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Trade, Migration and Productivity: A Quantitative Analysis of China

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Abstract

We study how misallocation due to goods- and labour-market frictions affect aggregate productivity in China. Combining unique data with a general equilibrium model of internal and international trade, and migration across regions and sectors, we quantify the magnitude and consequences of trade and migration costs. The costs were high in 2000, but declined afterward. The decline accounts for roughly two-fifths of aggregate labour productivity growth in China between 2000 and 2005. Reductions in internal rather than international costs are particularly important. Despite the decline, migration costs are still high and potential gains from further reform are large.

JEL Classification: F1, F4, R1, O4

Keywords: *Migration; internal trade; spatial misallocation; gains from trade; China*

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1 Introduction

Differences in aggregate total factor productivity (TFP) are a key source of large cross-country income differences (Klenow and Rodriguez-Clare, 1997; Hall and Jones, 1999; Caselli, 2005) and misallocation of inputs can be an important reason for low levels of aggregate TFP in poor countries (Banerjee and Duflo, 2005; Restuccia and Rogerson, 2008; Hsieh and Klenow, 2009; Bartelsman et al., 2013). It is therefore important to understand the sources of misallocation. Indeed, in a review of the recent literature on misallocation, Restuccia and Rogerson (2013) state "the most persuasive evidence in support of the role of misallocation will come from work that follows the direct approach in specific contexts, especially those in which we observe changes in some underlying source of misallocation and can measure the resulting change in misallocation and aggregate TFP." In this paper we provide direct evidence on frictions to labour and goods flows across space and sectors as a source of misallocation in China. We further quantify the contribution of changes in these frictions on China's growth between 2000 and 2005. It is well known that China in the early 2000s had substantial policy-induced migration costs (Poncet, 2006; Cai et al., 2008) and internal trade costs (Young, 2000; Poncet, 2005). Since then, the Chinese government has undertaken policy reforms and infrastructure investments that reduced both migration and trade costs and, at the same time, the Chinese economy has experienced significant aggregate productivity growth (Zhu, 2012). China therefore provides an excellent case study for evaluating how much of aggregate productivity growth could be attributed to reductions in migration and trade costs and the resulting decrease in misallocation.

As a framework for our quantitative analysis, we develop a two-sector multi-region general equilibrium model featuring internal trade, international trade, and worker migration. Our model builds on the recent work of Ahlfeldt et al. (2012) and Redding (2015). Following Redding (2015), we introduce within-country trade and worker mobility into the Eaton and Kortum (2002) model and explicitly model worker location choices in the presence of migration costs. Our main departure from these papers is that we introduce frictions to both between-region and within-region between-sector migration. Specifically, within each region there is an agricultural and a nonagricultural sector. Workers are heterogeneous in their productivity across regions and sectors. Some workers migrate or switch sectors despite the costs while others do not. Even with these rich and realistic features, the model is still analytically tractable and can be easily implemented for quantitative analysis.

We fit this model to China, mapping it directly into data for China's provinces and sectors, and the rest of the world. To estimate the level and changes in trade and migration costs, we use model-implied gravity equations and unique data over time on trade and migration flows. We use the 2002 and 2007 China Regional Input-Output Tables, which provide the full bilateral trading matrices for all provinces and for a variety of sectors, and the 2000 Population Census and 2005 Population Survey, which provide information on migration between and within provinces. Our estimates show that trade costs were large in 2002. In nonagriculture, average internal and external trade costs were 30% and 20% higher than the corresponding costs in Canada. In agriculture, the gaps were even larger: average internal and external trade costs were roughly three times higher than in Canada. Between 2002 and 2007, China's trade costs declined significantly: on average, internal costs fell by between 10-15% and international costs fell by almost 10% in nonagriculture and nearly 25% in agriculture.

Turning to migration costs, note that we consider them ongoing *flow* costs rather than *sunk* costs. China has a *Hukou* household registration system that imposes large costs of working and living outside one's *Hukou* registration region, primarily through restricted access to social services and limited employment rights. These costs are recurring and exist as long as migrants do not have a local *Hukou* residence status. An indication of how tightly migration costs bind is the large regional income disparity across provinces. In 2000, the ratio of the income per worker for the 90th and 10th percentile provinces in China was 3.2 (the corresponding ratio for U.S. states is around 1.5). With our model and data, we quantify the magnitude of these costs. According to our estimates for 2000, the average cost of within-province rural-urban migration is around 51% of annual income; the costs of between-province migration are even higher: 94% of annual income for rural-to-rural or urban-to-urban migration and 98% for rural-to-urban migration. These costs are prohibitive for most workers. For others with high individual productivity in the destination region and sector, the benefits of migrating outweigh the high costs. Between 2000 and 2005, average within-province migration costs declined around 11% and average between-province migration costs declined between 1.4% and 6%, much lower than the reductions in trade costs.

What are the consequences of these measured changes in trade and migration costs? In a series of quantitative exercises using the fully calibrated model, we evaluate how cost changes affect trade flows, migration, welfare, productivity, and regional income differences. Lower international trade costs increased the stock of both inter-provincial and within-province migrants by 4-6%. Lower internal trade costs results in about 2.3% fewer inter-provincial migrants and 2.3% more within-province migrants. Though migration responses are small, aggregate welfare responses are large – 10.9% gains from internal trade cost reductions, 3.1% for external, and 13.8% for both. The large gains from internal trade cost reductions, relative to the external reductions, are primarily because the share of spending going to producers outside one's local region but within China is larger than to producers outside China. In terms of regional income differences, internal trade cost reductions lower the variance in (log) real incomes across provinces by over 7% while reductions in international trade costs increase the variance by nearly 2%.

Trade cost changes may account for very little change in migration, but migration costs account for much more. In response to the measured migration cost reductions, the stock of within-province and between-province migrants increase by over 20% and 220%, respectively. The migration cost reductions also increased aggregate productivity and welfare by 12.1% and 7.3%, respectively.

With these results, we perform a growth accounting exercise to decompose China's aggregate labour productivity growth between 2000 and 2005 into components reflecting internal trade and migration cost reductions, external trade liberalization, and all other factors (sectoral productivity or capital accumulation, for example). Internal trade cost reductions account for one-fifth of China's aggregate real GDP per worker growth over the period. Migration cost reductions yield almost as much. International trade liberalization, however, accounted for only 7% of the growth, which is in stark contrast to perceptions that China's growth is an "export-led" experience. Overall, reductions in trade and migration costs account for close to half of China's aggregate labour productivity growth from 2000 to 2005.

Despite the decline in trade and migration costs, the scope for further cost reductions beyond those measured is still large. We find moving China's internal trade costs to levels measured in Canada yields welfare gains of roughly 12%. Gains are even larger if migration costs fall to match U.S. migration rates, with real GDP increasing nearly 23% and welfare by 15%.[1]

In summary, our quantitative analysis shows that domestic reforms that reduced internal trade and migration costs and the resulting misallocation accounts for a significant portion of China's aggregate productivity growth between 2000 and 2005. Further reforms that reduce China's costs to developed country levels may lead to equally significant aggregate productivity growth in China in the future.

