L_{Td}} = S(\tilde{P}_d/w_d)^{1-\epsilon_\sigma}$$

for some S *that is a function of* α *and* ϵ_σ *only and is common across locations. So:*

$$\tilde{Q}_{1d} = \frac{w_d L_d}{\tilde{P}_d}\left[1 + S(\tilde{P}_d/w_d)^{1-\epsilon_\sigma}\right]$$

Then taking logs and differentiating:

$$\begin{aligned}
\frac{\tilde{Q}_d'}{\tilde{Q}_d} &= \frac{L_d'}{L_d} + \frac{w_d'}{w_d} - \frac{\tilde{P}_d'}{\tilde{P}_d'} + \frac{\frac{\tilde{P}_d X_{1d}}{w_d L_{1d}}}{1+\frac{\tilde{P}_d X_{1d}}{w_d L_{1d}}} \frac{\left(\frac{\tilde{P}_d X_{1d}}{w_d L_{1d}}\right)'}{\frac{\tilde{P}_d X_{1d}}{w_d L_{1d}}} \\
&= \frac{L_d'}{L_d} + \frac{w_d'}{w_d} - \frac{\tilde{P}_d'}{\tilde{P}_d'} + S^X(\epsilon_\sigma - 1)\left(\frac{w_d'}{w_d} - \frac{\tilde{P}_d'}{\tilde{P}_d'}\right) \\
&= \frac{L_d'}{L_d} + [1 - S^X + S^X \epsilon_\sigma]\frac{\omega'}{\omega}
\end{aligned}$$

Finally, using (28), we obtain

$$\frac{\tilde{Q}_{1d}'}{\tilde{Q}_{1d}} = \frac{L_d'}{L_d} - \kappa - S^X \epsilon_\sigma \frac{\kappa}{1-S^X} \tag{B.4}$$

Step 3. ***In equilibrium for*** $\bar{t} = 0$**,** $Z_{od} = Q_o L_d$

In step 2 we showed that $\tilde{Q}_d = \omega L_d \left[1 + S\omega^{\epsilon_\sigma - 1}\right]$*, which we can write as* $\tilde{Q}_d = K L_d$ *for some common* K*. Using the common cost shares at* $\bar{t} = 0$*,*

$$Z_{od} = \frac{S_o^Z \tilde{P}_d \tilde{Q}_d}{p_{od}} = \frac{\tilde{P} S_o^Z}{p_o} K L_d \tag{B.5}$$

Summing (B.5) over d *and using* $\sum_d Z_{od} = Q_o, \sum_d L_d = 1$*, we obtain* $\frac{K\tilde{P}S_o^Z}{p_o} = Q_o$*. Plugging this back in (B.5) shows that* $Z_{od} = Q_o L_d$*.*

Step 4. ***In equilibrium for*** $\bar{t} = 0$**,** $S_d^Z = S_d^Q = L_d$

Equation (14) and (16) imply that at $\bar{t} = 0$*,* $p_m = \bar{p}/A_m$ *for some common* $\bar{p}$*; also* $\tilde{P}_d = \tilde{P}$*. In a similar fashion (18) implies* $Q_m = \bar{Q} L_m A_m$*. Then* $Q_m p_m = \bar{Q}\bar{p}L_m$*. Then we have*

$$\bar{Q}\bar{p}L_m = Q_m p_m = \sum_d Z_{md} p_{md} = \sum_d S_m^Z \tilde{P}\tilde{Q}_d = S_m^Z \sum_d \tilde{P} K L_d = S_m^Z \tilde{P} K$$

Summing this over m *implies* $\bar{Q}\bar{p}/(\tilde{P}K) = 1$*. Also dividing the equation above by* $\tilde{P}K$ *gives* $S_m^Z = \bar{Q}\bar{p}L_m/(\tilde{P}K)$*, which implies that* $L_m = S_m^Z$*.*

Next, at $\bar{t} = 0$ *zero profit conditions imply* $p_m Q_m = w_m L_m + \tilde{P}_m X_m = \tilde{P}_m C_m + \tilde{P}_m X_m = \tilde{P}_m \tilde{Q}_m$*. So:*

$$S_d^Q = \frac{p_d Q_d}{\sum_m p_m Q_m} = \frac{\sum_m p_d Z_{dm}}{\sum_m p_m Q_m} = \frac{\sum_m p_{dm} Z_{dm}}{\sum_m \tilde{P}_m \tilde{Q}_m} = \frac{\sum_m S_d^Z \tilde{P}_m \tilde{Q}_m}{\sum_m \tilde{P}_m \tilde{Q}_m} = S_d^Z$$

Step 5. ***Proof of equation*** (30) *The CES demand structure implies that*

$$\frac{Z'_{od}}{Z_{od}} - \frac{\tilde{Q}'_d}{\tilde{Q}_d} = -\epsilon_\rho \left(\frac{p'_{od}}{p_{od}} - \frac{\tilde{P}'_d}{\tilde{P}_d} \right) = -\epsilon_\gamma \left(\kappa_{o\leftarrow} - \kappa_{d\leftarrow} - \kappa + t_{od} A_o \right), \tag{B.6}$$

where we used Step 1. Then we use the identity

$$\begin{aligned} \frac{Z'_{od}}{Z_{od}} &= \frac{Z'_{od}}{Z_{od}} - \frac{\tilde{Q}'_{1d}}{\tilde{Q}_{1d}} + \frac{\tilde{Q}'_{1d}}{\tilde{Q}_{1d}} \\ &= -\epsilon_\gamma \left(\kappa_{o\leftarrow} - \kappa_{d\leftarrow} - \kappa + t_{od} A_o \right) + \frac{L'_d}{L_d} - \kappa - S^X \epsilon_\sigma \frac{\kappa}{1 - S^X}, \end{aligned}$$

where we used (B.6) *and* (B.4). *Step 3 states that $Z_{1od} = Q_{1o} L_d$, so we obtain:*

$$Z'_{1od} = Q_{1o} \left[-\epsilon_\gamma \left(\kappa_{o\leftarrow} - \kappa_{d\leftarrow} - \kappa + t_{od} A_o \right) L_d + L'_d - \left(\kappa + S^X \epsilon_\sigma \frac{\kappa}{1 - S^X} \right) L_d \right].$$

Summing over d, using the facts that $\sum_d L_d = 1, \sum_d L'_d = 0$ and for $\bar{t} = 0$, $L_d = S^Z_d = S^Q_d$ (Step 4) gives the result.

