Online Appendix to "Trade, Migration, and Productivity: A Quantitative Analysis of China"

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Appendix A provides source and summary information for our main data. Appendix B provides supplementary material not included in the main text.

Appendix A: Data Sources and Summary Statistics

GDP and Employment by Sector and Province – We use official nominal GDP and employment data for agriculture (primary sector) and non-agriculture (secondary and tertiary sectors) available through various Chinese Statistical Yearbooks. We accessed these data through the University of Michigan's China Data Online service (at chinadataonline.org).

Spatial Prices – We measure *real* GDP per worker by province and sector by deflating the official nominal GDP data with the spatial price data of Brandt and Holz (2006). We use the common basket price index for rural areas to deflate agriculture's nominal GDP in each province. Similarly, we use the common basket price index for urban areas to deflate non-agriculture's nominal GDP.

Migration Shares – Using China's 2000 Population Census and 2005 1% Population Survey, we calculate migration shares. Specifically, to measure m_{ni}^{jk}, we calculate the fraction of all employed workers with hukou registration in region n of type j (agricultural or non-agricultural hukou) currently working in province i and employed in sector k (agricultural or non-agricultural). Current industry of employment is classified using China's GB2002 classification system. We assign to agricultural all industries with GB2002 codes 01-05.

Trade Shares – We use the Interregional Input-Output data of Li (2010) to measure the initial equilibrium trade shares π_{ni}^{j} for 2002. The data is disaggregated by sector, with agriculture on its own. We aggregate all other sectors into non-agriculture. The trade share π_{ni}^{j} is the fraction of total spending by region n on goods in sector j sourced from region i. Total expenditure is the sum of final use and intermediates. To measure the change in trade costs between 2002 to 2007, we require data on changes in trade shares from 2002 to 2007. For this, we use the data of Zhang and Qi (2012), which provides similar data as Li (2010) but aggregated to eight broad regions. The eight regions are: Northeast (Heilongjiang, Jilin, Liaoning), North Municipalities (Beijing, Tianjin), North Coast (Hebei, Shandong), Central Coast (Jiangsu, Shanghai, Zhejiang), South Coast (Fujian, Guangdong, Hainan), Central (Shanxi, Henan, Anhui, Hubei, Hunan, Jiangxi), Northwest (Inner

Mongolia, Shaanxi, Ningxia, Gansu, Qinghai, Xinjiang), and Southwest (Sichuan, Chongqing, Yunnan, Guizhou, Guanxi, Tibet).

Production Shares **–** These are the share of gross output net of physical capital, since our model abstracts from physical capital. If production technologies are $Y = \tilde{A}H^{\tilde{\beta}}S^{\tilde{\eta}}K^{\tilde{\alpha}}Q^{1-\tilde{\beta}-\tilde{\eta}-\tilde{\alpha}}$, then gross output net of physical capital can be written as $Y = AH^{\beta}S^{\eta}Q^{1-\beta-\eta}$, where $\beta = \tilde{\beta}/(1-\tilde{\alpha})$ and $\eta = \tilde{\eta}/(1-\tilde{\alpha})$. So, the values of β and η can be inferred from the value-added share of gross output, $\tilde{\beta}+\tilde{\eta}+\tilde{\alpha}$, and each factors' share of value-added $\tilde{\beta}/(\tilde{\beta}+\tilde{\eta}+\tilde{\alpha})$, $\tilde{\eta}/(\tilde{\beta}+\tilde{\eta}+\tilde{\alpha})$, and $\tilde{\alpha}/(\tilde{\beta}+\tilde{\eta}+\tilde{\alpha})$.

Let's start with $\tilde{\alpha}$. In our data, returns to land are attributed to labour in the agricultural sector but to operating surpluses in non-agricultural sectors. Thus, non-labour's share of output in agriculture is capital's share in the data while we have to net out land's share from the non-agricultural sector. To do this, we assume land's share of value-added is 0.06, as in Caselli and Coleman (2001), which is subtracted from the 0.17 non-labour share of non-agricultural output in our data. Thus, we find $\tilde{\alpha}^{ag} = 0.06$ and $\tilde{\alpha}^{na} = 0.15$.

Next, consider $\tilde{\beta}$ and $\tilde{\eta}$. In our data, value-added's shares of gross output is 0.59 in agriculture and 0.35 in non-agriculture. As mentioned, labour and land value-added are both within agricultural labour compensation in our data. In recent work, Adamopoulos et al. (2017) estimate labour's share of value-added in China's agricultural sector as 0.46. Combined with our data, this implies land's share of value-added is 0.44. Thus, together with our estimates for capital's share of gross output, we have $\beta^{ag} = 0.46\times 0.59/(1-0.06) = 0.29$ and $\eta^{ag} = 0.44\times 0.59/(1-0.06) = 0.28$. In non-agriculture,we have $\beta^{na} = 0.53\times 0.35/(1-0.15) = 0.22$ and $\eta^{na} = 0.06\times 0.35/(1-0.15) = 0.03$.

Finally, input-output shares are directly from our input-output data. Overall, non-agricultural inputs are 0.25 of agricultural gross output and 0.61 of non-agricultural gross output. Further, agricultural inputs are 0.16 of agricultural gross output and 0.04 of non-agriculture. Thus,

$$\sigma^{jk} = \begin{bmatrix} 0.16 & 0.25 \\ 0.04 & 0.61 \end{bmatrix},$$

where the first row are the input shares for agriculture, from agriculture and non-agriculture respectively, and the second row are the input shares for non-agriculture.

Selected Summary Statistics, by Province **–** In the following tables, we report various summary measures of trade, real incomes, migration, employment, and other metrics for all provinces and sectors.

Table 12: Summary Data for China's Provinces, 2000

Province	Employment (millions)	Inter-Provincial Migrant Share of Employment	Intra-Provincial Migrant Share of Employment	Agriculture's Share of Employment	Relative Real Ag. Income	Relative Real Nonag. Income	Home Bias in Total Trade	International Export Share of Production
Anhui	33.73	0.004	0.113	0.60	0.31	1.09	0.619	0.024
Beijing	6.22	0.231	0.147	0.12	0.63	1.89	0.661	0.065
Chongqing	16.37	0.014	0.112	0.57	0.30	1.25	0.545	0.020
Fujian	16.60	0.077	0.285	0.47	0.64	1.99	0.807	0.118
Gansu	11.82	0.009	0.056	0.60	0.22	1.06	0.776	0.039
Guangdong	38.61	0.270	0.193	0.41	0.40	1.68	0.647	0.239
Guangxi	25.30	0.008	0.087	0.62	0.27	1.02	0.694	0.027
Guizhou	20.46	0.012	0.069	0.67	0.14	0.69	0.718	0.017
Hainan	3.34	0.051	0.150	0.61	0.67	1.13	0.624	0.031
Hebei	34.41	0.013	0.144	0.49	0.47	1.57	0.718	0.023
Heilongjiang	16.35	0.012	0.107	0.49	0.38	2.19	0.797	0.026
Henan	55.72	0.004	0.079	0.64	0.30	1.32	0.875	0.013
Hubei	25.08	0.011	0.127	0.48	0.45	1.65	0.857	0.016
Hunan	34.62	0.005	0.109	0.61	0.27	1.27	0.849	0.016
Inner Mongolia	10.17	0.023	0.123	0.54	0.55	1.41	0.775	0.020
Jiangsu	35.59	0.039	0.252	0.42	0.55	2.05	0.802	0.100
Jiangxi	19.35	0.006	0.140	0.52	0.41	1.01	0.790	0.015
Jilin	10.79	0.011	0.083	0.50	0.66	1.72	0.554	0.025
Liaoning	18.13	0.024	0.131	0.38	0.66	2.16	0.827	0.063
Ningxia	2.74	0.034	0.124	0.58	0.24	1.20	0.633	0.014
Qinghai	2.39	0.024	0.064	0.61	0.23	1.51	0.640	0.038
Shandong	46.62	0.011	0.152	0.53	0.44	1.95	0.830	0.060
Shanghai	6.73	0.240	0.168	0.13	0.49	3.39	0.645	0.179
Shaanxi	18.13	0.010	0.115	0.56	0.21	1.01	0.758	0.001
Shanxi	14.19	0.019	0.168	0.47	0.22	1.09	0.858	0.036
Sichuan	44.36	0.005	0.095	0.60	0.32	1.08	0.881	0.020
Tianjin	4.07	0.080	0.157	0.20	0.59	2.64	0.552	0.153
Xinjiang	6.72	0.095	0.098	0.58	0.59	2.40	0.757	0.025
Yunnan	22.95	0.028	0.080	0.74	0.17	1.54	0.807	0.017
Zhejiang	27.00	0.096	0.408	0.38	0.51	1.75	0.743	0.094

Notes: Reports various provincial characteristics in 2000. Employment and GDP data are from official sources, deflated using spatial price indexes. Migration data is constructed from the 2000 Population Census. See text for details. The last two columns use 2002 data on trade flows. Home-bias reports total production for domestic use as a share of total absorption (calculated as $1/(1+I/D)$, where I is total imports and D is gross output less total exports).

Appendix B: Supplementary Material

In this Appendix, we provide (1) the proofs for all main propositions, (2) details behind relative changes in key model variables that were not provided in the main text, (3) details behind estimating the Head-Ries method of estimating trade costs adjusted for asymmetries, and (4) various robustness exercises and alternative model specifications.