In addition to the misallocation literature discussed earlier, we contribute to a growing literature linking international trade flows with the spatial distribution of labour and economic activity within countries, such as Cosar and Fajgelbaum (2012); Dix-Carneiro and Kovak (2014); Allen and Arkolakis (2014); Bryan and Morten (2015); Redding (2015) and Caliendo et al. (2015). There are also papers investigating internal trade or migration costs separately, such as Morten and Oliveira (2014), Bryan and Morten (2015) or Ghani et al. (2012), and empirical investigations of trade's effect on internal migration, such as McCaig and Pavcnik (2012) for Vietnam or Aguayo-Tellez and Muendler (2009) and Hering and Paillacar (2012) for Brazil. There is also a large urban-economics literature investigating the role of international trade in altering the spatial distribution of firms and factors within a country, such as Hanson (1998). Little work has been done, however, investigating the case of China – perhaps the largest and fastest expansion of trade and internal migration ever recorded. Existing work, such as Lin, Wang and Zhao (2004) or Poncet (2006), typically abstracts from general equilibrium effects and investigates data only prior to 2000. Brandt et al. (2013) use a general equilibrium model to quantify the aggregate productivity loss due to misallocation of labour and capital across space in China, but the sources of misallocation are not explicitly modeled. In contrast, we model trade and migration costs as specific sources of misallocation.

[1] We compare China to Canada as Statistics Canada's internal trade data is superior to the U.S. For migration, we can compare China to U.S. migration flows.

2 China's Internal Migration and Trade

To set the stage for our quantitative analysis, we begin with a discussion of the data, the spatial aspects of the Chinese economy and the policy environment that affects workers and trade flows in China.

2.1 Data

We need data on real income by province and sector, internal and external trade, and internal migration for our quantitative analysis. For real income, we calculate real GDP per worker using the official statistics on nominal GDP and employment, and the rural and urban price levels provided by Brandt and Holz (2006). For trade, we use regional input-output tables for 2002 and 2007. Specifically, Li (2010) reports bilateral trade flows for all provinces and for a variety of sectors in 2002. For changes in trade flows, Zhang and Qi (2012) provide the bilateral trade flows between eight aggregate regions in both 2002 and 2007. For migration, we use the 2000 Population Census and 2005 1% Population Survey. We summarize some key features of the data here and provide a detailed description in Appendix A.

2.2 Spatial Distribution of Income

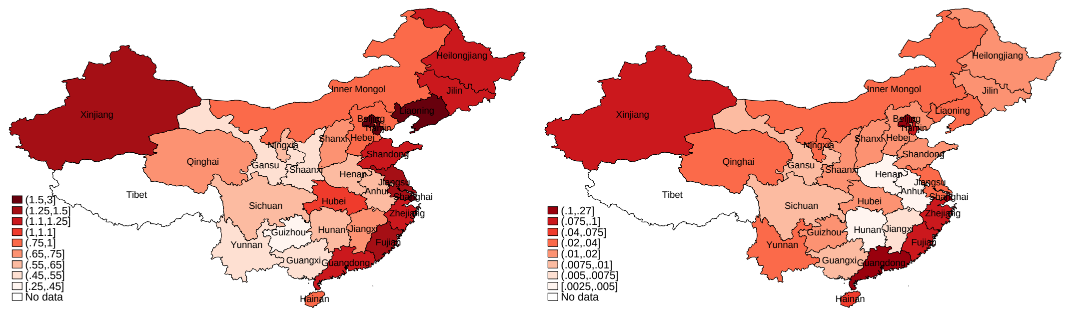
In Figure 1a, we display real incomes in 2000 for each province of China. There are stark differences in real income levels across provinces. The ratio of average real GDP per worker of the top five provinces to that of the bottom five provinces is almost 4:1. In general, the provinces of the coastal regions in the east have substantially higher levels of real GDP per worker than provinces in the central and western regions. Despite large income differences there was very little migration.

2.3 Migration Policies and Migration Patterns

In 1958, the Chinese government formally instituted a *Hukou* registration system to control population mobility. Chan (2010) provides a detailed discussion of the *Hukou* system; we summarize its key features. Each Chinese citizen is assigned a

Figure 1: Spatial Distribution of Real Incomes and Migration in 2000

(a) Real GDP/Worker, Relative to Mean (b) Migrant Share of Total Employment



Note: Displays choropleths of relative real income levels for each of China's provinces and the migrant share of total employment. Dark reds indicate both high relative real incomes and large migrant shares of employment.

Hukou (registration status), classified as "agricultural (rural)" or "nonagricultural (urban)" in a specific administrative unit that is at or lower than the county/city level. Approvals from local governments are needed for an individual to change the category (agricultural or non-agricultural) or location of *Hukou* registration, and it is extremely difficult to obtain such approvals. Before the economic reform started in 1978, working outside one's *Hukou* registration location/occupation category was prohibited. This prohibition was relaxed in the 1980s, but prior to 2003 workers without local *Hukou* still had to apply for a temporary residence permit. This was difficult, so many migrant workers were without a permit and faced the dire consequence of being arrested and deported by the local authorities. As the demand for migrant workers in manufacturing, construction and labour intensive service industries increased, many provinces, especially the coastal provinces, eliminated the requirement of temporary residence permit for migrant workers after 2003. This policy change helped to ease migration but the costs remain high. Even with a temporary residence permit, migrant workers without local *Hukou* have very limited access to local public services and face much higher costs for health care and for their children's education. More importantly, migrant workers always face these costs as long as they do not have local *Hukou*.

Table 1 presents the total number of inter-provincial and intra-provincial migrant workers for 2000 and 2005 and their shares of total employment. Any worker

Table 1: Stock of Migrant Workers in China

	Inter-Provincial		Intra-Provincial	
	2000	2005	2000	2005
Total Stock (millions)	26.5	49.0	90.1	120.4
Share of Total Employment	4.2%	7.2%	14.3%	17.7%

Notes: Migrants are defined based on their their *Hukou* registration location. Inter-provincial migrants are workers registered in another province from where they are employed. Intra-provincial migrants are workers registered in the same province where they are employed, but are either non-agricultural workers holding agricultural *Hukou* or vice-versa.

in a province other than the province of his/her *Hukou* is classified as an inter-provincial migrant. A worker within his/her *Hukou* registration province but in an occupation other than his/her *Hukou* category (agricultural or non-agricultural) is classified as an intra-provincial migrant. Most of the intra-provincial migrant workers are rural-to-urban migrants who have agricultural *Hukou* but work outside agriculture. Between 2000 and 2005, the numbers of inter- and intra-provincial migrant workers have both increased significantly. By 2005, there were 49 million workers who moved across provincial boundaries and 120 million workers who switched occupations within a province. While migration of this magnitude is unprecedented, as a share of total employment it is less impressive. Despite large income disparity across provinces, inter-provincial migrant workers accounted for only 4.2% of total employment in 2000 and 7.2% in 2005. There is heterogeneity across provinces, of course. Figure 1b plots for each province the migrant workers' share of total employment in 2000. Not surprisingly, richer provinces in coastal regions tend to have higher migrant worker shares than poorer interior provinces. Provinces with more inter-provincial migrant workers also tend to have higher intra-provincial migrant workers. We provide more detail in Appendix A.