Step 6. ***Derivation of equation*** (31) *Denote by L_{1o} the workers producing the nontransporation good o. We have the identity*

$$L_o = L_{1o} + L_{To} = Q_o \frac{L_{1o}}{Q_o} + \sum_d Z_{od} t_{od}\, \bar{t} \frac{L_{To}}{Q_{To}}.$$

Then differentiating with respect to $\bar{t}$ and evaluating at $\bar{t} = 0$,

$$L'_o = Q'_{1o} \frac{L_{1o}}{Q_o} + Q_o \left(\frac{L_{1o}}{Q_o} \right)' + \sum_d Z_{od} t_{od} \frac{L_{To}}{Q_{To}} \tag{B.7}$$

We will find the three expressions above separately. We have that

$$Q_o \left(\frac{L_{1o}}{Q_o} \right)' = L_{1o} \frac{\left(\frac{L_{1o}}{Q_o} \right)'}{\frac{L_{1o}}{Q_o}} = -L_{1o} \epsilon_\sigma \left(\frac{w'_o}{w_o} - \frac{p'_o}{p_o} \right) = L_{1o} \epsilon_\sigma \frac{S^X}{1 - S^X} \kappa.$$

Equation (30) *implies that*

$$Q'_o \frac{L_{1o}}{Q_o} = -L_{1o} \kappa - L_{1o} \epsilon_\sigma \frac{S^X}{1 - S^X} \kappa - L_{1o} \epsilon_\gamma \left(\kappa_{o\leftarrow} - \kappa + \kappa_{o\rightarrow} - \kappa \right).$$

Finally.

$$\sum_d Z_{od} t_{od} \frac{L_{To}}{Q_{To}} = \sum_d Q_o L_d t_{od} A_o \frac{L_{1o}}{Q_o} = L_{1o} \sum_d S_d^Z t_{od} A_o = L_{1o} \kappa_{o\to}.$$

Then noticing that at $\bar{t} = 0$, $L_o = L_{1o}$, summing the three expressions above implies the result.

$\square$

Lemma 2. *Define $tmargin_o \equiv \frac{\sum_d t_{od} Z_{od} p_{To}}{p_o Q_o}$. For $\bar{t} = 0$, $\kappa_{o\to} = tmargin_o$.*

Proof. Using the definition, $t_{od} p_{To}/p_o = \kappa_{od}$. So $tmargin_o = \frac{\sum_d Z_{od}\kappa_{od}}{Q_o}$. From Step 3 of the proof of proposition 2, $Z_{od} = Q_o L_d$. By Step 4, $L_d = S_d^Q$. Hence $Z_{od} = Q_o S_d^Q$. Therefore, $tmargin_o = \frac{\sum_d Z_{od}\kappa_{od}}{Q_o} = \sum_d S_d^Q \kappa_{od} = \kappa_{o\to}$. $\square$

C Model with Iceberg Transportation Costs

In this appendix, we consider a version of our model where transportation costs are modeled via the commonly used iceberg approach. The modifications of the model are minimal.

C.1 Model and solution

The model is identical to the baseline except for two modifications. First, there is no transportation sector. Second, as in the standard iceberg specification, in order to deliver one unit of good i from location o to destination d, $\tau_{iod} \geq 1$ units must be shipped.

The model solution is almost unchanged. All the price conditions are unchanged except for (14), which is replaced by

$$\tilde{p}_{jd} = \begin{cases} \left[\sum_{o=1}^{\ell} \frac{1}{\ell} \phi_{jod} (p_{jo} \cdot \tau_{jod})^{-\frac{\gamma}{1-\gamma}}\right]^{-\frac{1-\gamma}{\gamma}} & j \in \mathcal{P}_{\mathcal{T}} \\ p_{jd}. & j \in \mathcal{P}_{\mathcal{NT}} \end{cases} \tag{C.1}$$

By contrast with the baseline model, here the transportation cost affects the flow of goods from sector-region to sector-region directly, in addition to its effect on prices. Equation (15) is now modified as:

$$M_{\tilde{i}d,io} = \begin{cases} \tau_{iod} \frac{1}{\ell} \phi_{iod} \tilde{p}_{id}^{\frac{1}{1-\gamma}} (p_{io} \cdot \tau_{iod})^{-\frac{1}{1-\gamma}} & \text{if } i \in \mathcal{P}_{\mathcal{T}}, \\ 1 & \text{if } o = d \text{ and } i \in \mathcal{P}_{\mathcal{NT}}. \end{cases} \tag{C.2}$$

The rest of the model solution is completely unchanged, except that now the matrices M and J are of dimensions $2n\ell \times 2n\ell$; similarly the relevant column vectors have $2n\ell$ elements since there is no explicit transportation industry.

Hulten Theorem Here we discuss how to apply Hulten theorem to a model without an explicit transportation sector. We model lower transportation productivity by setting $\tau_{iod}^{1947} = \hat{\tau}\tau_{iod}^{2017}$ for all od and tradable i, where $\hat{\tau} > 1$.

If prices and quantities constitute an equilibrium with τ_{iod}^{1947}, they would also satisfy the equilibrium conditions for τ_{iod}^{2017} and $A_{io} = A_{io}^{2017}/\hat{\tau}$. Then the Hulten theorem implies:

$$\frac{d\ welfare}{welfare} = \sum_{i \in \mathcal{P}_T} \sum_{o} \frac{p_{io} Q_{io}}{GDP} \left(\frac{1}{\tau} - 1 \right).$$

C.2 Taking the model to the data

Since the BEA explicitly accounts for transportation and the iceberg model does not, we need to specify the model counterparts to the data.

Our approach is to construct a fictitious (in the model) transportation sector. In particular, for every shipment Z_{iod}, the fictitious transportation sector produces transportation services valued at $(\tau_{iod} - 1) Z_{io} p_{io}$.

Note that the resource constraint (embedded in the matrix M) is:

$$Q_{io} = \sum_{d} \tau_{iod} Z_{iod}.$$

Some of this output is attributed to the fictitious transportation sector, so net output is defined as:

$$Q_{io}^{net} = \sum_{d} Z_{iod}.$$

Introduce the $2n\ell \times 2n\ell$ matrix M^{fob} that is the equivalent of the matrix M net of the transportation costs:

$$M_{\tilde{i}d,io}^{fob} = \begin{cases} \frac{1}{\ell} \phi_{iod} \tilde{p}_{id}^{\frac{1}{1-\gamma}} (p_{io} \cdot \tau_{iod})^{-\frac{1}{1-\gamma}} & \text{if } i \in \mathcal{P}_{\mathcal{T}} \\ 1 & \text{if } o = d, i \in \mathcal{P}_{\mathcal{NT}} \end{cases}$$

and equal to the corresponding element of M elsewhere. Let $\hat{M}^{fob}$ be the submatrix of M^{fob} from the last $n \times \ell$ rows and the first $n \times \ell$ columns (demand from the tilde industries for the original industries); define $\hat{M}$ similarly as a submatrix of M. Then we have:

$$Q^{net} = (\hat{M}^{fob})' \tilde{Q},$$

which is net output of io; similarly

$$Q^t = (\hat{M} - \hat{M}^{fob})'\tilde{Q}$$

and

$$Q^{tval} = Q^t \circ p = [(\hat{M} - \hat{M}^{fob})'\tilde{Q}] \circ p.$$

Q_{io}^{tval} is the value of the fictitious transportation services required to move the output of sector io. So the value of transportation services produced in location o is $\sum_i Q_{io}^{tval}$.