Proofs of Propositions

Proposition 1: *Given real incomes for each region and sector V_i^k, migration costs between all regional pairs μ_{ni}^{jk}, adjustments for land rebates δ_{ni}^{jk}, and idiosyncratic preferences distributed $F_z(x)$, the share of (n,j) workers that migrate to (i,k) is*

$$m_{ni}^{jk} = \frac{\left(V_i^k \delta_{ni}^{jk} / \mu_{ni}^{jk}\right)^{\kappa}}{\sum_{k'} \sum_{i'} \left(V_{i'}^{k'} \delta_{ni'}^{jk'} / \mu_{ni'}^{jk'}\right)^{\kappa}}.$$

Proof: The share of people from (n,j) that migrate to (i,k) is the probability that each individual's utility in (i,k) exceeds that in any other region. Specifically,

$$m_{ni}^{jk} \equiv Pr\left(V_i^k \delta_{ni}^{jk} z_i^k / \mu_{ni}^{jk} \geq \max_{i',k'} \left\{ z_{i'}^{k'} \delta_{ni'}^{jk'} V_{i'}^{k'} / \mu_{ni'}^{jk'} \right\}\right).$$

Since $Pr\left(z_i^k \leq x\right) \equiv e^{-(\tilde{\gamma}x)^{-\kappa}}$ by assumption of Frechet distributed worker preferences, we have $Pr\left(V_i^k \delta_{ni}^{jk} z_i^k / \mu_{ni}^{jk} \leq x\right) = Pr\left(z_i^k \leq x\mu_{ni}^{jk} / V_i^k \delta_{ni}^{jk}\right) = e^{-\left(x/\phi_{ni}^{jk}\right)^{-\kappa}}$ where $\phi_{ni}^{jk} = V_i^k \delta_{ni}^{jk} / \mu_{ni}^{jk} \tilde{\gamma}$ The distribution of net income across workers from (n,j) in (i,k) is therefore also Frechet. Similarly, the distribution of the highest net real income in all other regions is described by

$$\begin{aligned}
Pr\left(\max_{k'\neq k, i'\neq i} \left\{ z_{i'}^{k'} V_{i'}^{k'} \delta_{ni'}^{jk'} / \mu_{ni'}^{jk'} \right\} \leq x\right) &= \prod_{k'\neq k} \prod_{i'\neq i} Pr\left(z_{i'}^{k'} V_{i'}^{k'} \delta_{ni'}^{jk'} / \mu_{ni'}^{jk'} \leq x\right), \\
&= \prod_{k'\neq k} \prod_{i'\neq i} Pr\left(z_{i'}^{k'} \leq x\mu_{ni'}^{jk'} / V_{i'}^{k'} \delta_{ni'}^{jk'}\right), \\
&= \prod_{k'\neq k} \prod_{i'\neq i} e^{-\left(\tilde{\gamma}x\mu_{ni'}^{jk'} / V_{i'}^{k'} \delta_{ni'}^{jk'}\right)^{-\kappa}}, \\
&= e^{-x^{-\kappa} \sum_{k'\neq k} \sum_{i'\neq i} \left(\tilde{\gamma}\mu_{ni'}^{jk'} / V_{i'}^{k'} \delta_{ni'}^{jk'}\right)^{-\kappa}}, \\
&= e^{-\left(x/\Phi_n^j\right)^{-\kappa}},
\end{aligned}$$

which is also Frechet, where $\Phi_n^j = \left(\sum_{k'\neq k} \sum_{i'\neq i} \left(V_{i'}^{k'} \delta_{ni'}^{jk'} / \tilde{\gamma}\mu_{ni'}^{jk'}\right)^{\kappa}\right)^{1/\kappa}$.

Returning to the original m_{ni}^{jk} expression, let $X = V_i^k \delta_{ni}^{jk} z_i^k / \mu_{ni}^{jk}$ and $Y = \max_{k'\neq k, i'\neq i} \left\{ z_{i'}^{k'} V_{i'}^{k'} \delta_{ni'}^{jk'} / \mu_{ni'}^{jk'} \right\}$, which are Frechet distributed with parameters $s_X = \phi_{ni}^{jk}$ and $s_Y = \Phi_n^j$, respectively. By the Law of Total Probability,

$$\begin{aligned} m_{ni}^{jk} &= \int_0^\infty Pr\left(X \geq Y \mid Y = y\right) f_Y(y) dy, \\ &= \int_0^\infty \left(1 - e^{-(y/s_X)^{-\kappa}}\right) \kappa s_Y^\kappa y^{-1-\kappa} e^{-(y/s_Y)^{-\kappa}} dy, \\ &= 1 - \int_0^\infty e^{-(s_X^\kappa + s_Y^\kappa) y^{-\kappa}} \kappa s_Y^\kappa y^{-1-\kappa} dy, \end{aligned}$$

With a change of variables $u = y^{-\kappa}$ and therefore $du = -\kappa y^{-\kappa-1} dy$,

$$\begin{aligned} m_{ni}^{jk} &= 1 + \int_{u=\infty}^{u=0} e^{-(s_X^\kappa + s_Y^\kappa) u} s_X^\kappa du, \\ &= 1 - s_Y^\kappa \int_0^\infty e^{-(s_X^\kappa + s_Y^\kappa) u} du, \\ &= 1 - \frac{s_Y^\kappa}{s_X^\kappa + s_Y^\kappa} = \frac{\left(V_i^k \delta_{ni}^{jk} / \mu_{ni}^{jk}\right)^\kappa}{\sum_{k'} \sum_{i'} \left(V_{i'}^{k'} \delta_{ni'}^{jk'} / \mu_{ni'}^{jk'}\right)^\kappa}, \end{aligned}$$

which is the result. ■

Proposition* 2*: *Given changes in migration and real incomes, the change aggregate welfare is*

$$\hat{W} = \sum_j \sum_{n=1}^N \omega_n^j \hat{\delta}_{nn}^{jj} \hat{V}_n^j \hat{m}_{nn}^{j\ -1/\kappa},$$

where $\omega_n^j \propto \bar{L}_n^j V_n^j m_{nn}^{j\ -1/\kappa}$ *is region n and sector j's initial contribution to welfare.*

Similarly, the change in real GDP is

$$\hat{Y} = \sum_j \sum_{n=1}^N \phi_n^j \hat{V}_n^j \hat{L}_n^j,$$

where $\phi_n^j \propto V_n^j L_n^j$ *is the contribution of region n and sector j to initial real GDP.*

Proof: A worker from (n, j) has different preferences for each potential region and sector in China. Building on the results of Proposition **1**, the probability that a given worker's welfare is below x is the probability that *no* region-sector pair gives utility above x. As $Pr\left(V_i^k \delta_{ni}^{jk} z_i^k / \mu_{ni}^{jk} \leq x\right) = e^{-\left(x/\phi_{ni}^{jk}\right)^{-\kappa}}$, the probability that all region-sector pairs are below x gives the distribution of welfare of workers from (n, i). That is,

$$F_{U_n^j}(x) = \prod_k \prod_i e^{-\left(x/\phi_{ni}^{jk}\right)^{-\kappa}} = e^{-\left(x/\Phi_n^j\right)^{-\kappa}},$$

where $\Phi_n^j = \left(\sum_k \sum_i \left(V_{i'}^{k'} \delta_{ni'}^{jk'} / \tilde{\gamma} \mu_{ni'}^{jk'}\right)^{\kappa}\right)^{1/\kappa}$.

To get our result, note that if $Pr(X < x) \equiv F(x) = e^{-(\tilde{\gamma}x/s)^{-\kappa}}$ then $E[X] = s$. So, the utility of workers from (n,i) after migration decisions – distributed according to $F_{U_n^j}(x)$ above – is Frechet with $E\left[U_n^j\right] = \Phi_n^j$. Given that the distribution of idiosyncratic preferences across regions and sectors has mean zero, real income and welfare are synonymous and therefore $\bar{V}_n^j \equiv E\left[U_n^j\right]$. From Proposition 1, $m_{ni}^{jk} = \frac{\left(V_i^k \delta_{ni}^{jk} / \mu_{ni}^{jk}\right)^{\kappa}}{\sum_{k'} \sum_{i'} \left(V_{i'}^{k'} \delta_{ni'}^{jk'} / \mu_{ni'}^{jk'}\right)^{\kappa}}$ and therefore $\bar{V}_n^j = V_n^j \delta_{nn}^{jj} \left(m_{nn}^{jj}\right)^{-1/\kappa}$. Aggregate welfare is the mean across all regions of registration, weighted by registration population shares $\lambda_n^j = \bar{L}_n^j / \left(\sum_{n'} \sum_{j'} \bar{L}_{n'}^{j'}\right)$, given by $W = \sum_n \sum_j \lambda_n^j V_n^j \delta_{nn}^{jj} \left(m_{nn}^{jj}\right)^{-1/\kappa}$. Taking the ratio of counterfactual W' to initial W yields

$$\begin{aligned} \hat{W} &= \frac{\sum_n \sum_j \lambda_n^j V_n^{j\,\prime} \delta_{nn}^{jj\,\prime} \left(m_{nn}^{jj\,\prime}\right)^{-1/\kappa}}{\sum_n \sum_j \lambda_n^j V_n^j \delta_{nn}^{jj} \left(m_{nn}^{jj}\right)^{-1/\kappa}}, \\ &= \sum_n \sum_j \omega_n^j \hat{V}_n^j \hat{\delta}_{nn}^{jj} \left(\hat{m}_{nn}^{jj}\right)^{-1/\kappa}, \end{aligned}$$

where $\omega_n^j = \left(\lambda_n^j V_n^j \delta_{nn}^{jj} \left(m_{nn}^{jj}\right)^{-1/\kappa}\right) / W$, which is our result.