2.4 Trade Policies

Several researchers have documented high internal trade costs in China in the 1990s (Young, 2000; Poncet, 2005). It has also been documented that the degree of local market protection in a province was directly related to the size of the state sector in that province (Bai et al., 2004). Since 2000, these trade barriers have been reduced

Table 2: Internal and External Trade Shares of China

Importer	Exporter: North-east	Beijing Tianjin	North Coast	Central Coast	South Coast	Central Region	North-west	South-west	Abroad	Total Other Prov.
Year 2002										
Northeast	87.9	0.7	1.0	0.8	1.3	1.1	0.8	0.9	5.5	6.6
Beijing/Tianjin	3.9	63.4	9.4	3.0	2.6	3.3	1.4	1.2	11.9	24.8
North Coast	1.8	3.3	79.8	3.4	1.8	3.8	0.9	0.8	4.4	15.8
Central Coast	0.2	0.2	0.6	81.0	1.5	2.4	0.5	0.5	13.3	5.7
South Coast	0.5	0.4	0.5	2.6	72.3	1.9	0.4	1.5	19.8	7.9
Central Region	0.6	0.3	1.1	4.8	2.3	87.8	0.7	0.7	1.8	10.4
Northwest	2.0	0.8	2.1	3.3	4.5	3.6	77.4	3.8	2.6	20.0
Southwest	0.9	0.3	0.4	1.8	4.3	1.4	0.9	88.0	2.0	10.0
Abroad	0.0	0.0	0.0	0.1	0.2	0.0	0.0	0.0	99.6	–
Year 2007										
Northeast	78.7	2.0	2.0	0.9	2.7	1.0	1.4	0.9	10.4	10.9
Beijing/Tianjin	3.8	62.3	10.1	1.5	2.4	1.8	2.1	0.7	15.5	22.2
North Coast	2.1	5.8	76.8	1.5	1.5	3.7	2.3	0.8	5.5	17.7
Central Coast	1.1	0.7	1.4	76.8	1.8	4.8	1.7	0.9	10.8	12.4
South Coast	1.5	0.9	1.7	5.2	68.5	3.6	1.8	2.8	14.1	17.4
Central Region	1.7	1.4	4.5	4.9	4.0	73.0	2.9	1.8	5.9	21.1
Northwest	2.3	2.2	4.8	2.7	5.5	3.6	65.6	3.6	9.8	24.6
Southwest	1.6	1.2	1.7	1.7	8.4	1.9	3.2	73.8	6.6	19.6
Abroad	0.0	0.1	0.1	0.4	0.2	0.0	0.0	0.0	99.1	–

Note: Displays the share of each importing region's total spending allocated to each source region. See Appendix A (Trade Shares) for the mapping of provinces to regions. The column "Total Other Prov." reports the total spending share each importing region allocated to producers in other provinces of China. The diagonal elements (the "home share" of spending), the share imported from abroad, and the share imported from other provinces will together sum to 100%.

significantly. Some of the reduction was due to the deliberate policy reforms undertaking by the government. For example, the state council under then premier Zhu Rongji issued a directive in 2001 that prohibits local government from engaging in local market protections. More importantly, as a result of various SOE reforms, the size of the state sector has declined significantly and consequently lowered local government incentives to engage in local market protections. Improved transport infrastructure and logistics also helped lower internal trade cost.

2.5 Internal and External Trade Patters

We extract province-level trade data, both between province pairs and internationally, from the regional input-output tables for 2002 and 2007. Table 2 reports the aggregate bilateral flows between the eight regions and each other, and the rest of the world (see Appendix A for a list of provinces by region). To ease comparisons, we normalize all flows by the importing region's total expenditures, resulting in a table of expenditure shares $\pi_{ni} = x_{ni} / \sum_{i=1}^{N} x_{ni}$, where x_{ni} is the spending by region n on goods from region i. In addition to the bilateral trade flows, we also report in the last column the share of a region's expenditures that are spent on goods from all other regions within China. A useful measure of a region's trade openness is the fraction of its expenditures allocated to its own producers – that is, it's "home share." The diagonal elements of Table 2 provide these values for each region. Interior regions of China have much higher home-share than coastal regions. In 2002, the central region's home share is 0.88 compared to only 0.72 for the south coast and 0.63 for Beijing and Tianjin.

While regions in China generally import more from abroad than from any particular region within China, the total imports from the rest of China are still higher than imports from abroad for most of the regions. The Central Coast and South Coast regions are the exceptions. In 2000, their imports from abroad were significantly higher than imports from the rest of China; they also had substantial international exports.

All trade values reported so far are at the regional level. For 2002, we also compute trade shares for each individual province and for each sector (agriculture and nonagriculture) separately. Consistent with the regional data, interior provinces have higher home-shares than coastal provinces, and coastal provinces export a larger fraction of production internationally. These province and sector level trade data will play a crucial role in our quantitative exercises to come. They also provide information critical to estimate internal and external trade costs. We turn now to our quantitative model.

3 Quantitative Model

In this section, we develop a two-sector model of trade and migration building on Eaton and Kortum (2002), Ahlfeldt et al. (2012) and Redding (2015). The model features two tradable sectors and multiple regions of China between which goods and labour may flow. Our main departure from these papers is that we introduce between-region migration frictions and within-region rural-to-urban migrations.

There are $N+1$ regions representing China's provinces plus the rest of the world. Each region has two sectors: agriculture and nonagriculture, denoted $j \in \{ag, na\}$. Each region is also endowed with a fixed factor (land, structures), denoted S_n^j, that is used for housing and production. Finally, there are $\bar{L}_n^j$ workers *registered* in region n and sector j. Workers differ in region-sector specific productivity (or effective units of labour), and we denote the supply of effective labour in region n and sector j as H_n^j with the total supply of effective labour as $H_n = H_n^{ag} + H_n^{na}$. Workers can migrate between rural and urban sectors within a region and between provinces within China, but there is no labour mobility between China and the world.