Input-Output Table In the BEA IO table, purchases of intermediate goods are net of transportation costs. We construct the model-implied IO table in the same fashion, after stripping out the model-implied transportation cost. First, we define FOB price of the aggregated commodity as:

$$\tilde{p}^{fob} = \hat{M}^{fob} p.$$

Then S_{ij} is constructed as:

$$S_{ij} = \frac{\sum_{d=1}^{\ell} Q_{id}^{net} M_{id,\tilde{jd}} \tilde{p}_{jd}^{fob}}{\sum_{d=1}^{\ell} p_{id} Q_{id}^{net}}.$$

In order to construct a fictitious transportation sector we need the transportation cost embedded in $\tilde{jd}$:

$$\tilde{p}_{jd}^{t} = \sum_{o=1}^{\ell} (\tau_{jod} - 1) p_{jo} Z_{jo,d}^{*} = \tilde{p}_{jd} - \tilde{p}_{jd}^{fob},$$

so

$$S_{it} = \frac{\sum_{d=1}^{\ell} \sum_{j=1}^{n} Q_{id}^{net} M_{id,\tilde{jd}} \tilde{p}_{jd}^{t}}{\sum_{d=1}^{\ell} p_{id} Q_{id}^{net}}.$$

The transportation row of the input-output table is computed as follows:
The production of the transportation in region o by sector i is $Q_{io}^t = \sum_d (\tau_{iod} - 1) Z_{iod}$. We need to compute the intermediate inputs j used to produce the Q_{io}^t units of product io (and then sum across io). For each unit of product io, firms purchase $M_{io,\tilde{jo}}$ units of good j sold at producer price $\tilde{p}_{jo}^{fob}$. Thus, we have:

$$S_{tj} = \frac{\sum_o \sum_i \tilde{p}_{jo}^{fob} M_{io,\tilde{jo}} Q_{io}^t}{\sum_o \sum_i p_{io} Q_{io}^t}.$$

And S_{tt} is similar to S_{it}:

$$S_{tt} = \frac{\sum_i \sum_d \sum_j Q^t_{id} M_{id,\tilde{j}d} \tilde{p}^t_{jd}}{\sum_d \sum_i p_{id} Q^t_{id}}.$$

Employment The labor used directly in sector io is given by:

$$\hat{L}_{io} = Q^{net}_{io} z_{io},$$

where as a reminder Z_{iod} is the shipment of i from o to d (net of transportation requirements) and z_{id} is the labor requirement. Similarly for the transportation sector,

$$\hat{L}_{to} = \sum_i Q^t_{io} z_{io}.$$

Transportation margins Now the transportation margins are computed as:

$$\kappa_{io} = \frac{p_{io} Q^t_{io}}{p_{io} Q^{net}_{io}}$$

and

$$\kappa_i = \frac{\sum_o p_{io} Q^t_{io}}{\sum_o p_{io} Q^{net}_{io}}$$

C.3 Calibration of the iceberg model

We follow the same calibration strategy as for the baseline model and set the parameter values to match the same targets, that is, the employment shares, the input-output table, the value added shares, the distance elasticity and the out-of-region coefficient. The ratio of the value added to gross output of the transportation sector is not included for this specification as there is no natural counterpart to this statistics in the iceberg model.

The iceberg parameters and the regional production parameter can be obtained directly from the estimated distance elasticity and the out-of-region coefficient. Indeed, comparing the expression for the trade flows (without the part used for transportation services),

$$\ln Z_{iod} = -\frac{1}{1-\gamma} \ln \tau_{iod} + \frac{1}{1-\gamma} (\ln \tilde{p}_{id} - \ln p_{io}) - \ln \tilde{Q}_{id} + \ln \phi_{iod} - \ln \ell,$$

with the gravity equation (32), gives $-(1/(1-\gamma)) \ln(\tau_{iod}) = \varphi_{1i} \ln(distance_{od})$ and $\ln(\phi_{iod}) = \varphi_{2i} 1_{o \neq d}$, while the other terms are absorbed by the fixed effects. For simplicity, we parametrize $\tau_{iod} = (distance_{od})^{\zeta_i}$ and thus obtain $\zeta_i = -(1-\gamma)\varphi_{1i}$.

D Data

In this section we describe the data sources and the construction of the calibration targets, all computed from 2017 data unless noted otherwise. These include statistics that we use to directly pin down some of the model parameters.

D.1 Industrial Classification Our starting point is the 71 industries at the 3-digit classification used by the Bureau of Economic Analysis to report Input-Output tables, regional employment and capital stocks. Spanning *Farms (111CA)* to *State and local government enterprises (GSLE)*, these groupings broadly follow NAICS codes but deviate from them for a number of cases. We exclude five government sectors (GFXX and GSXX) and aggregate the remaining 66 private industries into the seven sectors used in our quantitative analysis. **Agriculture** (*111CA Farms and 113FF Forestry, fishing, and related activities*) and **mining** (*211 Oil and gas extraction, 212 Mining, except oil and gas, 213 Support activities for mining*) are straightforward. For the others, we follow the following procedures:

Services Jensen et al. (2005) classify NAICS industries into tradable vs non-tradable based on their geographic concentration under the assumption that only tradable activities exhibit excess clustering over and above the spatial distribution of population. Using their Table 2-4, we classify relevant industries into a binary indicator of tradability. Non-tradable services are as follows: Utilities (22), Construction (23), Retail (44-4A), services under NAICS 56 and higher. Tradable services include Wholesale (42) and services under NAICS 51-55.

Transportation Out of NAICS codes within 2-digit categories 48-49 spanning *Transportation and Warehousing*, we only include subsectors associated with freight and overhaul of commodities. These are Rail Transportation (482), Water Transportation (483), Truck Transportation (484) and Pipeline Transportation (486). BEA aggregates four subsectors, Scenic and Sightseeing Transportation (487), Support Activities for Transportation (488), Couriers and Messengers (492) and Warehousing and Storage (493), into a composite sector 487OS as "Other transportation and support activities," which we include within our transportation sector. In constructing the empirical targets related to transportation, we remove its direct use as final consumption and account for in-house transportation services provided internally by firms. These accounting adjustments are described below in detail. Finally, air transportation (481) is categorized as tradable service as it does not constitute a significant share of domestic shipments. Transit and

Ground Passenger Transportation (485) is treated as a non-tradable service sector.

Heavy and light manufacturing We use the 2017 Freight Analysis Framework data (which is based on the Commodity Flow Survey for the manufacturing sector but also includes agriculture and mining industries) and estimate a gravity regression of domestic flows at the level of 3-digit industries between the 18 regions depicted in Figure 1a. We rank manufacturing industries by their estimated distance elasticities and group them into heavy vs light so as to achieve a balanced division of employment within manufacturing. Finally, aggregating manufacturing into these two categories and re-estimating the gravity regression generates the distance elasticities reported in the data column of Table 2. The distance elasticities for agriculture and mining are imputed with the same procedure. The next Appendix section (subsection **Regional trade and distances**) gives further details about the estimation framework.

D.2 Calibration Targets

Input-output shares To take into account the fact that many firms produce transportation services in-house for their own use (to transport raw materials or intermediate inputs or to deliver output to customers), we use the input-output table published in the Transportation Satellite Accounts (TSA) from the Bureau of Transportation Statistics (BTS) for the year 2017. In producing the TSA, the BTS reorganizes the standard IO use tables from the BEA and introduces fictitious industries "in-house transportation" and "household production of transportation services" (HPTS). We abstract away from HPTS and compute the input-output shares after grouping together for-hire and in-house transportation and aggregating the used and using industries to our 7 sectors. We compute the input-output shares as the value of the intermediate inputs used by each industry, divided by the gross output of the industry. Note that the value of intermediate inputs is measured in producer prices and therefore does not include transportation and wholesale trade costs (even if they were paid by the producer). Note also that by construction, the input-output shares include imported intermediates while our model abstracts from international trade.

Sectoral value added shares For consistency with our assumption of no direct final use of transportation, we do not use published data on the industries' value added; rather, we compute the value added shares from the input-output and final use data, adjusted for consistency with the model.