Next, consider the change in real GDP. The derivation is simple as we construct it in a way that matches how we measure it in the data. Nominal GDP in region n and sector j is $(\eta^j + \beta^j) R_n^j + r_n^j S_n^j = w_n^j L_n^j$ (since trade balances). Then let real GDP be this nominal GDP deflated by the overall price index $\left(P_n^{ag\,\varepsilon} P_n^{na\,1-\varepsilon}\right)^{\alpha} r_n^{j\,1-\alpha}$. Since $\hat{r}_n^j = \hat{w}_n^j \hat{L}_n^j$, the change in real GDP in (n,j) is $\left(\hat{w}_n^j \hat{L}_n^j / \hat{P}_n^{ag\,\varepsilon} \hat{P}_n^{na\,1-\varepsilon}\right)^{\alpha}$ or $\hat{V}_n^j \hat{L}_n^j$. Thus, the aggregate change in real GDP is

$$\hat{Y} = \sum_j \sum_{n=1}^{N} \phi_n^j \hat{V}_n^j \hat{L}_n^j,$$

where $\phi_n^j \propto V_n^j L_n^j$ is the contribution of (n,j) to initial national real GDP.■

Relative Changes in Key Variables

Equations 3, 4 and 5 imply

$$\hat{c}_{ni}^{j} = \hat{w}_i^{j\,\beta^j} \hat{r}_i^{j\,\eta^j} \left(\prod_{k \in \{ag,na\}} \hat{P}_i^{k\,\sigma^{jk}} \right), \tag{18}$$

$$\hat{\pi}_{ni}^{j} = \frac{\hat{T}_i^j \left(\hat{\tau}_{ni}^j \hat{c}_i^j \right)^{-\theta}}{\sum_{m=1}^{N+1} \pi_{nm}^j \hat{T}_m^j \left(\hat{\tau}_{nm}^j \hat{c}_m^j \right)^{-\theta}}, \tag{19}$$

$$\hat{P}_n^j = \left[\sum_{m=1}^{N+1} \pi_{nm}^j \hat{T}_m^j \left(\hat{\tau}_{nm}^j \hat{c}_m^j \right)^{-\theta} \right]^{-1/\theta}. \tag{20}$$

Given $\pi_{ni}^{j\,'} = \hat{\pi}_{ni}^j \pi_{ni}^j$, equations 2, 6 and 7 solve counterfactual expenditures $X_{ni}^{j\,'}$, revenues $R_{ni}^{j\,'}$, and incomes $\sum_j v_n^{j\,'} L_n^{j\,'}$. We therefore know $\hat{w}_n^j = \hat{R}_n^j / \hat{L}_n^j$ and $\hat{r}_n^j = \hat{R}_n^j$. All together, these expressions give changes in prices $\hat{P}_n^j$, trade flows $\hat{\pi}_{ni}^j$, and wages $\hat{w}_n^j$ per effective worker as a function of changes in trade costs ($\hat{\tau}_{ni}^j$), underlying productivity ($\hat{T}_n^j$), and employment ($\hat{L}_n^j$). It remains to solve for changes in migration flows. As the change in real incomes is

$$\hat{V}_n^j = \frac{\hat{w}_n^{j\,\alpha}}{\left(\hat{P}_n^{ag\,\varepsilon} \hat{P}_n^{na\,1-\varepsilon} \right)^{\alpha} \hat{L}_n^{j\,1-\alpha}}, \tag{21}$$

which, given exogenous changes in migration costs $\hat{\mu}_{ni}^{jk}$, changes in migration shares are

$$\hat{m}_{ni}^{jk} = \frac{\left(\hat{\delta}_{ni}^{jk} \hat{V}_i^k / \hat{\mu}_{ni}^{jk} \right)^{\kappa}}{\sum_k \sum_{i'=1}^{N} m_{ni'}^{jk'} \left(\hat{\delta}_{ni'}^{jk'} \hat{V}_{i'}^{k'} / \hat{\mu}_{ni'}^{jk'} \right)^{\kappa}}. \tag{22}$$

These shares then imply $L_n^{j\,'} = \sum_{i,k} m_{in}^{kj\,'} \bar{L}_i^k$ and, from equation 9, $\hat{\delta}_{ni}^{jk}$.

Solving for Equilibrium Changes due to Land Reform

To solve the model for counterfactual changes in land ownership, we modify the model to provide workers from (n, j) an equal per-capita rebate $r_n^j S_n^j / \bar{L}_n^j$ regardless of where they live. Previously, only non-migrant locals received this rebate. Thus, migrants gain while non-migrants lose so the equilibrium number of migrants will increase. To solve the new counterfactual of the model, let $\rho_n^j = r_n^j S_n^j / \bar{L}_n^j$ be the land rebates per registrant of region n and sector j. From section 3.3, we have

$$\delta_{ni}^{jk} = 1 + \frac{(1-\alpha) v_n^j L_n^j + \frac{\eta^j}{\beta^j} w_n^j L_n^j}{w_i^k \bar{L}_n^j}. \tag{23}$$

Migration costs are held constant, so

$$\frac{\hat{m}_{ni}^{jk}}{\hat{m}_{nn}^{jj}} = \left(\frac{\hat{\delta}_{ni}^{jk}\hat{V}_i^k}{\hat{\delta}_{nn}^{jj}\hat{V}_n^j}\right)^{\kappa}, \tag{24}$$

where $\hat{\delta}_{ni}^{jk} = 1 + \rho_n^{j\,\prime}/w_i^{k\,\prime}$ if $n \neq i$ or $j \neq k$ and $\hat{\delta}_{nn}^{jj} = \frac{1+\rho_n^{j\,\prime}/w_n^{j\,\prime}}{1+\left(\rho_n^j/m_{nn}^{jj}\right)/w_n^j}$ otherwise. Thus, the first-order effect of land reform is to increase migration disproportionately to regions of low wages from regions of high land income. That is, between pairs where $\rho_n^{j\,\prime}/w_i^{k\,\prime}$ is large, such as from urban areas to rural.

To solve equilibrium aggregate outcomes, begin with total income in region n and sector j as

$$v_n^{j\,\prime} L_n^{j\,\prime} = w_n^{j\,\prime} L_n^{j\,\prime} + \sum_{i,k} \rho_i^{k\,\prime} m_{in}^{kj\,\prime} \bar{L}_i^{k\,\prime}. \tag{25}$$

With this, we solve counterfactual spending, incomes, prices, and so on, largely as before. In particular, equations 2, 6 and 7 combine to yield

$$w_n^{j\,\prime} L_n^{j\,\prime} = \beta^j \sum_{i=1}^{N+1} \pi_{ni}^{jk\,\prime} \left[\alpha\varepsilon^j \sum_k v_n^{k\,\prime} L_n^{k\,\prime} + \sum_k \frac{\sigma^{kj}}{\beta^k} w_n^{k\,\prime} L_n^{k\,\prime}\right]. \tag{26}$$

It remains to solve for counterfactual land incomes. As before, $r_n^{j\,\prime} S_n^{j\,\prime} = (1-\alpha) v_n^{j\,\prime} L_n^{j\,\prime} + \frac{\eta^j}{\beta^j} w_n^{j\,\prime} L_n^{j\,\prime}$ but, unlike before, the right-side of this expression is no longer proportional to wages. But, given $v_n^{j\,\prime}$, $w_n^{j\,\prime}$, $L_n^{j\,\prime}$, and the initial equilibrium, we have $\hat{r}_n^j$. From equations 18 to 20, we then solve for counterfactual prices $\hat{P}_n^j$ and trade shares $\hat{\pi}_{ni}^{jk}$. Given the new trade shares, equations 25 and 26 solve $v_n^{j\,\prime}$ and $w_n^{j\,\prime}$. With these, the new prices for goods and housing, equations 23 and 24 imply new labor allocations $L_n^{j\,\prime}$. Thus we have an algorithm to solve the new equilibrium in full.

Estimating Trade Costs

We begin with a standard Head-Ries index of trade costs. From equation 15 and our data on trade shares, we estimate $\bar{\tau}_{ni}^{j}$. We summarize the average values of this for various bilateral trade flows between regions of China. A value of $\bar{\tau}_{ni}^{j} = 1$ implies zero trade costs and $\bar{\tau}_{ni}^{j} = 2$ implies trade costs equivalent to a 100% tariff-equivalent trade costs. Overall, we find the trade-weighted average trade cost between regions of China is 300% in agriculture and 200% in non-agriculture. Care must be taken when interpreting these values, however, as they reflect trade costs between regions *relative to trade costs within each region* – after all, we normalize $\tau_{nn}^{j} = 1$ for all n and j.