3.1 Worker Preferences

Workers derive utility from final goods and residential housing. We assume that preferences are homothetic so that we can express workers' problem in effective labour terms. The representative worker in sector j maximizes the Cobb-Douglas utility

$$u_n^j = \left[\left(c_n^{j,ag}\right)^{\varepsilon} \left(c_n^{j,na}\right)^{1-\varepsilon} \right]^{\alpha} s_{u_n}^{j\ 1-\alpha}, \tag{1}$$

where $c_n^{j,ag}$, $c_n^{j,na}$ and $s_{u_n}^j$ are agricultural goods, nonagricultural goods, and housing land per effective unit of labour. The parameters α and ε respectively determine the optimal share of total expenditures on goods in general and on agricultural goods in particular. Overall, total consumption of k goods in region n sector j is $c_n^{j,k} H_n^j$. Households are subject to a budget constraint $r_n^j s_{u_n}^j + P_n^{ag} c_n^{j,ag} + P_n^{na} c_n^{j,na} \leq v_n^j$, where P_n^{ag}, P_n^{na}, and r_n^j respectively denote the price of final goods and housing and v_n^j denotes nominal income per effective unit of labour. Goods prices do not depend on a worker's sector of employment, as we assume trade costs within provinces are zero (for reasons we discuss shortly).

3.2 Production, Trade and Prices

Agricultural and nonagricultural goods are a composite of a continuum of horizontally differentiated varieties $y_n^j(\nu)$. A perfectly competitive firm produces good j

using the CES technology

$$Y_n^j = \left(\int_0^1 y_n^j(\nu)^{(\sigma-1)/\sigma} d\nu \right)^{\sigma/(\sigma-1)}, \tag{2}$$

where σ is the (constant) elasticity of substitution across varieties. Each variety ν may be sourced from local producers or imported, whichever minimizes costs. The goods Y_n^j are either consumed directly by households or used as intermediate inputs by producers of $y_n^j(\nu)$. These varieties are produced by perfectly competitive firms using labour, intermediate inputs, and land. A firm with productivity φ has the following production technology

$$y_n^j(\varphi) = \varphi H_n^j(\varphi)^{\beta^j} S_{Yn}^j(\varphi)^{\eta^j} Q_n^j(\varphi)^{1-\beta^j-\eta^j}, \tag{3}$$

where β^j and η^j are sector-specific input shares for labour and land. Notice that producers also use intermediate inputs $Q_n^j(\varphi)$. As these intermediate inputs are from sector j's final good in region n, we have $Y_n^j = c_n^j H_n + Q_n^j$, where Q_n^j is the total intermediates demanded by all firms supplying sector j in region n. Land is used either in production or for residential housing, and therefore $s_{Y_n}^j + s_{u_n}^j = S_n^j$, where S_n^j is the total fixed supply of land in region n for sector j.

Productivity differs across firms and, following Eaton and Kortum (2002), we assume that φ is drawn from a Frechet distribution with CDF $F_i(\varphi) = e^{-T_i^j \varphi^{-\theta}}$. We assume that the dispersion parameter θ is common to all regions and sectors. As in Caliendo et al. (2013) and Albrecht and Tombe (forthcoming), this parameter is the same within as between countries. In the calibration to come, we argue that the existing within-country estimate of θ is close to the between-country estimates.

Given perfectly competitive markets, prices equal marginal costs. A firm in sector j of region i with productivity φ charges a buyer in region n, $p_{ni}^j(\varphi) = \tau_{ni}^j w_i^{j\,\beta^j} r_i^{j\,\eta^j} P_i^{j\,1-\beta^j-\eta^j}/\varphi$, where $\tau_{ni}^j \geq 1$ is an iceberg trade cost, w_i^j are wages per effective labour, r_i^j is the price of land, and P_i^j is the price for the final good, all of them are each sector-specific. Notice that we suppose trade costs τ_{ni}^j do not depend on the purchasing sector, only the type of good. That is, an agricultural household faces the same consumer prices as a nonagricultural household. We make this simplifying assumption because we only have trade flow data between provinces within sectors, not by urban or rural areas within provinces.

Purchasers in each region source individual varieties $y_n^j(\nu)$ from the lowest cost location. This results in expenditures being allocated across regions according to each region's technology, input costs, and trade costs. Denote π_{ni}^j the fraction of region n spending allocated to sector j goods produced in region i (trade shares). As in Eaton and Kortum (2002), it is straightforward to show the Frechet distribution of technology implies trade shares are

$$\pi_{ni}^j = \frac{T_i^j \left(\tau_{ni}^j w_i^{j\,\beta^j} r_i^{j\,\eta^j} P_i^{j\,1-\beta^j-\eta^j}\right)^{-\theta}}{\sum_{m=1}^{N+1} T_m^j \left(\tau_{nm}^j w_m^{j\,\beta^j} r_m^{j\,\eta^j} P_m^{j\,1-\beta^j-\eta^j}\right)^{-\theta}}, \tag{4}$$

and final good prices are

$$P_n^j = \gamma \left[\sum_{m=1}^{N+1} T_m^j \left(\tau_{nm}^j w_m^{j\,\beta^j} r_m^{j\,\eta^j} P_m^{j\,1-\beta^j-\eta^j}\right)^{-\theta}\right]^{-1/\theta}, \tag{5}$$

where $\gamma = \Gamma\left(1+\frac{1-\sigma}{\theta}\right)^{1/(1-\sigma)}$.

3.3 Nominal and Real Incomes

Let R_n^j be the total revenue of intermediate good producing firms in region n sector j. Given Cobb-Douglas production technologies, total labour income is $w_n^j H_n^j = \beta^j R_n^j$. In addition to labour income, all payments to land in a given region and sector are rebated to the workers of that region and sector. Spending on sector j land is $(1-\alpha)v_n^j H_n^j + \eta^j R_n^j$, where v_n^j is the nominal income per effective worker. So we have $v_n^j H_n^j = \beta^j R_n^j + (1-\alpha)v_n^j H_n^j + \eta^j R_n^j$, which implies

$$v_n^j = \frac{\beta^j + \eta^j}{\alpha \beta^j} w_n^j. \tag{6}$$

To determine real income, we must deflate nominal income by the price of consumption goods P_n^j and of housing r_n^j; that is,

$$V_n^j = \frac{v_n^j}{\left(P_n^{ag\ \varepsilon} P_n^{na\ 1-\varepsilon}\right)^{\alpha} r_n^{j\ 1-\alpha}}, \tag{7}$$

Finally, land market clearing will solve for r_n^j. Specifically, total spending on land is $(1-\alpha)v_n^j H_n^j + \eta^j R_n^j$ and total income to land is $r_n^j S_n^j$. The two must equal. This market clearing condition, combined with equation 6 and $w_n^j H_n^j = \beta^j R_n^j$, yields the following:

$$r_n^j = \left(\frac{(1-\alpha)\beta^j + \eta^j}{\alpha\beta^j}\right)\frac{w_n^j H_n^j}{S_n^j}. \tag{8}$$

3.4 Internal Labour Migration

Labour is mobile within China, across provinces and sectors, but not internationally. Workers are registered to provinces and assigned either an agricultural or a nonagricultural status. Let m_{ni}^{jk} denote the share of workers holding a $j \in \{ag, na\}$ registration in region n who moved to region i to work in sector $k \in \{ag, na\}$.