We compute the valued added as $V = Q - diag(Q)M$. The matrix M is the input-output shares matrix (with element M_{ij} denoting the value of the intermediate inputs produced in sector j and purchased by sector i, divided by the gross output of sector i), Q is the vector of sectoral gross output, computed as $Q = (I - M')^{-1}D$, where I is the identity matrix and D is the vector of sectoral final uses, where for $i = 1, ..., n$, $D_i = \text{cons}_i + \text{inv}_i$ is equal to sum of Personal consumption expenditures and Investment (computed as the sum of Nonresidential private fixed investment in structures, Nonresidential private fixed investment in equipment, Nonresidential private fixed investment in intellectual property products and Residential private fixed investment). In line with our assumption, we leave aside the direct final use of transportation (for example, passenger transportation) and compute the final use of the transportation sector as the value of transportation services used in the shipment of final products, that is $D_{n+1} = margin \times \text{cons}_{n+1} + \text{inv}_{n+1}$. The transportation margin ratio for personal consumption expenditures, $margin$, is computed as the ratio of transportation costs (for the shipment of personal consumption expenditures) over the producers' value of personal consumption expenditures. The final use data are obtained from the table "Use of Commodities by Industries" (2017, Before redefinitions, in producers' price) and transportation margins computed from the supplemental table "Margin details" (2012, after redefinitions), both published by the BEA (The most recent year for which the margins data is available is 2012.)

Regional employment shares We use two datasets to construct sectoral employment shares by region: BEA data and County Business Patterns (CBP) data from the Census. In principle, the former reports all state-industry employment numbers needed for aggregation in our regional and sectoral groupings. However, it has a high number of data disclosure restrictions for various state-industry cells other than Farms (111CA). Since BEA data has complete coverage for all states without any data suppression for this sector, we use it to construct regional employment. For all other sectors, we use the CBP data which reports employment intervals for missing cells at the 6-digit industry level. Taking the mid-point of these intervals and aggregating up reduces the noise from filling in these suppressed cells.

Regional trade and distances As mapped in Figure 1a, we aggregate US states into 18 regions such that these can be further aggregated up to 9 Census divisions for the purposes of using inter-regional trade data from the 1963 Census of Transportation. Geodesic distances between regional centroids are used. 2017 data for gravity regressions comes from Freight Analysis Framework, which utilizes Commodity Flow Survey for manufacturing goods and

Table 7: Gravity Regression Results

	Agriculture	Mining	Heavy M.	Light M.
$\ln(dist_{od}), \varphi_{1i}$	-2.034	-3.051	-1.650	-1.201
	(0.095)	(0.163)	(0.060)	(0.054)
Out-of-region dummy, φ_{2i}	-1.796	-0.616	-1.045	-1.610
	(0.264)	(0.455)	(0.167)	(0.150)
N	324	324	324	324
Adjusted R^2	0.860	0.771	0.918	0.925

Notes: Dependent variable is $\ln(weight_{iod})$. All regressions include origin region and destination region fixed effects. Standard errors in parentheses.

complements it with shipments of agricultural and extractive products. Table 7 presents the detailed results from the estimation of the gravity regression specified in equation (32) in the paper and used as calibration targets (Table 2).

Capital shares in value added We use sectoral data on compensation of employees and Gross Operating Surplus from TSA IO tables. We aggregate to our 7 sectors. Then we compute

$$\theta_i' = \frac{\text{Gross Operating Surplus}_i}{\text{Gross Operating Surplus}_i + \text{Compensation of Employees}_i}.$$

We drop "Taxes on production and imports, less subsidies" to be consistent with our model (which does not have government).

The estimated θ_i' may be affected by self-employment. We therefore scale all θ_i' by the same factor to match the estimated labor share of the private economy. In particular, we set

$$\theta_i = \theta_i' \frac{\theta_{aggregate} \sum_i VA_i}{\sum_i VA_i \theta_i'},$$

where VA_i is the value added share of sector i and $\theta_{aggregate} = 1$ -Labor share of private business sector. We use the labor share estimated by the BLS (Table "Total factor productivity and Related measures of major sectors") available in `https://www.bls.gov/productivity/tables/total-factor-productivity-major-sectors.xlsx`

Capital flow We use estimates of capital flow data from vom Lehn and Winberry (2021). We use their baseline 37 sector classification, except for Farms, which are not included in the baseline. To get estimates for Farms, we combine the 41 sectors specification (which is in terms of shares, not flows) and data for Fixed Assets Investments from the BEA. We aggregate to our classification using NAICS codes for crosswalk and set $\eta_{ij} = I_{ij} / \sum_j I_{ij}$.

Sector-specific depreciation rates We use the BEA fixed assets tables for current cost depreciation estimates for the relevant year (2017) (table 3.4ESI) and for current cost estimates for the net stock of assets (table 3.1ESI). We aggregate both up to our degree of disaggregation and compute depreciation rates.

D.3 Backing out Transportation Productivity

Following the Solow residual approach (see Section 5.2), we combine the production function and first-order condition of the firms, both applied at the sectoral level, to express the productivity ratio $B_{Tt'}/B_{Tt}$, in 1947 and 1963, as a function of changes in the capital stock, in labor and real intermediate inputs, and the intermediate input shares. Because the 1947 raw real gross output and input-output data are not available at the same level of aggregation as the 1963 and 2017 data, we are not able to divide up the industries exactly as described in D.1. Specifically, air transportation (classified as a tradable service) and passenger transportation (classified as a non-tradable service) cannot be separated from the rest of the transportation sector in 1947. Hence, we use the aggregate transportation sector (including air and passenger transportation) in 1947 and, we remove air transportation (which only accounts for 3% of employment in 1947) for both 1963 and 2017. We kept passenger transportation because the sector accounts for a non negligible share of the sector in 1947 and we applied the same perimeter to all the variables used to compute the productivity change. Note that removing passenger transportation would only marginally modify the measured productivity change.

Another aggregation issue is related to the housing sector and other real estate activities (tradable services), which are grouped in 1947. We classify that grouping as nontradable and, for consistency, we regroup housing and other real estate in 1963 and 2017 as well. We now describe how to compute all the variables used in the derivation of the productivity ratio.

Real gross output The real gross output data are obtained from the BEA Industry Economic Accounts data. The gross output by industry is available separately for the period 1947-1997 and for 1997-2022. We compute real gross output by dividing nominal gross output by the corresponding chain-type price index for the relevant aggregation level. When the price index is not readily available at the relevant aggregation level, we compute it as the weighted average of the subindustries.

Employment We measure employment using the number of full-time equivalent employees published by the BEA in NIPA tables 6.5B, 6.5C and 6.5D.

Capital The real capital stock over the period 1947-2017 is constructed by multiplying real quantity index for capital stock (BEA fixed assets table 3.2ESI) with current cost estimates for the year 2017 (BEA fixed assets table 3.1ESI).