To arrive at our preferred estimate of trade costs τ_{ni}^{j}, we must augment the Head-Ries index $\bar{\tau}_{ni}^{j}$ to reflect trade cost asymmetries. As discussed in the main text, given an exporter-specific trade cost t_{i}^{j}, we have $\tau_{ni}^{j} = \bar{\tau}_{ni}^{j}\sqrt{t_{i}^{j}/t_{n}^{j}}$. How do we estimate these export costs? Within the same class of models for which the Head-Ries estimate holds, a normalized measure of trade flows is

$$ln\left(\pi_{ni}^{j}/\pi_{nn}^{j}\right) = S_{i}^{j} - S_{n}^{j} - \theta ln\left(\tau_{ni}^{j}\right),$$

where S captures any country-specific factor affecting competitiveness, such as factor prices or productivity. See Head and Mayer (2014) for details behind this and related gravity regressions.

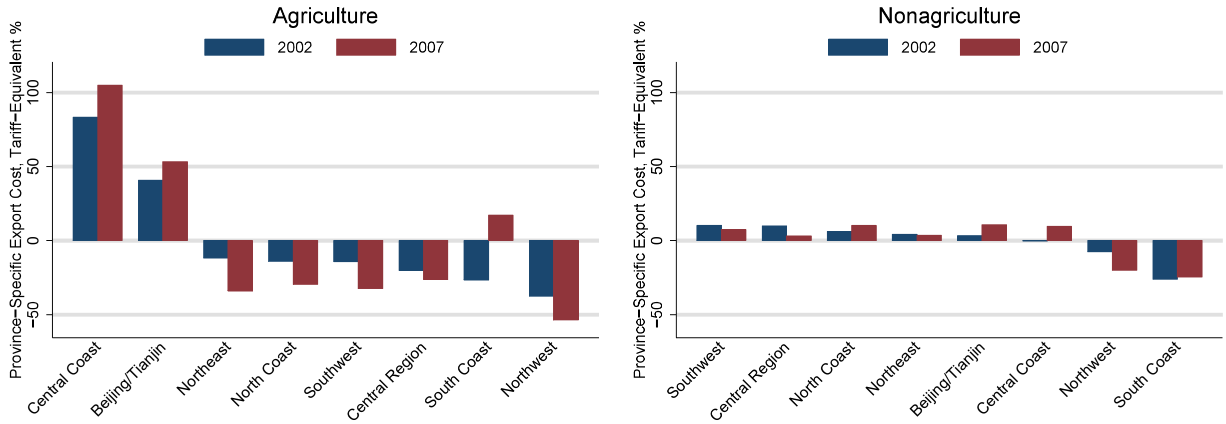
If trade costs have only a symmetric and exporter-specific component, and if the symmetric component is well proxied by geographic distance, then we can estimate t_{i}^{j} from

$$ln\left(\pi_{ni}^{j}/\pi_{nn}^{j}\right) = \delta^{j} ln\left(d_{ni}\right) + \iota_{n}^{j} + \eta_{i}^{j} + \varepsilon_{ni}^{j}, \tag{27}$$

where δ^{j} is the distance-elasticity of trade costs, d_{ni} is the (population-weighted) geographic distance between region n and i, and ι_{n}^{j} and η_{i}^{j} are sector-specific importer- and exporter-effects. Distance between China's provinces and the world is the distance between each region and all other countries weighted by total trade between China and each other country. As the exporter effect is $\hat{\eta}_{i}^{j} = S_{i}^{j} - \theta ln\left(t_{i}^{j}\right)$ and the importer effect is $\hat{\iota}_{n}^{j} = -S_{n}^{j}$, we infer export costs as $ln\left(\hat{t}_{n}^{j}\right) = -\left(\hat{\iota}_{n}^{j} + \hat{\eta}_{n}^{j}\right)/\theta$.

We use the regional input-output data described in the previous section to estimate this regression. We find distance-elasticities in line with international trade results; specifically, $\hat{\delta}^{ag} = -1.33$ and $\hat{\delta}^{na} = -1.06$ for 2007 with standard errors of 0.38 and 0.22, respectively. For the 2002 trade data, we find $\hat{\delta}^{ag} = -1.43$ and $\hat{\delta}^{na} = -1.04$ with standard errors of 0.41 and 0.28. Finally, we display the estimates of $ln\left(\hat{t}_{n}\right)$ for both 2002 and 2007 in Figure 3. As the overall level of export costs is undetermined, we express values relative to the mean across all regions within each year. Overall, it is more costly for poor regions to export non-agricultural goods than rich regions – consistent with international evidence from Waugh (2010). For agriculture, this pattern is less clear. There were also very few changes to the ranking across regions in trade cost asymmetries between 2002 and 2007. Combined with the Head-Reis Index estimates $\bar{\tau}_{ni}^{j}$, we estimate our preferred measure of trade costs and display their level in 2002 by sector and the relative changes between 2002 and 2007 is displayed in Tables 13 and 14.

Figure 3: Asymmetries in Trade Costs: Exporter-Specific Costs



Notes: Displays the tariff-equivalent (in percentage points) region-specific export costs. All expressed relative to the average for the year. A value of 10 implies exporting is 10 percent more costly relative to the average region.

Table 13: Initial Bilateral Trade Costs (Year 2002)

	Exporter								
Importer	North-east	Beijing Tianjin	North Coast	Central Coast	South Coast	Central Region	North-west	South-west	Abroad
Trade Costs in Agriculture, τ_{ni}^{ag}									
Northeast		4.13	3.31	8.28	4.06	3.24	2.09	4.22	2.89
Beijing/Tianjin	2.59		2.08	7.30	4.42	2.89	2.00	4.74	1.99
North Coast	3.40	3.40		6.89	4.18	2.87	2.29	4.53	3.28
Central Coast	3.99	5.60	3.24		3.25	1.83	2.56	4.06	1.84
South Coast	4.89	8.48	4.91	8.11		3.21	3.14	4.04	2.52
Central Region	3.58	5.08	3.10	4.20	2.95		2.33	3.55	4.27
Northwest	2.96	4.51	3.17	7.53	3.70	2.98		3.70	4.49
Southwest	4.34	7.78	4.55	8.67	3.46	3.31	2.69		4.41
Abroad	5.94	6.51	6.56	7.82	4.30	7.93	6.51	8.79	
Trade Costs in Non-agriculture, τ_{ni}^{na}									
Northeast		2.58	2.84	3.63	2.65	3.34	2.69	3.27	3.48
Beijing/Tianjin	2.60		1.92	3.13	2.42	3.09	2.71	3.41	2.93
North Coast	2.78	1.87		2.69	2.48	2.57	2.56	3.56	3.30
Central Coast	3.79	3.24	2.86		2.15	2.35	2.72	3.26	2.49
South Coast	3.73	3.38	3.56	2.90		3.02	3.07	2.89	2.63
Central Region	3.16	2.91	2.48	2.13	2.03		2.48	3.07	4.06
Northwest	3.02	3.03	2.93	2.93	2.46	2.95		2.82	4.63
Southwest	3.09	3.20	3.43	2.95	1.94	3.07	2.37		4.23
Abroad	4.86	4.05	4.69	3.33	2.61	5.98	5.73	6.24	

Note: Displays bilateral trade cost (relative to within-region costs) for agriculture and nonagriculture for eight broad regions. The eight regions are classified as: Northeast (Heilongjiang, Jilin, Liaoning), North Municipalities (Beijing, Tianjin), North Coast (Hebei, Shandong), Central Coast (Jiangsu, Shanghai, Zhejiang), South Coast (Fujian, Guangdong, Hainan), Central (Shanxi, Henan, Anhui, Hubei, Hunan, Jiangxi), Northwest (Inner Mongolia, Shaanxi, Ningxia, Gansu, Qinghai, Xinjiang), and Southwest (Sichuan, Chongqing, Yunnan, Guizhou, Guanxi, Tibet).

Though we use asymmetric trade costs in our main analysis, our results do not depend on it. To ensure our quantitative analysis is robust to only measuring trade costs, we re-estimate trade cost changes based only on $\bar{\tau}_{ni}^{j}$. We report these results in Table 15. Quantitatively, there are only minor changes.

Table 14: Relative Changes of Bilateral Trade Costs

Importer	Exporter								
	North-east	Beijing Tianjin	North Coast	Central Coast	South Coast	Central Region	North-west	South-west	Abroad
Change in Trade Costs in Agriculture, $\hat{\tau}_{ni}^{ag}$									
Northeast		1.34	0.88	1.17	1.66	1.24	1.31	0.90	0.96
Beijing/Tianjin	0.92		0.63	0.79	1.16	0.91	0.92	0.64	0.72
North Coast	0.80	0.83		0.82	1.11	0.77	0.72	0.61	0.72
Central Coast	0.78	0.77	0.60		1.41	0.83	0.65	0.77	0.76
South Coast	0.78	0.79	0.57	0.99		0.87	0.72	0.70	0.73
Central Region	1.01	1.08	0.68	1.01	1.50		0.86	0.87	0.77
Northwest	1.31	1.35	0.79	0.98	1.54	1.07		0.81	0.61
Southwest	0.85	0.89	0.64	1.10	1.41	1.02	0.76		0.73
Abroad	0.95	1.03	0.78	1.12	1.53	0.93	0.60	0.76	
Change in Trade Costs in Non-agriculture, $\hat{\tau}_{ni}^{na}$									
Northeast		0.90	0.91	0.84	0.79	0.82	0.83	0.88	0.80
Beijing/Tianjin	0.84		0.90	0.91	0.89	0.79	0.73	0.86	0.79
North Coast	0.87	0.93		1.00	0.86	0.78	0.72	0.78	0.81
Central Coast	0.76	0.88	0.95		0.85	0.82	0.75	0.86	0.82
South Coast	0.77	0.93	0.88	0.92		0.80	0.72	0.81	0.94
Central Region	0.87	0.91	0.86	0.96	0.88		0.76	0.84	0.75
Northwest	0.95	0.91	0.86	0.96	0.85	0.83		0.88	0.68
Southwest	0.89	0.94	0.83	0.97	0.84	0.80	0.78		0.74
Abroad	0.87	0.92	0.92	0.98	1.05	0.76	0.64	0.79	

Note: Displays changes in bilateral trade cost for agriculture and nonagriculture for eight broad regions. In the simulation, we apply these changes to the provinces within each region.