Workers face costs to work outside their region-sector of registration. We model these costs as proportional to income, where a worker from region n and sector j loses a fraction $1-\mu_{ni}^{jk}$ of their income in region i and sector k. These migration costs can be considered a reduction in a migrant's productivity due to the move. In addition, workers have heterogeneous productivity that varies by region and sector; this creates differences in worker migration incentives. 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 $\mu_{ni}^{jk} z_i^k V_i^k$.

With this structure, it is straightforward to solve for migration flows. As z_j^k is a random variable across the continuum of individuals from (n, j), the law of large numbers ensures the proportion of these workers who migrate to region i is

$$m_{ni}^{jk} = Pr\left(\mu_{ni}^{jk} z_i^k V_i^k \geq \max_{m,s}\left\{\mu_{nm}^{js} z_m^s V_m^s\right\}\right).$$

For a particular distribution of productivity, this proportion can be solved explicitly. Assume that productivity follow a Frechet distribution with CDF $F_z(x) = e^{-(x\tilde{\gamma})^{-\kappa}}$, where κ governs the degree of dispersion across individuals. A large κ implies little dispersion. The parameter $\tilde{\gamma} = \Gamma\left(1-\kappa^{-1}\right)$ is a normalizing constant so that the mean of z is one. Here Γ denotes the Gamma function.

Proposition 1 *Given real incomes for each region and sector, V_i^k, migration costs between all region-sector pairs μ_{ni}^{jk}, and heterogeneous productivity distributed $F_z(x)$, the share of region n workers from sector j that migrate to region i and sector k is*

$$m_{ni}^{jk} = \frac{\left(V_i^k \mu_{ni}^{jk}\right)^{\kappa}}{\sum_{k\in\{ag,na\}}\sum_{m=1}^{N}\left(V_m^j \mu_{nm}^{jk}\right)^{\kappa}}. \tag{9}$$

Proof: All proofs of propositions are given in Appendix B.

With the migration decisions fully characterized, we can solve for the effective labour supply in each region and sector H_n^j.

Proposition 2 *The total supply of effective labour in region n sector j is*

$$H_n^j = \sum_{k\in\{ag,na\}}\sum_{i=1}^{N}\mu_{in}^{kj}\left(m_{in}^{kj}\right)^{-1/\kappa} m_{in}^{kj}\bar{L}_i^k. \tag{10}$$

Moreover, $h_{in}^{kj} = \mu_{in}^{kj}\left(m_{in}^{kj}\right)^{-1/\kappa}$ is the average productivity of workers from region i and sector k that work in region n and sector j, and therefore $H_n^j = \sum_k\sum_i h_{in}^{kj} m_{in}^{kj}\bar{L}_i^k$.

3.5 General Equilibrium and Welfare

Total revenue of firms in each region and sector equals total sales to buyers in all other locations; that is,

$$R_n^j = \sum_{i=1}^{N+1}\pi_{in}^j X_i^j \tag{11}$$

where X_i^j is total expenditures of region i on sector j goods. With region i's total income denoted I_i, where

$$I_i = v_i^{ag}H_i^{ag} + v_i^{na}H_i^{na}, \tag{12}$$

spending on sector j goods by region i is

$$X_i^j = \alpha \varepsilon^j I_i + (1 - \eta^j - \beta^j) R_i^j \tag{13}$$

From equation 6, the two equations above, and the fact that $w_n^j H_n^j = \beta^j R_n^j$, we have

$$w_n^j H_n^j = \sum_{i=1}^{N+1} \pi_{in}^j \left[\alpha \varepsilon^j \beta^j \left(\sum_{k=ag,na} \frac{\beta^k + \eta^k}{\alpha \beta^k} w_i^k H_i^k \right) + \left(1 - \eta^j - \beta^j\right) w_i^j H_i^j \right]. \tag{14}$$

Definition 1 *An equilibrium is a set of wages $\{w_n^j\}$, rental prices of land $\{r_n^j\}$, goods prices $\{P_n^j\}$, trade shares $\{\pi_{ni}^j\}$, migration shares $\{m_{ni}^{j,k}\}$ and effective labour supplies $\{H_n^j\}$, for all regions $n = \{1,...,N+1\}$ and sectors $j = \{ag, na\}$, such that equations 4 through 10 and equation 14 hold.*

With real income per effective worker given by V_n^j and the average units of effective labour for workers from (n, j) that work in (i, k) defined in Proposition 2, the average real income per worker for those workers is $h_{ni}^{jk} V_i^k$. From equation 9, $m_{ni}^{jk\,1/\kappa} / m_{nn}^{jj\,1/\kappa} = V_i^k \mu_{ni}^{jk} / V_n^j$. Rewriting yields $m_{nn}^{jj\,-1/\kappa} V_n^j = \mu_{ni}^{jk} m_{ni}^{jk\,-1/\kappa} V_i^k$ and therefore $h_{nn}^{jj} V_n^j = h_{ni}^{jk} V_i^k$. That is, the average real income of workers from (n, j) that remain is the same as the average real income (net of migration costs) of those that migrate to (i,k). This implies that m_{ni}^{jk} is not only the share of workers that migrate but also the share of total real income (net of migration costs) earned by all (n, j)-registered workers earned by those working in (i,k).[2] It is straightforward to show the following.

Proposition 3 *If worker productivity z_i is distributed Frechet with variance parameter κ, and agents are able to migrate between regions at cost μ_{ni}^{jk}, then aggregate average real income (welfare) is*

$$W = \sum_{j \in \{ag,na\}} \sum_{n=1}^{N} \lambda_n^j V_n^j m_{nn}^{j\,-1/\kappa} = \sum_{j \in \{ag,na\}} \sum_{n=1}^{N} \lambda_n^j h_{nn}^{jj} V_n^j ,$$

[2]This property is analogous to the well-known feature of Eaton and Kortum (2002) models, where π_{ni}^j represents both the share of sector j *varieties* that region n sources from region i but also the share of region n's *spending* on sector j goods that is allocated to producers in region i.

where $\lambda_n^j = \bar{L}_n^j / \sum_{k\in\{ag,na\}} \sum_{i=1}^N \bar{L}_i^k$ *is the share registered in region i.*

With the initial equilibrium now fully characterized, we move on to express how the model responds to changes in exogenous parameters.