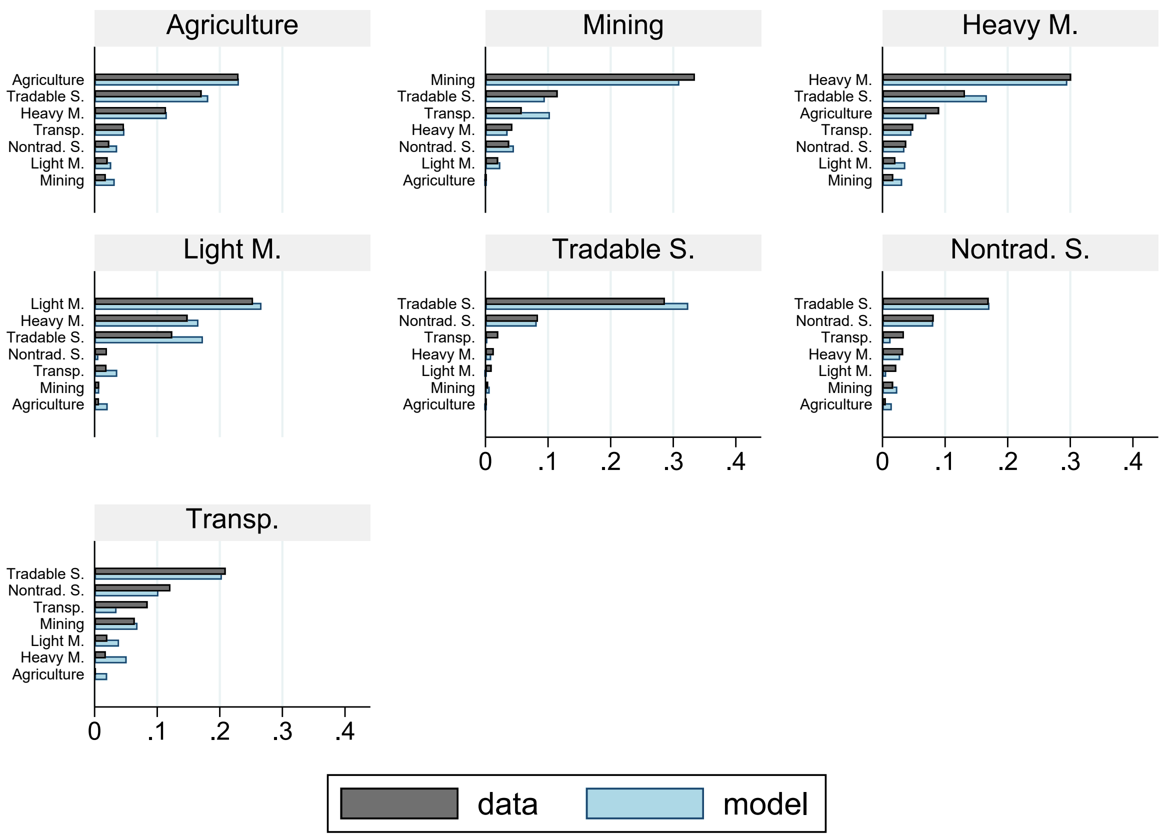
Intermediate inputs and their shares The intermediate input shares are computed from the "Use table, before redefinition, Producer Value", available from the BEA Industry Accounts for 1947, 1963, and 2017. These tables do not adjust for in-house transportation services (no TSA input-output table is available for 1947). To obtain real intermediate inputs, we deflate the nominal values in the Use table using the gross output price index published by the BEA Industry Accounts.

Labor and capital cost shares We measure the cost share of labor wL_T/p_TQ_T as the product of the share of the labor costs to value added by the share of value added to gross output. The share of labor costs to value added is computed exactly like 1-θ_T, as the compensation of employees divided by the sum of gross operating surplus and the compensation of employees, with an adjustment to match the economy-wide labor share estimated by the US Bureau of Labor Statistics. Because of data availability constraints in 1947 and 1963, we impute the cost share of labor in these two years assuming that the change in the economy-wide labor share applied uniformly to all sectors. That is, we write $(wL_T/VA_T)_{1947} = (wL/VA)_{1947}/(wL/VA)_{2017} \times (1 - \theta_T)_{2017}$, and thus $(wL_T/p_TQ_T)_{1947} = (wL_T/VA_T)_{1947}(VA_T/p_TQ_T)_{1947}$. The same calculation is applied in 1963. The cost share of capital rK_T/p_TQ_T is then measured as $(1 - wL_T/p_TQ_T - \sum_j p_jX_{Tj}/p_TQ_T)$ in all years.

E Calibration: Model Fit

To calibrate the model, we minimize the sum of the squared differences between the data targets and the model-generated counterparts. To make the scales of targets comparable, we assign a weight of 100 to the share of transportation in GDP and to the sector's value-added to gross output ratio ; we use of weight of 0.10 for the distance elasticities and the out-of-region coefficients; all other parameters are given a unit weight. Figure 5 reports the model fit for input-output shares. The comparison of the model and data employment shares, value added shares, distance elasticities and out-of-region coefficients are reported in the main text.

Figure 5: Calibration Fit of Input-Output shares



Notes: Each panel is a purchasing sector with bars reporting shares in that sector's gross output. The use of transportation services is not targeted.

F Additional Results

F.1 No reallocation results

F.1.1 Equilibrium Definition

Now we allow a (potentially) different wage w_{io} for each occupation (i)-location (o) pair. Given wages, the rest of the equilibrium follows with very little modifications. The definition of equilibrium posed in section 3.3 still holds with the following modifications:

1. Equation (A.5) is modified to

$$q_{io} = [(r + \delta_i)p_{io}^k]^{\theta_i} w_{io}^{1-\theta_i}.$$

2. Real wage equalization (condition (b), equation (12)) does not necessarily hold, so the real wage (potentially) depends on location and occupation:

$$\omega_{io} = \frac{w_{io}}{P_d}.$$

3. Per capita real consumption by agents in cell io is given by $c_{io} = \lambda(r)\omega_{io}$ and

$$\tilde{C}_{jo} = \tilde{c}_{jo}\lambda(r) \sum_i \omega_{io} L_{io}$$

and hence $G_{id,\tilde{j}d} = \xi_i \left(\frac{\tilde{p}_{id}}{P_d}\right)^{-\frac{1}{1-\chi}} \omega_{id}^*$ and 0 elsewhere.

Finding the vector of wages (and hence the equilibrium) requires additional conditions.

No reallocation between locations If agents are free to switch occupations, but not locations, wages in a location must be equalized. We have that $w_{1o} = w_{2o} = \cdots w_{n+1,o} = w_o$. The wages are determined by the condition

$$\sum_i L_{id} = L_d^s,$$

where L_d^s is the equilibrium amount of labor before the transportation productivity shock.

No reallocation between occupations The next case we consider is of agents free to reallocate between locations but not between occupations. Then we will have in equilibrium:

$$\frac{w_{io}}{P_{io}} = \frac{w_{id}}{P_{id}}, \forall i, o, d,$$

which implies

$$w_{io} = \frac{w_{i1}}{P_1} P_o,$$

so we can express the wages as

$$w_{io} = w_i^{occ} \times w_o^{loc}$$

with

$$\frac{w_o^{loc}}{P_o} = \frac{w_d^{loc}}{P_d}.$$

Finally, the occupational component of wages is pinned by the condition:

$$\sum_{o=1}^{\ell} L_{io} = \sum_{o=1}^{\ell} L_{io}^s.$$

No reallocation between locations-occupation pairs Finally in the case of complete immobility, the equilibrium condition is simply