Changes in Productivity Parameters

So far we have held the efficiency parameters T_n^j constant. Not surprisingly, the implied change in real GDP per worker does not match data. We now calibrate changes $\hat{T}_n^j$ such that, when migration and trade costs decline as measured, the resulting change in real GDP per worker in each province-sector matches data. The changes in T_n^j could be the results of changes in the average efficiency or average capital intensity of the firms in region n and sector j, or the changes in capital allocation among these firms, or some combination of these changes. With $\hat{T}_n^j$ thus calibrated, the model precisely matches $\hat{V}_n^j$ and therefore also $\hat{m}_{ni}^{jk}$.

We display our main results in Table 16. The first row displays the effect of $\hat{T}_n^j$ alone. Aggregate labor productivity, welfare, and trade volumes all rise significantly, but trade shares change little. The stock of inter-provincial migrants increases significantly because some rich provinces like Shanghai have larger increase in productivity than other less rich provinces. Within-province between-sector migration increases slightly. We also display the marginal effects of trade and migration cost changes in the second panel of Table 16. The marginal effects of changing trade costs are similar to our earlier results, though there are some notable interaction effects. Internal migration cost changes, for example, contribute more to aggregate real GDP growth with the change in productivity parameters. Again, this is because faster productivity growth in rich regions such as Shanghai makes the gain from inter-provincial migration larger.

Alternative Parameter Values

We also report our main results for a variety of alternative values of the income-elasticity of migration κ. This is one of the more important parameters in our model, and we demonstrate here

Table 15: Results With Only Symmetric Trade Costs

Measured Change for	Trade Shares (p.p. Change) Internal	External	Migrant Stock Within Province	Between Province	Real GDP	Aggregate Welfare
Baseline Model: Main Results						
Internal Trade	9.2	-0.7	0.8%	-1.8%	11.2%	11.4%
External Trade	-0.7	3.9	1.8%	2.4%	4.1%	2.9%
All Trade	8.2	2.8	2.5%	0.5%	15.2%	14.1%
Migration	0.1	0.1	14.5%	80.8%	4.8%	11.1%
Internal Changes	9.2	-0.6	15.1%	78.1%	16.4%	23.8%
Everything	8.3	3.0	16.9%	83.0%	20.8%	26.8%
With Only Symmetric Trade Costs $\bar{\tau}_{ni}^{j}$						
Internal Trade	9.0	-0.7	0.5%	-2.0%	10.9%	11.0%
External Trade	-0.6	3.5	0.7%	0.7%	3.4%	2.9%
All Trade	8.1	2.6	1.2%	-1.1%	14.4%	13.8%
Migration	0.1	0.1	14.5%	80.8%	4.8%	11.1%
Internal Changes	9.0	-0.5	14.9%	77.5%	16.1%	23.3%
Everything	8.1	2.7	15.6%	80.0%	19.8%	26.4%

Notes: Displays the main counterfactual experiments if all trade costs changes were based only on the Head-Reis Index for trade costs. These exclude all asymmetries estimated from the fixed effects regression decribed in the appendix.

our main results are not overly sensitive to alternative values of it. We report in Table 17 the main results of the baseline model and for values of κ ranging from 1 to 3. In general, the smaller the value of this parameter, the larger are the gains from migration and the larger is the change in the number of migrants to the measured change in migration costs. This is clear across panels in Table 17, and largely to the measure of migration cost estimates are decreasing in κ for given values of real income and migration shares (see Section 4.1). The same is true for the inferred changes in migration costs. But, offsetting this, is that the welfare gains described in Theorem 2 show that for any given change in migration, aggregate gains are smaller for smaller κ.

Finally, we repeat these robustness exercises for alternative values of the trade-cost elasticity parameter θ. In Table 18 we report our main results for θ ranging from 3 to 8, which encompass the bulk of estimates found in the literature. More recent estimates, using a variety of methods, have converged to values around 4, which motivates it as for our main results. As with the migration elasticity, there are two offsetting effects of changing this parameter. First, a larger θ implies smaller trade costs are inferred from a set of trade share observations. After all, a higher cost elasticity means lower costs are required to match observed trade shares relative to the frictionless counterfactual. But second, a larger θ means the welfare gains from any given change in trade shares will be larger. The latter effect tends to dominate, and our main results are therefore on the conservative side of possible results within a reasonable range for the parameter θ.

Age-Specific Migration Costs in 2005

To explore the variation in migration costs across workers by age, we use China's 2005 Population Census. This data reports individual worker income, which we use to re-estimate μ_{ni}^{jk} by age cohort. We are unable to estimate migration cost changes, as the Census 2000 data does not

Table 16: Effects of Various Cost and Productivity Parameter Changes

Measured Change for	Trade Shares (p.p. Change) Internal	External	Migrant Stock Within Province	Between Province	Aggregate Outcomes GDP/Worker	Welfare
Efficiency, $\hat{T}_n^j$	-0.1	0.0	3.6%	28.0%	42.5%	35.9%
All Changes *	7.9	2.7	22.2%	131.3%	77.2%	74.7%
Marginal Effects (changes relative to what productivity delivers)						
Internal Trade	9.1	-0.7	0.8%	-3.7%	11.1%	11.5%
External Trade	-0.6	3.5	4.8%	5.6%	5.4%	1.8%
All Trade	8.2	2.5	5.5%	1.9%	16.5%	13.2%
Migration	0.0	0.2	12.4%	77.9%	6.6%	9.8%
Internal Changes	8.9	-0.5	13.1%	71.6%	18.1%	22.6%
Everything	8.0	2.7	17.9%	80.7%	24.3%	24.2%
No Change in Productivity (consistent with earlier tables)						
Internal Trade	9.2	-0.7	0.8%	-1.8%	11.2%	11.3%
External Trade	-0.7	3.9	1.8%	2.4%	4.1%	2.9%
All Trade	8.2	2.8	2.5%	0.5%	15.2%	14.1%
Migration	0.1	0.1	14.5%	80.8%	4.8%	11.1%
Internal Changes	9.2	-0.6	15.1%	78.1%	16.4%	23.8%
Everything	8.3	3.0	16.9%	83.0%	20.8%	26.8%

Notes: Displays aggregate response to various cost changes with and without changes in the region-sector specific efficiency $\hat{T}_n^j$. Marginal effects reflect the changes relative to the equilibrium with only efficiency changes. The migrant stock is the number of workers living outside their province of registration. * The data on trade to GDP ratios is from the model, which matches the region level trade share changes described in Section 2. The region-level data under-reports internal trade by neglecting inter-provincial trade among provinces within the same broader region. Our model (and 2002 data) is at the province-level. The reported change in the migrant stock reflects matching migration shares from the Census perfectly, though differs from Table 1 due to, for example, changes in *hukou* registration status that we do not model.

include individual income. As in the text, we estimate

$$\mu_{ni,a}^{jk} = \frac{1}{\delta_{nn}^{jj}} \left(\frac{V_{i,a}^k}{V_{n,a}^j}\right) \left(\frac{m_{nn,a}^{jj}}{m_{ni,a}^{jk}}\right)^{1/\kappa} \qquad for\ n \neq i,$$

using age-cohort a migration shares $m_{ni,a}^{jk}$, and cohort-specific real income levels $v_{n,a}^j$. For the non-migrant land income adjustment δ_{nn}^{jj} we use a common value for all ages. To estimate real income levels in a manner consistent with aggregate real GDP per worker data by province and sector, we adjust the Census reported incomes $v_{n,a}^j$ as $V_{n,a}^j = V_n^j \cdot \left(\frac{v_{n,a}^j}{\sum_{a'} \omega_{n,a}^j v_{n,a}^j}\right)$, where V_n^j is province n and sector j's real GDP per worker, as in the text, and $\omega_{n,a}^j = \frac{l_{n,a}^j}{\sum_{a'} l_{n,a'}^j}$ is the share of that province and sector's employment accounted for by age cohort a. While the aggregate estimate of migration costs is $\mu_{ni}^{jk} = 2.3$ in 2005, we find this varies systematically across age groups. We display all estimates across age cohorts from 15 to 54 in Figure 4. We find migration costs range from a low of $\mu_{ni,a}^{jk} = 1.5$ for workers under the age of 24, to a high of nearly $\mu_{ni,a}^{jk} = 3$ for older workers.