3.6 Counterfactual Relative Changes

To ease our quantitative analysis and calibration, we follow Dekle, Eaton and Kortum (2007) and express counterfactual values relative to initial equilibrium values. That is, let $\hat{x} = x'/x$, where x' is the counterfactual value of x. Given counterfactual trade shares $\pi_{ni}^{j\,\prime}$, equations 11 and 13 solve counterfactual expenditures $X_{ni}^{j\,\prime}$, revenues $R_{ni}^{j\,\prime}$, and incomes I_n'. To solve for counterfactual trade shares, note that equations 4 and 5 imply counterfactual trade shares

$$\pi_{ni}^{j\,\prime} = \frac{\pi_{ni}^j \hat{T}_i^j \left(\hat{\tau}_{ni}^j \hat{w}_i^{j\,\beta^j} \hat{r}_i^{j\,\eta^j} \hat{P}_i^{j\,1-\beta^j-\eta^j}\right)^{-\theta}}{\sum_{m=1}^{N+1} \pi_{nm}^j \hat{T}_m^j \left(\hat{\tau}_{nm}^j \hat{w}_m^{j\,\beta^j} \hat{r}_m^{j\,\eta^j} \hat{P}_m^{j\,1-\beta^j-\eta^j}\right)^{-\theta}}, \tag{15}$$

and relative price changes

$$\hat{P}_n = \left[\sum_{m=1}^{N+1} \pi_{nm}^j \hat{T}_m^j \left(\hat{\tau}_{nm}^j \hat{w}_m^{j\,\beta^j} \hat{r}_m^{j\,\eta^j} \hat{P}_m^{j\,1-\beta^j-\eta^j}\right)^{-\theta}\right]^{-1/\theta}. \tag{16}$$

From equation 8 and with revenue proportional to labour income, we have $\hat{R}_n^j = \hat{w}_n^j \hat{H}_n^j$ and $\hat{r}_n^j = \hat{w}_n^j \hat{H}_n^j$. 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 effective labour ($\hat{H}_n^j$).

It remains to solve for counterfactual migration flows, which is straightforward to do. First, the counterfactual real income per effective labour is

$$\hat{V}_n^j = \frac{\hat{w}_n^{j\,\alpha}}{\left(\hat{P}_n^{ag\,\varepsilon} \hat{P}_n^{na\,1-\varepsilon}\right)^{\alpha} \hat{H}_n^{j\,1-\alpha}}, \tag{17}$$

which uses equations 6 and 7 and $\hat{r}_n^j = \hat{w}_n^j \hat{H}_n^j$ from equation 8.

Given the change in real income per effective worker, and exogenous changes in migration costs $\hat{\mu}_{ni}^{jk}$, equation 9 gives

$$m_{ni}^{jk\,\prime} = \frac{m_{ni}^{jk}\left(\hat{V}_i^j \hat{\mu}_{ni}^{kj}\right)^{\kappa}}{\sum_{k\in\{ag,na\}}\sum_{m=1}^{N} m_{ik}^{jk}\left(\hat{V}_m^j \hat{\mu}_{nm}^{jk}\right)^{\kappa}}, \tag{18}$$

and therefore $\hat{m}_{ni}^{jk} = \hat{m}_{nn}^{jj}\left(\hat{V}_i^k \hat{\mu}_{ni}^{jk}/\hat{V}_n^j\right)^{\kappa}$. This, with equation 10, yields

$$H_n^{j\,\prime} V_n^{j\,\prime} = \sum_{k\in\{ag,na\}}\sum_{i=1}^{N}\left(m_{ii}^{kk\,\prime}\right)^{-1/\kappa} V_i^{k\,\prime} m_{in}^{kj\,\prime} \bar{L}_i^k. \tag{19}$$

Of course, these migration expressions hold only between provinces of China. There is no international migration, so $\hat{H}_{N+1}^j = 1$ for both sectors. This completely characterizes the model's equilibrium response to exogenous changes in trade costs, migration costs, and productivity.

There are additional outcomes that may be of interest. First, counterfactual employment L_n' (rather than effective labour H_n') is $L_n' = \sum_{i=1}^{N} m_{in}' L_i^0$. Second, aggregate welfare changes, from proposition 3, is

$$\hat{W} = \sum_j \sum_{n=1}^{N} \omega_n^j \hat{V}_n^j \hat{m}_{nn}^{j\;-1/\kappa}, \tag{20}$$

where $\omega_n^j = \frac{\lambda_n^j V_n^j m_{nn}^{j\;-1/\kappa}}{\sum_j \sum_{m=1}^{N} \lambda_m^j V_m^j m_{mm}^{j\;-1/\kappa}}$. Finally, value-added from production plus total housing services, each valued at initial equilibrium prices, is real GDP. It is straightforward to show the aggregate real GDP change is

$$\hat{Y} = (1+\alpha) + \alpha \sum_j \sum_{n=1}^{N} \phi_n^j \hat{R}_n^j / \hat{P}_n^j, \tag{21}$$

where $\phi_n^j = \frac{(\beta^j+\eta^j)R_n^j/\alpha}{\sum_j \sum_{n=1}^{N} (\beta^j+\eta^j)R_n^j/\alpha}$ is region n and sector j's share of initial nominal GDP and the $1-\alpha$ captures the real value of housing services.

3.7 Calibrating the Model

Using the method we described to calculate the impact of the changes in trade costs, migration costs, and the underlying productivity on the changes in equilibrium prices and quantities, aggregate GDP and welfare, we only need to know the values of observables, registered workers $\bar{L}_i^j$, initial GDP Y_i^j, initial trade shares π_{ni}^j and initial migration shares m_{ni}^{jk} , rather than the unobserved trade costs, migration costs and initial levels of the underlying productivity. Specifically, the model takes parameters $(\alpha, \beta^j, \eta^j, \theta, \kappa)$ and initial values $(\pi_{ni}^j, m_{ni}^{jk}, \bar{L}_i^j, Y_i^j)$ as given. This section describes their calibration, with a summary in Table 3.

3.7.1 Parameters on Factor Shares

The production function parameters are the labour and land shares of gross output: β and η. 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 the factor shares of value-added $\tilde{\beta}/(\tilde{\beta}+\tilde{\eta}+\tilde{\alpha})$, $\tilde{\eta}/(\tilde{\beta}+\tilde{\eta}+\tilde{\alpha})$, and $\tilde{\alpha}/(\tilde{\beta}+\tilde{\eta}+\tilde{\alpha})$. For value-added's shares of gross output, we calculate them directly from China's Input-Output table, which turns out to average around 0.59 in agriculture and 0.35 in nonagriculture. For factor shares of value-added, we do not use the Chinese data because: (1) There are significant factor market distortions in China so that reported factor shares do not necessarily equal the corresponding factor elasticities in the production function; and (2) there is no separate reporting of spending on land due to a lack of private land ownership–it is implicitly included in the reported spending on labour in agriculture and reported spending on capital in non-agriculture. To avoid these problems, we instead use the sector-specific factor shares of value-added for the US as reported in Caselli and Coleman (2001). Specifically, they report labour's share of 0.6 in both sectors. Land's share is 0.19 in agriculture and 0.06 in nonagriculture. Capital's share is therefore 0.21 in agriculture and 0.34 in nonagriculture. Based on these, we have $\tilde{\beta}^{ag} = 0.60 \times 0.59 = 0.354$ and similarly

Table 3: Calibrated Model Parameters and Initial Values

Parameter	Set To	Description
(β^{ag}, β^{na})	$(0.404, 0.238)$	Labour's share of output
(η^{ag}, η^{na})	$(0.128, 0.024)$	Land's share of output
α	0.87	Non-Housing expenditure share
θ	4	Elasticity of Trade
κ	2.54	Income-Elasticity of Migration
π_{ni}^{j}	*Data*	Bilateral trade shares
m_{ni}^{j}	*Data*	Bilateral migration shares
$\bar{L}_{n}^{j}$	*Data*	Hukou registrations

Notes: Displays model parameters, their targets, and a description. See text for details.