$$L_{io} = L_{io}^s \quad \forall i, o.$$

F.1.2 Regional and Sectoral Impacts

Figure F1: Welfare Changes Relative to Baseline without Regional Mobility

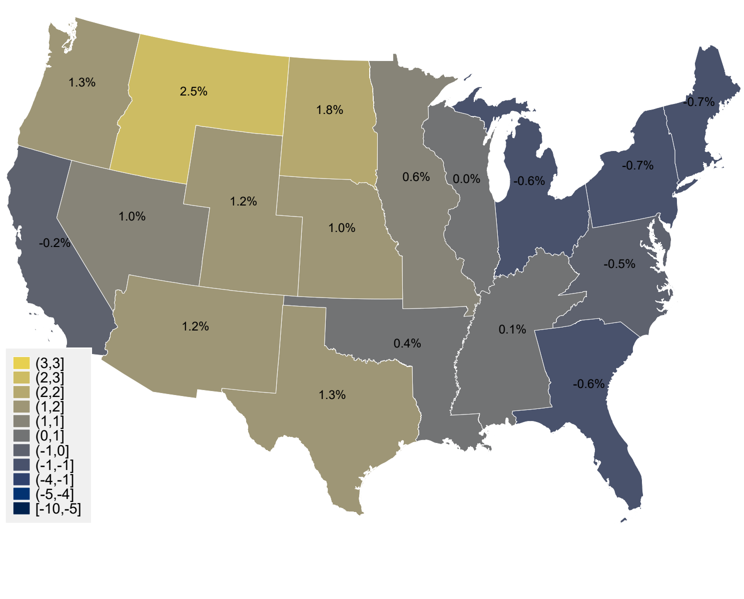
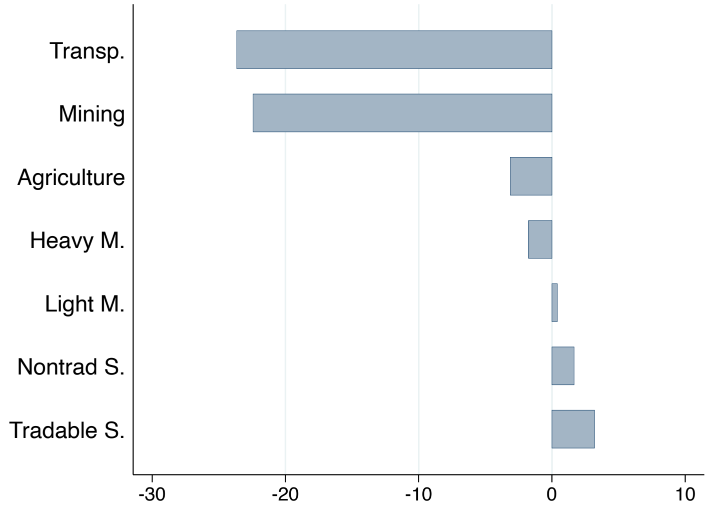


Figure F2: Welfare Changes Relative to Baseline without Sectoral Mobility



F.2 Theoretical Analysis of Labor mobility

Next, we consider a special case of our model without capital and intermediates that can be solved analytically. We show that for some parameter values, counterintuitively, average real consumption after a negative transportation shock declines *less* without labor mobility.

F.2.1 Setup

There are two locations and only one good with its regional varieties; thus this is a special case of the model in the paper with $\ell = 2, n = 1$. Labor is the only factor of production, so $Q_o = B_o L_{1o}$ and $Q_{To} = B_T L_{To}$, withe Q_o the output of the local variety and Q_{To} the output of transportation services. As before, supplying a unit of local variety o to region d requires t_{od} units of transportation services. We set $t_{oo} = 0$ and shorten notation t_{1od} for $d \neq o$ to t_o.

All goods are used for consumption only. Let c_{od} denote consumption of good from origin o in location d. Let $\epsilon_\gamma = 1$, which implies Cobb-Douglas preferences over local varieties:

$$\tilde{c}_d = \xi_1^{-\xi_1} \xi_2^{-\xi_2} c_{1d}^{\xi_1} c_{2d}^{\xi_2}.$$

F.2.2 Equilibrium

Prices Perfect competition implies that the prices are given by

$$p_{od} = \begin{cases} \frac{w_o}{B_o} & \text{if } o = d \\ \frac{w_o}{B_o} + \frac{w_o t_{od}}{B_T} = \frac{w_o}{B_o} \underbrace{(1 + t_{od} B_o / B_T)}_{z_o} & \text{if } o \neq d \end{cases}$$

Consumer optimization The ideal price index is

$$P_d = \prod_{o=1}^{2} p_{od}^{\xi_o} = w_1^{\xi_1} w_2^{\xi_2} B_1^{-\xi_1} B_2^{-\xi_2} z_x^{\xi_x}, \tag{F.1}$$

where $x \neq d$. Consumers demand $c_{od} = \xi_o \frac{w_d}{p_{od}}$.

Equilibrium with mobility The equilibrium definition is the same as in the main body of the paper. The equations for prices, the price index and real wage equalization fully characterize the welfare in this economy. Substituting real wage equalization $w_1/P_1 = w_2/P_2$ into (F.1) implies that $\frac{w_2}{w_1} = \frac{z_1^{\xi_1}}{z_2^{\xi_1}}$. This implies that

$$\tilde{c} = \frac{w_d}{P_d} = B_1^{\xi_1} B_2^{\xi_2} z_1^{-\xi_1 \xi_2} z_2^{-\xi_1 \xi_2}$$

Finally, we can find the spatial distribution of agents from the resource constraints. In an economy without capital and intermediate goods, labor income in location o is given by the total spending on goods (including transportation) from location o:

$$w_o L_o = \xi_o (w_1 L_1 + w_2 L_2).$$

Then

$$\frac{L_1}{L_2} = \frac{\xi_1 w_2}{\xi_2 w_1} = \frac{\xi_1 z_1^{\xi_1}}{\xi_2 z_2^{\xi_2}}$$

The equation above implies that

$$L_o = \frac{\xi_o z_o^{\xi_o}}{\xi_1 z_1^{\xi_1} + \xi_2 z_2^{\xi_2}}. \tag{F.2}$$

Equilibrium without mobility Now suppose that the workers are distributed exogenously, L_1^s, L_2^s. The equilibrium is defined exactly the same as before, but now instead of real wage equalization we have the condition that agents are cannot move between locations, so $L_d = L_d^s$. Conditional on wages, the equations for prices and consumption remain the same, but wages are now pinned down by the equilibrium in the labor markets and not by real wage equalization. The Cobb-Douglas utility specification and equilibrium conditions imply

$$w_o L_o^s = \xi_o (w_1 L_1^s + w_2 L_2^s),$$

which, after taking ratios, implies:

$$\frac{w_2}{w_1} = \frac{L_1^s (1 - \xi_1)}{(1 - L_1^s)\xi_1}. \tag{F.3}$$

Normalizing $w_1 = 1$ gives w_2; then substituting in the expressions for prices and allocations gives everything else.

F.2.3 Welfare impacts of lower transport productivity with vs without mobility

Now let's consider the response of the economy to a transportation productivity shock. We simplify the algebra considerably by assuming that initially transportation is costless, i.e., $B_T = \infty$ (so $z_d = 1$) and the economy is in its long-run equilibrium (that is agents are indifferent between two locations). Then we lower B_T to some finite value (so $z_d > 1$) and compare *average* real consumption in the case of (1) allowing agents to move between location and (2) maintaining the old distribution over locations.