Table 17: Results Under Alternative Migration Elasticities κ

Measured Change for	Trade Shares (p.p. Change) Internal	External	Migrant Stock Within Province	Between Province	Real GDP	Aggregate Welfare
Baseline Model: Main Results, $\kappa = 1.5$						
Internal Trade	9.2	-0.7	0.8%	-1.8%	11.2%	11.4%
External Trade	-0.7	3.9	1.8%	2.4%	4.1%	2.9%
All Trade	8.2	2.8	2.5%	0.5%	15.2%	14.1%
Migration	0.1	0.1	14.5%	80.8%	4.8%	11.1%
Internal Changes	9.2	-0.6	15.1%	78.1%	16.4%	23.8%
Everything	8.3	3.0	16.9%	83.0%	20.8%	26.8%
For $\kappa = 1$						
Internal Trade	9.2	-0.7	0.6%	-1.3%	11.2%	11.2%
External Trade	-0.7	3.9	1.4%	1.9%	3.9%	2.8%
All Trade	8.2	2.8	2.0%	0.5%	15.1%	13.9%
Migration	0.2	0.2	15.5%	91.1%	5.6%	16.1%
Internal Changes	9.2	-0.6	16.0%	89.0%	17.4%	29.2%
Everything	8.3	3.0	17.5%	93.1%	21.6%	32.2%
For $\kappa = 2$						
Internal Trade	9.2	-0.7	0.9%	-2.3%	11.2%	11.4%
External Trade	-0.7	3.9	2.1%	2.9%	4.2%	3.0%
All Trade	8.2	2.8	2.9%	0.5%	15.3%	14.3%
Migration	0.1	0.1	14.0%	73.4%	4.2%	8.8%
Internal Changes	9.2	-0.6	14.7%	70.3%	15.7%	21.2%
Everything	8.3	3.0	16.7%	75.6%	20.2%	24.4%
For $\kappa = 3$						
Internal Trade	9.2	-0.7	1.2%	-2.9%	11.1%	11.5%
External Trade	-0.7	3.9	2.5%	3.6%	4.3%	3.1%
All Trade	8.3	2.8	3.5%	0.5%	15.4%	14.5%
Migration	0.0	0.1	13.7%	63.8%	3.4%	6.6%
Internal Changes	9.2	-0.6	14.6%	60.1%	14.7%	18.8%
Everything	8.2	2.9	16.8%	65.8%	19.3%	22.0%

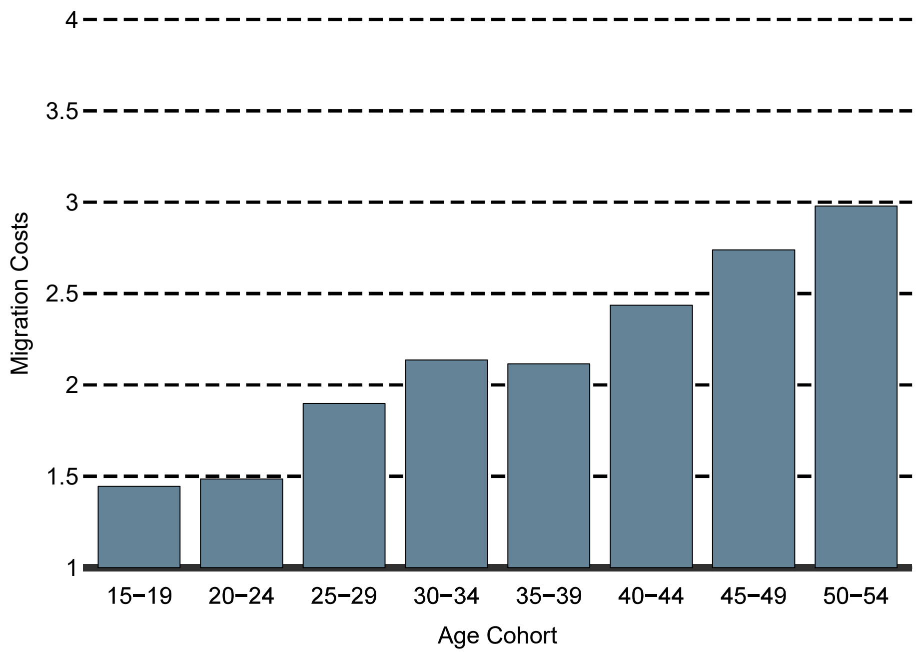
Notes: Displays the main counterfactual experiments under various migration elasticities.

Table 18: Results Under Alternative Trade Elasticities θ

Measured Change for	Trade Shares (p.p. Change) Internal	External	Migrant Stock Within Province	Between Province	Real GDP	Aggregate Welfare
Baseline Model: Main Results, $\theta = 4$						
Internal Trade	9.2	-0.7	0.8%	-1.8%	11.2%	11.4%
External Trade	-0.7	3.9	1.8%	2.4%	4.1%	2.9%
All Trade	8.2	2.8	2.5%	0.5%	15.2%	14.1%
Migration	0.1	0.1	14.5%	80.8%	4.8%	11.1%
Internal Changes	9.2	-0.6	15.1%	78.1%	16.4%	23.8%
Everything	8.3	3.0	16.9%	83.0%	20.8%	26.8%
For $\theta = 3$						
Internal Trade	6.6	-0.6	0.6%	-1.7%	10.2%	10.4%
External Trade	-0.5	2.7	1.3%	2.0%	3.6%	2.7%
All Trade	6.0	1.9	1.8%	0.2%	13.8%	13.0%
Migration	0.1	0.1	14.6%	79.7%	4.6%	11.0%
Internal Changes	6.7	-0.5	15.0%	77.3%	15.3%	22.6%
Everything	6.1	2.0	16.2%	81.4%	19.1%	25.6%
For $\theta = 6$						
Internal Trade	15.0	-1.0	1.2%	-2.0%	13.4%	13.5%
External Trade	-1.1	6.9	3.0%	3.4%	5.4%	3.6%
All Trade	13.0	5.1	4.1%	1.4%	18.5%	16.6%
Migration	0.1	0.2	14.5%	82.2%	4.9%	11.1%
Internal Changes	14.9	-0.8	15.4%	78.9%	18.8%	26.2%
Everything	12.9	5.2	18.7%	85.7%	24.6%	29.6%
For $\theta = 8$						
Internal Trade	21.5	-1.3	1.7%	-2.0%	15.8%	15.8%
External Trade	-1.8	11.2	4.3%	4.3%	7.3%	4.7%
All Trade	17.7	8.0	6.0%	2.6%	22.6%	19.6%
Migration	0.1	0.2	14.6%	83.2%	5.1%	11.2%
Internal Changes	21.2	-1.1	15.9%	79.5%	21.4%	28.8%
Everything	17.5	8.1	20.8%	88.2%	29.0%	32.8%

Notes: Displays the main counterfactual experiments under various alternative trade elasticities.

Figure 4: Migration Costs μ_{ni}^{jk}, by Age Cohort in 2005



Notes: Displays the average migration cost mu_{ni}^{jk} for migrants in 2005 by age cohort.

Migration Costs vs Geographic Distance

Migration costs between provinces are strongly related to geographic distance. To estimate bilateral distance, we construct the population weighted distance between provinces from the Gridded Population of the World data. The average distance is nearly 1,400 kilometers, ranging from a high of 122 to 3,730 kms. As in Section 3.6.2, we presume here that migration costs take the form $\mu_{ni}^{jk} = \bar{\mu}_n^j d_{ni}^{\rho} \xi_{ni}^{jk}$. We then estimate

$$ln\left(\mu_{ni}^{jk}\right) = \rho \, ln\left(d_{ni}\right) + \delta_n^j + \varepsilon_{ni}^{jk},$$

where δ_n^j is a source province-sector fixed effect, and ρ is the elasticity of migration costs with respect to distance. We find $\rho = 1.01$ in 2000 and $\rho = 0.94$ in 2005. The change in migration costs $\hat{\mu}_{ni}^{jk}$ is also related to distance. Using the same specification as above, but with migration changes as the dependent variable, we find $\rho = -0.07$. This implies that the further apart two provinces are, the greater the reduction in migration costs between 2000 and 2005. We report these results in Table 19. In addition, we incorporate information on new highway construction between the capital cities of each province pair. Specifically, we construct a dummy variable that equals one for a given province-pair if there exists a highway connecting their two capital cities in 2005 but not 2000, and zero otherwise. We find that while there is no statistically significant relationship between changes in migration costs and new highway construction. But, for distant province pairs, new highways matter. The mean value for $ln(d_{ni})$ is 7.1, so the coefficient on our interaction term implies that province pairs that are further apart than average and saw a new highway connection

Table 19: Migration Costs and Distance Regressions

	Migration Costs μ_{ni}^{jk}		Change in Migration Costs $\hat{\mu}_{ni}^{jk}$		
	Year 2000	Year 2005			
Log Bilateral Distance, $ln(d_{ni})$	1.01	0.94	-0.07	-0.07	0.03
	[0.03]	[0.03]	[0.02]	[0.02]	[0.03]
New Highway Built				0.01	1.67
				[0.03]	[0.29]
Distance : New Highway					-0.24
					[0.04]
origin province-sector FEs	Yes	Yes	Yes	Yes	Yes
Obs.	3480	3480	3480	3480	3480
R^2	0.573	0.615	0.227	0.227	0.235

Notes: Displays the relationship between distance, migration costs, and migration cost changes. The "New Highway Built" dummy identifies whether a new highway was completed between 2000 and 2005 connecting the capital cities of the two provinces.

built experienced a greater drop in migration costs than those that did not see a new highway connection built. The positive coefficient on new highways does not imply that migration costs increases between those provinces relative to others, just that their costs did not decrease as much.

Non-Homothetic Preferences

With equal-proportional rebates to all workers, we can introduce one additional modification to the model: non-homothetic preferences.