$\tilde{\beta}^{na} = 0.21$, $\tilde{\eta}^{ag} = 0.1121$, $\tilde{\eta}^{na} = 0.021$, $\tilde{\alpha}^{ag} = 0.1239$, and $\tilde{\alpha}^{na} = 0.119$. Thus, we have our main parameter values $\beta^{ag} = 0.354 \div (1 - 0.1239) = 0.404$ and similarly $\beta^{na} = 0.238$, $\eta^{ag} = 0.128$, and $\eta^{na} = 0.024$.

To calibrate α, we use consumer expenditure data from China's most recent National Statistical Yearbook. The fraction of urban household spending on housing is 11% and for rural households is 15%. We set $\alpha = 0.87$, implying the housing share of expenditures is 13%.

3.7.2 Cost-Elasticity of Trade

There is a large literature on the productivity dispersion parameter θ. This parameter governs productivity dispersion across firms and, consequently, determines the sensitivity of trade flows to trade costs. Between-countries, there are many estimates of this elasticity to draw upon. For example, Simonovska and Waugh (2011) use cross-country price data to estimate $\theta \approx 4$. Parro (2013) estimates $\theta \in [4.5, 5.2]$ for manufacturing using trade and tariff data. Based on this method, Tombe (2015) estimates $\theta = 4.1$ for agriculture and 4.6 for nonagriculture. Within-countries, however, there is little evidence to draw upon. Using firm-level productivity dispersion in the US, Bernard et al. (2003) estimates $\theta = 3.6$. We set $\theta = 4$.

3.7.3 Income-Elasticity of Aggregate Migration

Similar to the cost-elasticity of trade is the income-elasticity of aggregate migration κ. The elasticity of migration is driven by the degree of heterogeneity in region-specific productivity across workers; given the Frechet distribution of productivity, the proof of Proposition 3 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 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.[3]

3.7.4 Initial Equilibrium Values

The total registrants by province and sector ($\bar{L}_n^j$) are directly observable in China's 2000 Population Census (see Appendix A). Total national employment for China is 636.508 million. Total employment in the rest of the world ($\sum_j L_{N+1}^j$) is 2,103 mil-

[3]Controlling for wide variety of individual characteristics (age, gender, education, health, etc.) has little affect on these results, resulting in $\kappa = 2.85$. In models of occupational mobility in the U.S., Hsieh et al. (2013) estimate $\kappa = 3.44$ and Cortes and Gallipoli (2014) find $\kappa = 3.23$.

lion. This is inferred from the Penn World Table as the total non-China employment for 2000. The initial migration shares m_{ni}^{jk} are also calculated directly from the 2000 Population Census. Since we don't have trade data in 2000, we use the trade shares generated from the 2002 China Regional Intput-Output Tables to approximate the values of the trade shares π_{ni}^{j} in 2000.

We have direct data on real GDP per worker by province and sector, denoted $(Y_n^j)^{data}$ which corresponds to the initial equilibrium of $H_n^j V_n^j$ in the model. From equations 9 and 10, we have the following equations

$$(Y_n^j)^{data} = \sum_{k\in\{ag,na\}} \sum_{i=1}^{N} m_{in}^{kj} \left(m_{ii}^{kk}\right)^{-1/\kappa} V_i^k \bar{L}_i^k,$$

which are used along with the N^2 equations from 9 and 10 in Section 3.3 to solve for the $N+N^2$ unknowns $(H_n^j, V_n^j, \mu_{ni}^{jk})$. See Appendix A for values.

4 Inferring Trade and Migration Costs

In this section, we quantify migration costs within China and trade costs within and between China's provinces and the world.

4.1 Migration Costs

Equation 9 provides a simple representation of migration decisions through which we infer migration costs. Using data on migration shares m_{ni} and our calibrated real income per effective worker V_n from the previous section, we find an average (migration-weighted) value of μ_{ni}^{jk} of 0.38. Migration costs therefore average 0.62. Of course, migration costs differ for different types of migration. We summarize these costs, their changes, and the initial migration flows in Table 4. Overall, migration costs are largest for migrants switching both sectors and provinces – with an average initial $1-\mu_{ni}^{jk}$ of 0.98. In contrast, to switch sectors within one's home province incurs average migration costs of 0.51.

How do these costs change over time? We report the change in average migration costs in the last column Table 4. Overall, migration costs declined by almost

Table 4: Migration Rates and Average Costs, by Sector and Province

	Migrant Share of Employment	Average Migration Costs $1-\mu_{ni}^{jk}$ 2000	2005	Change
Overall	0.174	0.62	0.57	-7.9%
Agriculture to Nonagriculture Migration Cost Changes				
Overall	0.16	0.59	0.54	-8.3%
Within Prov.	0.13	0.51	0.45	-11.2%
Between Prov.	0.03	0.98	0.97	-1.4%
Between Provinces Migration Cost Changes				
Overall	0.04	0.97	0.95	-2.3%
Within Ag.	0.003	0.94	0.88	-5.9%
Within Nonag.	0.01	0.94	0.91	-3.9%

Notes: Displays average migration rates and costs in 2000 and 2005. The migrant share of employment summarizes m_{ni}^{jk} in 2000. Average migration costs are weighted by initial migrants shares. We use initial (year 2000) weights to average the 2005 costs to ensure the displayed change reflects changes in costs and not migration patterns.

8% and the average migrant worker captured a larger share of their real income. Costs to switch between sectors within one's home province fell the most, from 0.51 to 0.45, especially compared to the cost of switching both sector and province, which fell only from 0.98 to 0.97. For workers remaining within their sector of registration, the costs of moving across provinces also fall – by nearly 6% for agricultural workers and nearly 4% for nonagricultural workers. Overall, the cost of migrating across provinces fell from 0.97 to 0.95.

4.2 Modified Head-Ries Index of Trade Costs

We estimate trade costs using a method developed in Head and Ries (2001), generalized by Novy (2013), and increasingly featured in international trade research. This method applies to a broad class of trade models, including the model described in Section 3. It is straightforward to show average trade costs between region n and i for sector j goods is

$$\bar{\tau}_{ni}^{j} \equiv \sqrt{\tau_{ni}^{j}\tau_{in}^{j}} = \left(\frac{\pi_{nn}^{j}\pi_{ii}^{j}}{\pi_{ni}^{j}\pi_{in}^{j}}\right)^{1/2\theta}, \tag{22}$$

which is a direct result of equation 4. This method has a number of advantages. First, $\bar{\tau}_{ni}^{j}$ is not affected by trade volumes or by third-party effects. For example, if region i experiences a massive increase in trade with some other region k, say due to lower trade costs between i and k, then region i will lower its trade with region n *by the same proportion* as it lowers its purchases from itself. The estimated trade costs between i and n is therefore unaffected. It also applies equally well whether trade balances or not.