Let's denote real consumption in the frictionless case by $\bar{c} = B_1^{\xi_1} B_2^{\xi_2}$. Then we can apply the formula directly and find that with mobility,

$$\tilde{c}^{mobile} = \bar{c} z_1^{-\xi_1 \xi_2} z_2^{-\xi_1 \xi_2} = (\bar{c} z_2^{-\xi_2})^{\xi_1} (\bar{c} z_1^{-\xi_1})^{\xi_2}.$$

On the other hand, consider the case when agents remain in place after the shock. Applying equation (F.2) to the frictionless economy ($z_1 = z_2 = 1$) implies $L_1^s = \xi_1; L_2^s = \xi_2$. Then using (F.3) we get that *after* the transportation shock $w_2 = w_1$. Normalizing $w = 1$ we obtain price indices

$$P_d = \bar{c}^{-1} z_x^{\xi_x},$$

where x denotes the other location, $d \neq x$. Real consumption is just the reciprocal:

$$\tilde{c}_d = \bar{c} z_x^{-\xi_x}.$$

Interestingly, the transportation costs *from* the own location are irrelevant. The reason is that agents do not pay them to buy the good from their own location and with Cobb-Douglas preferences the total spending of the other location on location d goods and services are independent of the real price (and hence on the transportation productivity).

Finally, the average real consumption is $\tilde{c}^{immobile} = \xi_1 \bar{c} z_2^{-\xi_2} + \xi_2 \bar{c} z_1^{-\xi_1}$.

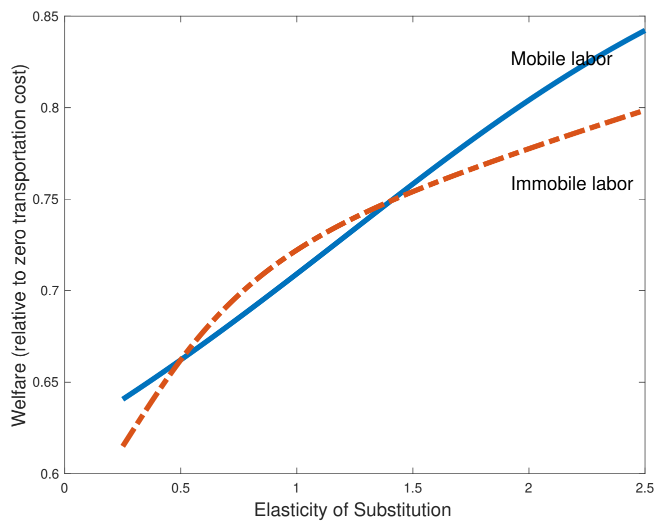
Then in both cases average real consumption is the average of $\bar{c}z_1^{-\xi_1}, \bar{c}z_2^{-\xi_2}$ with weights ξ_2, ξ_1. However with mobile consumers we have a geometric average (GA) while with immobile consumers we have an arithmetic average (AA). We know that, except for the knife-edge case $z_1^{-\xi_1} = z_2^{-\xi_2}$, $AA > GA$, so

$$\tilde{c}^{immobile} \geq \tilde{c}^{mobile}$$

with strict inequality if $z_1^{-\xi_1} \neq z_2^{-\xi_2}$.

With mobility, the location with less exposure to transportation costs in its consumption basket sees an influx of people. This increases demand for the other location's goods which bids up wages until real wages are equalized. So, the original inhabitants of the more attractive location lose from mobility. In the particular case of Cobb-Douglas, the losses of the incumbents are greater than the benefit to the movers.

Figure F3: Average Real Consumption with and without Mobility



Numerical comparative statics Finally, we demonstrate the result above for different values of the elasticity of substitution $\frac{1}{1-\gamma}$ in Figure F3. In all cases $z_1 = 1 + \frac{t_{12}B_1}{B_T} = z_2 = 1 + \frac{t_{21}B_2}{B_T} = 1.5$. A reallocation requires some asymmetry, so in the exercise we assume $\xi_1 = 1/4$. As transportation costs increase, the real price index in location 2 rises less (since more of its consumption comes from home) and as a result there is a pressure for agents to move to location 2. As theoretically predicted for the Cobb-Douglas case ($\frac{1}{1-\gamma} = 1$), over a certain range of elasticity of substitution average welfare is higher when there is no mobility.

F.3 Alternative production function specifications

We describe here the changes made to the model and to the calibration procedure for the alternative specifications presented in the section 7.

F.3.1 Cobb-Douglas production functions

The specification with Cobb-Douglas production functions differs from the baseline specification only with respect to the values of the commodities production function and consumption parameters, ρ, σ and χ, which are all set equal to zero.

With this specification, the calibration procedure is simpler since the optimization condition pins down the input-output coefficients at purchaser price:

$$\frac{\tilde{p}_{jo}\tilde{X}_{io,jo}}{p_{io}Q_{io}} = \alpha_i v_{ij}.$$

We set the parameters $\alpha_i v_{ij}$ using this equation. Note that as the input-output tables are expressed at producer prices, the input-output coefficients are not exactly matched for all sectors. The gap is however very small, and the median absolute error for the input-output shares is smaller than that of the baseline model (0.001 vs 0.009). Finally, note that we use the same counterfactual transportation productivity to simplify the comparison.

F.3.2 Model without sectoral linkages

We consider a version of the model without input-output linkages and without capital goods. All the equilibrium condition specified above still hold in this special version of the model, but it is helpful to highlight the equations which are simplified.

Technology & preferences The local composite production function is the same as the baseline (equation (1)), but the commodities production function is now:

$$Q_{id} = B_{id}L_{id}, \tag{F.4}$$

and the output of transportation services available in region o is given by:

$$T_o = B_T L_{To}. \tag{F.5}$$

The per period real consumption bundle of agents is region d is the same as in the baseline specification, (8).

Consumer optimization The result of consumer optimization is identical to the baseline model with the ideal price index given by (10) and the optimal consumption choices are specified by (11).

Producer optimization The price of the composite good $\tilde{p}_{jd}$ is identical to the baseline (14) and the corresponding optimal flows are given by (15) but the commodities price now simplifies to:

$$p_{jo} = w_o / B_{jo}. \tag{F.6}$$

Market clearing conditions The market clearing conditions are exactly the same as in the baseline (part (f) of the equilibrium definition), but the absence of investment or intermediate goods simplifies equation (25) to

$$\tilde{Q}_{io} \quad = \quad L_o \tilde{c}_{io} \tag{F.7}$$

Solving for the equilibrium allocation In equilibrium, consumer welfare and real wage is identical in all locations, as specified by (12). To solve for the wage, we first write $\tilde{p}_{jd}$ as a function of the vector of local wages w_o, using equations (14) and (F.6). Then, combining equation (10) and the real wage equalization condition, we obtain $\ell - 1$ wages. We set $w_1 = 1$ as the numeraire. Given wages, we can solve for all the prices.

To solve for the equilibrium allocation, we rewrite the demand for product io, using equations (24) and (F.7),

$$Q_{io} = \sum_d Z_{iod} = \sum_d \frac{Z_{iod}}{\tilde{Q}_{id}} \tilde{Q}_{id} = \sum_d \frac{Z_{iod}}{\tilde{Q}_{id}} \frac{\tilde{c_{id}}}{c_d} L_d c_d.$$

Hence,

$$B_{io} L_{io} = \sum_d \frac{Z_{iod}}{\tilde{Q}_{id}} \frac{\tilde{c_{id}}}{c_d} \left(\sum_j L_{jd} \right) \omega.$$

Given prices, we obtain regional and sectoral shares $Z_{iod}/\tilde{Q}_{id}$ and $\tilde{c}_{id}/c_d$. Finally, we find the labor allocation L_{io} by solving for the system of equations given by the equation above, where the right hand side is a function of labor only. We have thus a system of $(n+1) \times \ell$ unknowns and the same number of equations. In matrix form,

$$M' \cdot G' \cdot L = \text{diag}(B) \cdot L, \tag{F.8}$$

where L is a vector of size $\ell \times (n+1)$, and G and M are $\ell \times (n+1)$ by $\ell \times (n+1)$ matrices, with $G_{jd,id} = \frac{\tilde{c_{id}}}{c_d}\omega$ (same value for all j), $M_{id,io} = \frac{Z_{iod}}{\tilde{Q}_{id}}$ and $M_{id,To} = t_{iod}M_{id,io}$; all other elements of the M and G matrices are zeros, $\text{diag}(B)$ is a diagonal matrix with B_{io} on the diagonal. As before our convention is to list all the locations of a sectoral good. Equation (F.8) is similar to equation (27) in the main text (with M and G defined in a simpler way).