As the choice between agricultural and non-agricultural employment is a critical dimension of our model, we explore how non-homothetic preferences might affect the results. To that end, let utility be given by the familiar Stone-Geary form

$$u_n^j = \left[\left(c_n^{j,a} - \bar{a} \right)^{\varepsilon} \left(c_n^{j,m} \right)^{1-\varepsilon} \right]^{\alpha} s_{u_n}^{j\,1-\alpha}, \tag{28}$$

where $\bar{a}$ is a minimum subsistence food intake requirement. As in Tombe (2015), it is useful to use data on household food budget shares $b_n^j \equiv P_n^a c_n^{j,a} / v_n^j$ to define final demand

$$D_n^j = \begin{cases} b_n^j v_n^j L_n^j & \text{if} \quad j = a \\ \alpha \left(1 - \varepsilon\right) \left(\frac{1 - b_n^j}{1 - \alpha\varepsilon} \right) v_n^j L_n^j & \text{if} \quad j = m \\ \left(1 - \alpha\right) \left(\frac{1 - b_n^j}{1 - \alpha\varepsilon} \right) v_n^j L_n^j & \text{if} \quad j = s \end{cases} \tag{29}$$

This is useful to define how demand and spending patterns respond in our counterfactuals without actually calibrating the subsistence parameter $\bar{a}$ or food price levels. Given budget shares b_n^j from data, counterfactual subsistence spending is $P_n^{ag\,\prime}\,\bar{a} = \left(\frac{b_n^j - \alpha\varepsilon}{1-\alpha\varepsilon}\right) v_n^j \hat{P}_n^a$ and therefore

$$D_n^{j\,\prime} = \begin{cases} \left(\left(\frac{b_n^j-\alpha\varepsilon}{1-\alpha\varepsilon}\right)\hat{P}_n^a + \alpha\varepsilon\left(\hat{v}_n^j\hat{L}_n^j - \left(\frac{b_n^j-\alpha\varepsilon}{1-\alpha\varepsilon}\right)\hat{P}_n^a\right)\right) v_n^j L_n^j & \text{if} \quad j=a \\ \alpha\left(1-\varepsilon\right)\left(\hat{v}_n^j\hat{L}_n^j - \left(\frac{b_n^j-\alpha\varepsilon}{1-\alpha\varepsilon}\right)\hat{P}_n^a\right) v_n^j L_n^j & \text{if} \quad j=m \\ \left(1-\alpha\right)\left(\hat{v}_n^j\hat{L}_n^j - \left(\frac{b_n^j-\alpha\varepsilon}{1-\alpha\varepsilon}\right)\hat{P}_n^a\right) v_n^j L_n^j & \text{if} \quad j=s \end{cases} \tag{30}$$

With these, spending is simply

$$X_i^j = D_n^j + \sum_k \sigma^{kj} R_i^k. \tag{31}$$

Another important change to the model governs how land prices change. Spending on land is $\eta^j R_n^j + s_n^{land} v_n^j L_n^j$ and labor income is $\beta^j R_n^j$ So nominal income is $(\eta^j + \beta^j) R_n^j + s_n^{land} v_n^j L_n^j$. Equilibrium price of land is

$$r_n^j S_n^j = \eta^j R_n^j + s_n^{land} v_n^j L_n^j$$

and since $v_n^j L_n^j = (\eta^j + \beta^j) R_n^j + s_n^{land} v_n^j L_n^j = \frac{(\beta^j+\eta^j) R_n^j}{1-s_n^{land}}$ we have

$$r_n^j S_n^j = \left[\eta^j + \frac{s_n^{land}}{1-s_n^{land}}(\beta^j + \eta^j)\right] R_n^j,$$

which simplifies to something similar to our earlier equation

$$r_n^j S_n^j = \left[\frac{s_n^{land}\beta^j + \eta^j}{(1-s_n^{land})\beta^j}\right] w_n^j L_n^j.$$

Thus,

$$\hat{r}_n^j = \frac{\left[\frac{s_n^{land\,\prime}\beta^j+\eta^j}{(1-s_n^{land\,\prime})}\right]}{\left[\frac{s_n^{land}\beta^j+\eta^j}{(1-s_n^{land})}\right]} \hat{w}_n^j \hat{L}_n^j$$

The initial land share is $(1-\alpha)\left(\frac{1-b_n^j}{1-\alpha\varepsilon}\right)$ and the new land share is $(1-\alpha)\left(1 - \left(\frac{b_n^j-\alpha\varepsilon}{1-\alpha\varepsilon}\right)\frac{\hat{P}_n^a}{\hat{v}_n^j \hat{L}_n^j}\right)$. Real GDP changes are as before, but with nominal incomes deflated by $\hat{P}_n^j = \left(\hat{P}_n^{ag}\right)^{s_n^{ag}} \left(\hat{P}_n^{na}\right)^{s_n^{na}} \left(\hat{r}_n^j\right)^{s_n^{land}}$.

Finally, we solve for welfare changes and migration decisions. Optimal consumption demand by households are $P_n^a c_n^{j,a} = \bar{a} P_n^a + \alpha\varepsilon\left(v_n^j - \bar{a} P_n^a\right)$ for agriculture, $P_n^m c_n^{j,m} = \alpha(1-\varepsilon)\left(v_n^j - \bar{a}P_n^a\right)$ for manufactured goods, and finally $r_n^j s_{u_n}^j = (1-\alpha)\left(v_n^j - \bar{a}P_n^a\right)$ for housing. All together, indirect utility is

$$u_n^j \propto \frac{v_n^j - \bar{a}P_n^a}{\left(P_n^{j,a}\right)^{\alpha\varepsilon}\left(P_n^{j,m}\right)^{\alpha(1-\varepsilon)}\left(r_n^j\right)^{1-\alpha}}.$$

Given $P_n^a c_n^{j,a} = b_n^j v_n^j$, the indirect utility becomes

$$u_n^j \propto \left(\frac{v_n^j}{\left(P_n^a\right)^{\alpha\varepsilon} \left(P_n^m\right)^{\alpha(1-\varepsilon)} \left(r_n^j\right)^{1-\alpha}} \right) \left(\frac{1-b_n^j}{1-\alpha\varepsilon} \right).$$

As with Cobb-Douglas preferences, real incomes matter for welfare, but are adjusted in the non-homothetic preference case by excess non-food spending. Counterfactual food spending shares are $b_n^{j\,\prime} = \left(b_n^j - \alpha\varepsilon\right) \hat{P}_n^a / \hat{v}_n^j + \alpha\varepsilon$ and therefore welfare changes are

$$\hat{u}_n^j = \underbrace{\hat{\rho}\,\hat{w}_n^j \hat{P}_n^{-1}}_{\text{Real Wages}} \cdot \underbrace{\hat{\Gamma}_n}_{\text{Subsistence}} \tag{32}$$

where $\hat{P}_n = \left(\hat{P}_n^a\right)^{\alpha\varepsilon} \left(\hat{P}_n^m\right)^{\alpha(1-\varepsilon)} \left(\hat{r}_n^j\right)^{1-\alpha}$ and $\hat{\Gamma}_n^j \equiv \frac{1-b_n^{j\,\prime}}{1-b_n^j} = \frac{1-\alpha\varepsilon}{1-b_n^j} \left(1 - \left(\frac{b_n^j - \alpha\varepsilon}{1-\alpha\varepsilon}\right) \frac{\hat{P}_n^a}{\hat{v}_n^j}\right)$. Non-homothetic preferences means welfare changes and real income changes are different, and this effect is captured by the change in non-food spending shares $\hat{\Gamma}_n^j$. With these welfare expressions in hand, worker migration decisions now result in

$$m_{ni}^{jk} = \frac{\left(u_i^k / \mu_{ni}^{jk}\right)^{\kappa}}{\sum_{m,s} \left(u_m^s / \mu_{nm}^{js}\right)^{\kappa}}.$$

With this alternative specification, we repeat the main counterfactual experiments of the paper. We use data on food spending share from China's yearly Provincial Macro-economy Statistics through the University of Michigan's *China Data Online*. The data distinguishes between rural and urban areas, which allows us to pin down b_n^j for each province and sector. We provide all results in the third panel of Table 20, which are not qualitatively different from the results in the second panel. In fact, the results are slightly stronger for trade cost reductions in the sense that they have a larger effect on GDP, and lead to larger migration flows (and therefore movements out of agriculture).

Heterogeneous Worker Productivity

Maintain the equal-proportional rebates to all workers from the previous two sub-sections, but now consider a final alternative model of worker heterogeneity. In our baseline model, differences in migration incentives were due to heterogeneous preferences. Now, consider workers with different levels of human capital across space and sectors. Formally, workers are endowed with a vector z_n^k of productivity for each of the $N \times 2$ region-sectors – these are i.i.d. across workers, regions, and sectors. Workers then choose where to live to maximize their real income net of migration costs $\mu_{ni}^{jk} z_i^k V_i^k$. The parameter z_i^k is distributed i.i.d. Frechet across all regions and sectors. This corresponds to an earlier version of our working paper.

The changes to the model are fairly straightforward, and involve introducing the notion of effective labor supply in addition to employment. Specifically, the total supply of effective labor

Table 20: Main Results With Non-Homothetic Preferences

Measured Change for	Trade Shares (p.p. Change) Internal	External	Migrant Stock Within Province	Between Province	Aggregate Outcomes Real GDP	Welfare
Baseline Model: Homothetic Preference						
Internal Trade	9.2	-0.7	0.8%	-1.8%	11.2%	11.4%
External Trade	-0.7	3.9	1.8%	2.4%	4.1%	2.9%
All Trade	8.2	2.8	2.5%	0.5%	15.2%	14.1%
Migration	0.1	0.1	14.5%	80.8%	4.8%	11.1%
Internal Changes	9.2	-0.6	15.1%	78.1%	16.4%	23.8%
Everything	8.3	3.0	16.9%	83.0%	20.8%	26.8%
Non-Homothetic Preferences						
Internal Trade	9.1	-0.7	4.4%	3.5%	12.4%	14.8%
External Trade	-0.6	3.7	4.3%	6.3%	5.7%	4.3%
All Trade	8.2	2.7	8.1%	8.6%	18.0%	18.9%
Migration	0.1	0.2	12.1%	70.1%	2.9%	8.3%
Internal Changes	9.1	-0.5	16.1%	76.8%	15.8%	24.8%
Everything	8.3	2.9	19.6%	85.5%	21.9%	29.6%

Notes: Displays the main counterfactual experiments with non-homothetic preferences.

in region n sector j is

$$H_n^j = \sum_{k \in \{ag,na\}} \sum_{i=1}^{N} \mu_{in}^{kj} \left(m_{in}^{kj}\right)^{-1/\kappa} m_{in}^{kj} \bar{L}_i^k., \tag{33}$$

where $h_{in}^{kj} = \mu_{in}^{kj} \left(m_{in}^{kj}\right)^{-1/\kappa}$ is the average productivity of workers from region i and sector k that work in region n and sector j, and therefore $H_n^j = \sum_k \sum_i h_{in}^{kj} m_{in}^{kj} \bar{L}_i^k$. With this in mind, all per-worker variables in the model are simply re-interpreted as per-effective-worker. All other aspects of the model remain unchanged, but with effective labor replacing employment where appropriate and with key model variables interpreted in per-effective worker terms. For instance, V_n^j would be real income per effective worker in region n and sector j.

In this framework, we can calibrate κ using observable wage data instead of an empirical estimates of the income-elasticity of migration. Given the Frechet distribution of productivity, the proof of Proposition 2 provides a means of estimating κ from individual earnings data. Namely, after migration ex-post earnings across individuals are distributed Frechet. The log of a Frechet distribution is Gumbel, with a standard deviation proportional to κ^{-1}. Specifically, log real incomes are distributed Gumbel with CDF

$$G(x) = e^{-\left[\sum_k \sum_{i=1}^{N} \left(\mu_{ni}^{jk} V_i^k\right)^{\kappa}\right] e^{-\kappa x}},$$

which has a standard deviation $\pi/(\kappa\sqrt{6})$. Importantly, the standard deviation of real earnings is independent of μ_{ni}^{jk} and V_i^k.

How do we estimate this standard deviation from data? In the data, we observe nominal earnings, which corresponds to $\mu_{ni}^{jk} z_i^k v_i^k$. The above expression, however, applies to *real* earnings. Fortunately, the difference between the two is identical for all sector k workers in region i and

Table 21: Results with Worker Productivity Differences

Measured Change for	Trade Shares (p.p. Change) Internal	External	Migrant Stock Within Province	Between Province	Per-Capita Income Variation	Aggregate Outcomes Real GDP	Welfare
With Baseline $\kappa = 1.50$							
Internal Trade	9.2	-0.7	1.3%	-1.4%	-7.3%	9.5%	10.6%
External Trade	-0.7	3.9	2.4%	3.1%	5.0%	4.2%	2.1%
All Trade	8.3	2.9	3.5%	1.5%	-2.0%	13.8%	12.6%
Migration	0.3	-0.1	11.3%	57.4%	-14.5%	8.3%	1.2%
Internal Changes	9.5	-0.8	12.0%	55.7%	-19.5%	18.8%	12.1%
Everything	8.5	2.7	13.9%	60.5%	-16.5%	23.4%	14.1%
Matching Observable Moments in the Earnings Distribution, for $\kappa = 2.54$							
Internal Trade	9.3	-0.7	1.6%	-2.3%	-7.1%	9.4%	10.9%
External Trade	-0.6	3.9	2.8%	3.6%	5.8%	4.8%	2.5%
All Trade	8.3	2.9	4.2%	1.1%	-1.1%	14.2%	13.3%
Migration	0.3	-0.1	10.6%	63.3%	-0.9%	10.4%	2.0%
Internal Changes	9.5	-0.8	11.6%	59.9%	-6.6%	20.7%	13.3%
Everything	8.6	2.8	14.0%	66.2%	-3.5%	26.2%	15.6%

Notes: Displays aggregate response to various cost changes when worker heterogeneity is over productivity rather than spatial preferences. Marginal effects reflect the changes relative to the equilibrium with only productivity change. The migrant stock is the number of workers living outside their province of registration. Regional income variation is the variance of log real incomes *per capita* across provinces.

therefore $var(log(z_i^k V_i^k)) = var(log(z_i^k v_i^k))$. Next, μ_{ni}^{jk} is common to all (n, j)-registered workers now in sector k of region i; therefore, $var(log(\mu_{ni}^{jk} z_i^k V_i^k)) = var(log(\mu_{ni}^{jk} z_i^k v_i^k))$ across those workers. We therefore identify the value of κ from the within-group nominal earnings variation, with groups defined by region-sector of registration and current region-sector of employment. From the 2005 Population Survey, we find an average within-group standard deviation of log earnings of 0.50, so $\kappa = 2.54$. Individual income data is not reported in the 2000 Census.

We report the main results in Table 21, and find our results are qualitatively robust to this alternative framework although one notable difference is worth pointing out. The real GDP effect of migration is larger, and larger than the gains in welfare. This is unsurprising, as migrant workers are now, on average, more productive. Their gains are also not mainly in terms of higher utility as in the baseline model, but higher real incomes. The extent to which observed aggregate real GDP growth in China accounted for by lower migration costs will therefore be larger in this formulation than our baseline model in the paper.

Unbalanced Trade

Over the period we study, China's trade surplus was quite large – roughly 3% of GDP. The quantitative analysis in the paper, and many of the derivations, depended on trade balancing, not just between China and world, but for each of China's provinces. This was an innocuous assumption. Importantly, our estimates of trade and migration costs are unaffected by unbalanced trade. But to see if our other main quantitative results are affected, we augment the model here to incorporate exogenous trade surpluses and deficits, at the province level, in a fairly standard way.

The change to the model are fairly minor. Let S_n^j denote province n and sector j's trade surplus. Total income is then $v_n^j L_n^j = \frac{1}{\alpha}\left(\frac{\eta^j+\beta^j}{\beta^j} w_n^j L_n^j - S_n^j\right)$. That is, a trade surplus is a capital outflow, which shrinks a region's nominal income below its total sales. Another change to the model is how land rents change. Instead of $\hat{r}_n^j = \hat{w}_n^j \hat{L}_n^j$, as in the main model, we now have $\hat{r}_n^j = \omega_n^j \hat{w}_n^j \hat{L}_n^j + 1 -$

Table 22: Results with Province-Level Trade Imbalances

Measured Change for	p.p. Change in Share of Internal Trade	External Trade	Ag. Emp.	Migrant Stock Within Province	Between Province	Per-Capita Income Variation	Aggregate Outcomes Real GDP	Welfare
Internal Trade	9.3	-0.8	0.0	0.8%	-1.9%	-6.1%	10.0%	10.6%
External Trade	-0.7	4.0	-0.5	1.9%	2.3%	1.9%	3.4%	2.7%
All Trade	8.2	3.0	-0.5	2.6%	0.4%	0.6%	14.0%	13.2%
Migration	0.1	0.1	-3.0	14.6%	82.4%	-14.5%	4.3%	8.5%
Internal Changes	9.3	-0.7	-2.9	15.2%	79.3%	-19.6%	14.8%	20.1%
Everything	8.3	3.1	-3.5	17.1%	84.1%	-15.9%	19.0%	22.7%

Notes: Displays aggregate response to various cost changes when trade does not balance at the province level. The model is augmented to incorporate exogenous and fixed imbalances that correspond to our data in the initial equilibrium.

ω_n^j, where $\omega_n^j = \left(\frac{\beta^j(1-\alpha)+\eta^j}{\alpha} w_n^j L_n^j\right) / \left(\frac{\beta^j(1-\alpha)+\eta^j}{\alpha} w_n^j L_n^j - S_n^j \frac{1-\alpha}{\alpha}\right)$. All other model expressions remain unchanged.

Our data on trade flows allow us to estimate S_n^j only imperfectly for each province and region. We have province-level trade imbalances, and simply presume the trade surplus as a share of GDP is the same for both rural and urban regions within a province. Overall, rich provinces have surplus – in Shanghai, for example, the surplus is over 6% of GDP – and poor provinces have deficits. For the country as a whole, the trade surplus is 3% of GDP. With this data, we set S_n^j to match these surplus-to-GDP ratios in the initial equilibrium to match the data. We then infer the imbalance for the rest of the world such that $\sum_{n=1}^{N+1} S_n^j = 0$.

With these adjustments, we repeat our main quantitative experiments and display the results in Table 22. We see the falling migration and trade costs are similar to our main results in the paper. Importantly, the aggregate real GDP and welfare changes are only modestly different. We conclude our results are robust to the presence of unbalanced trade.