We solve for the eigenvector associated with the unit eigenvalue of the matrix

$$(\text{diag}(B))^{-1}(M' \cdot G').$$

Here as well we use the same counterfactual transportation productivity to simplify the comparison with the baseline model.

We then compute the GDP as $\sum_o \sum_i p_{io}Q_{io}$ and the sectoral value added share by $\sum_o p_{io}Q_{io} / \sum_o \sum_i p_{io}Q_{io}$.

F.3.3 Figures for the Cobb-Douglas and no-sectoral-linkages specifications.

We report here additional results for the Cobb-Douglas and the no-sectoral-linkages (no IO) specifications.

Figure F4: Regional gross output changes, no sectoral-linkages economy, gap with baseline (percentage points)

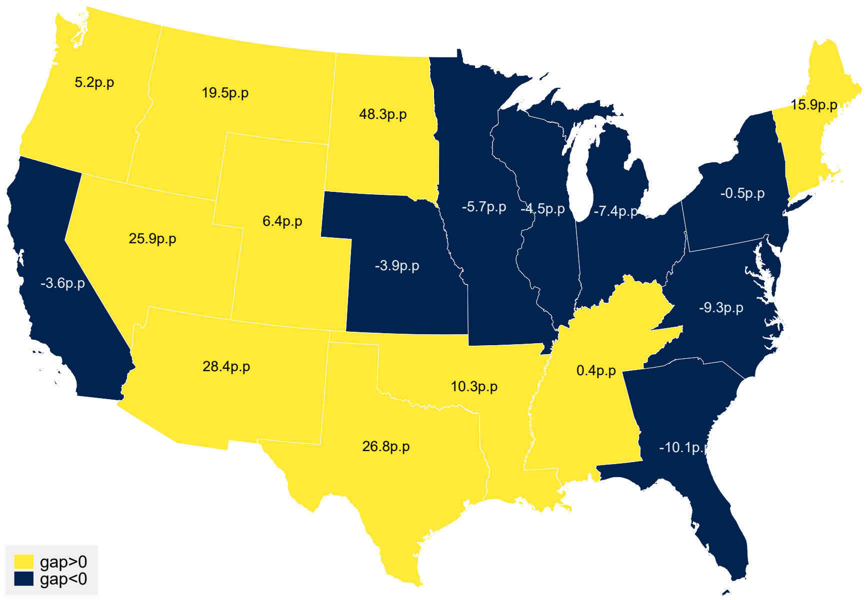


Figure F5: Robustness: gross output, no IO vs Baseline calibration

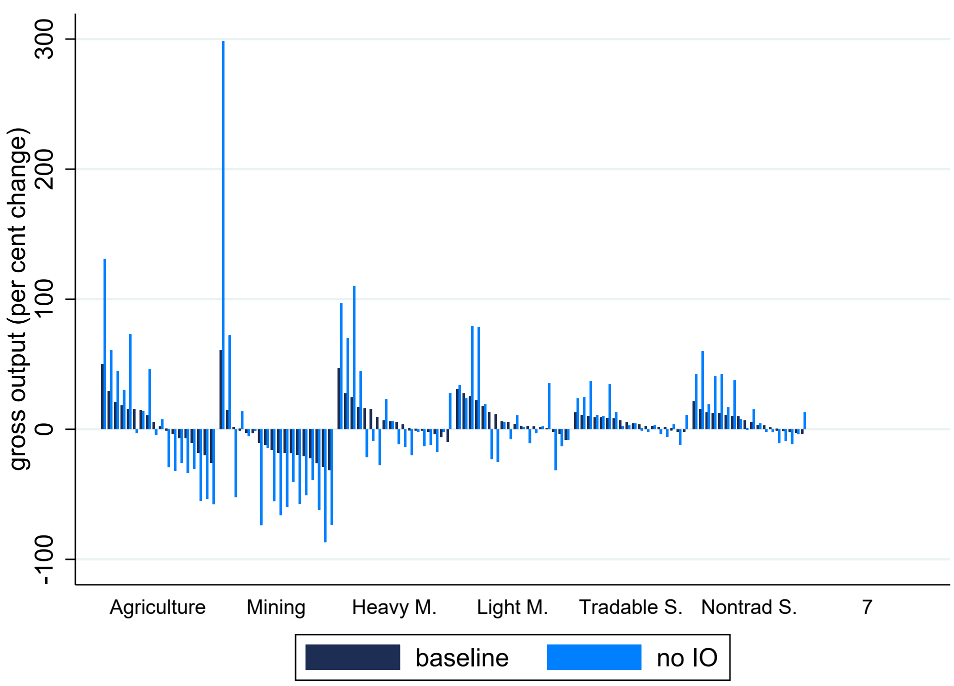


Figure F6: Robustness: Cobb-Douglas vs Baseline calibration

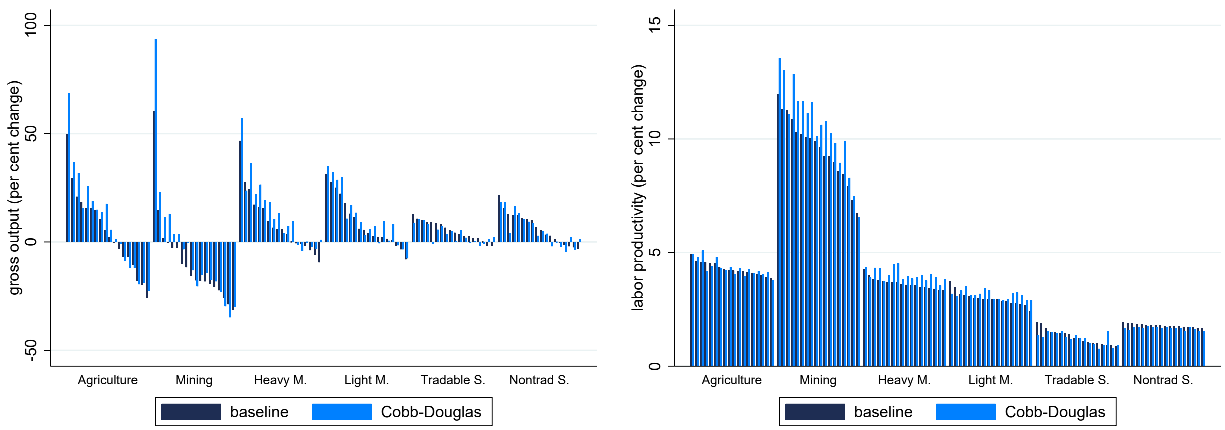


Figure F7: Robustness: $\varepsilon_\gamma = 4$ vs Baseline calibration