Unfortunately, these trade cost estimates are symmetric in the sense that goods moving from i to n is as costly as moving goods from n to i. This matters, as Waugh (2010) demonstrates trade costs systematically differ depending on the direction of trade. In particular, he shows that additional costs facing *exporters* is key; that is, $\tau_{ni}^{j} = t_{ni}^{j} t_{i}^{j}$, where t_{ni}^{j} are symmetric costs ($t_{ni}^{j} = t_{in}^{j}$) and t_{i}^{j} are costs of exporting. This and equation 22 imply $\tau_{ni}^{j} = \bar{\tau}_{ni}^{j}\sqrt{t_{i}^{j}/t_{n}^{j}}$. This way of adjusting the Head-Ries index of trade costs to incorporate asymmetries is also found in Tombe (2015).

As we have data on π_{ni}^{j}, and therefore can estimate $\bar{\tau}_{ni}^{j}$ using equation 22, it remains for us to estimate the exporter-specific trade costs t_{n}^{j}. We closely follow the existing literature here, so leave details to Appendix B. Essentially, we use a standard gravity regression to infer asymmetries from fixed effects. Overall, we find that poor regions face the highest exporter-specific trade costs – consistent with existing cross-country evidence. Export costs are also largely unchanged from 2002 to 2007. See Appendix B for the precise estimates.

Combining these export costs with the Head-Ries index $\bar{\tau}_{ni}^{j}$ yields τ_{ni}^{j} for 2007 and 2002, and therefore we have our $\hat{\tau}_{ni}^{j}$. We display the resulting estimates for the relative change in trade costs in Table 5. Some notable patterns emerge, though it is important to keep in mind that these trade costs are *relative to within-region* trade costs. Within China, trade costs are largely decreasing, with trade-weighted change in trade costs within China of $\bar{\hat{\tau}}_{ni}^{ag} = 0.87$ and $\bar{\hat{\tau}}_{ni}^{na} = 0.89$. For trade between China and the world, the average change in costs were $\bar{\hat{\tau}}_{ni}^{ag} = 0.77$ and $\bar{\hat{\tau}}_{ni}^{na} = 0.92$.

What is behind the measured reduction in trade costs? Consider isolating the portion of trade costs $\bar{\tau}_{ni}^{j} = t_{ni}^{j}\sqrt{t_{i}^{j} t_{n}^{j}}$ due to geographic distance between regions using the regression

$$ln(\bar{\tau}_{ni}^{j}) = \delta ln(d_{ni}) + \iota_{n}^{j} + \eta_{i}^{j} + \varepsilon_{ni}^{j},$$

Table 5: Relative Change 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 Nonagriculture, $\hat{\tau}_{ni}^{na}$									
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 (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). In the simulation, we apply these changes to the provinces within each region.

where d_{ni} is the geographic distance between region n and i, and ι_n^j and η_i^j are importer and exporter fixed-effects by sector (to control for t_i^j and t_n^j). We include only regions within China for this regression. The results for 2002, we estimate $\hat{\delta}^{ag} = 0.51$ and $\hat{\delta}^{na} = 0.38$. For 2007, these elasticities fall to 0.40 and 0.36, respectively. The contribution of distance to trade costs is therefore lower, perhaps due to infrastructure improvements within China. If all other factors remain unchanged, the relative change in trade costs between region n and i would have been $\hat{\tau}_{ni}^{ag} = d_{ni}^{-0.11}$ and $\hat{\tau}_{ni}^{na} = d_{ni}^{-0.02}$. Overall, this averages across pairs to $\bar{\hat{\tau}}_{ni}^{ag} = 0.48$ and $\bar{\hat{\tau}}_{ni}^{na} = 0.90$. Though this is a rough approximation, it suggests nearly all of the change in nonagricultural trade costs are due to lower costs related to distance. For agriculture, this more than accounts for the measured change, suggesting non-distance costs grew larger on average.

5 Quantitative Analysis

In our quantitative analysis, we fit the initial equilibrium of our model to the Chinese data in 2000[4] and then quantify the impacts on aggregate productivity and welfare of various changes in trade and migration costs. In particular, we examine how much of China's GDP growth between 2000 and 2005 can be accounted for by the measured reduction in trade costs and migration costs.

5.1 Gains from Trade and Migration

But first, by how much are welfare and productivity in China affected by the observed trade and migration flows in 2000? This is a standard question in international trade research. It involves comparing the initial equilibrium of our model to a counterfactual of no trade and/or no migration.

Gains from International Trade. We start with the initial equilibrium in 2000 and set the changes in trade costs as follows: $\hat{\tau}_{ni}^{j} = \infty$ if either n or i is the rest of the world, and $\hat{\tau}_{ni}^{j} = 1$ otherwise. This will eliminate all international trade between each province and the rest of the world. The inverse of the change in aggregate welfare and aggregate real GDP are the welfare and productivity gains, respectively. We find welfare gains of 4.7% and productivity gains of 6.9%. Note that these are aggregate gains for China as a whole. Productivity gains from international trade for coastal provinces are significantly higher: over 26% for Guangdong and 21% for Shanghai, for example.

Gains from Internal Trade. In this case, we keep the international trade costs unchanged from the initial equilibrium but set the internal trade costs to infinity. The welfare and productivity gains are 18.9% and 16.8%, respectively. These gains are significantly higher than the gains from external trade because in the initial equilibrium most provinces import more from other provinces in China than from abroad. Interestingly, the gains from internal trade for Guangdong and Shanghai are 11.5% and 14.9%, respectively, smaller than their gains from external trade.

Gains from Between-Province Migration. To quantify the gains from migration

[4]There is no regional input-output table for 2000 in China, so we use trade shares from the 2002 China Regional Input-Output Tables to approximate trade shares in 2000.

flows observed in 2000, consider a similar exercise where we make migration prohibitively costly. Eliminating between-province migration entails setting $\hat{\mu}_{ni}^{jk} = 0$ if $n \neq i$ for all j or k but $\hat{\mu}_{ni}^{jk} = 1$ otherwise. The aggregate welfare and productivity gains are 1.1% and 1.9%. Provinces that are popular destinations for migrants experience larger gains. In Guangdong, Beijing, and Shanghai, for example, productivity gains from inter-provincial migration are 11%, 8.4% and 4.3%, respectively.

Gains from Within-Province Migration. Finally, consider the gains from migrating between sectors within provinces. In this case, workers may still switch sectors but must also move across provinces. No worker with an agricultural *Hukou*, for example, can remain within their province of registration yet work in the nonagricultural sector. We find these within-province moves have both welfare and productivity gains of 2.4%. The variation in gains across provinces is minor, with the exception of Zhejiang, which experiences productivity gains of 11.7% from within-province migration.

In summary, the Chinese economy in 2000 benefited significantly from internal trade, less from international trade and least from internal migration due to the extremely high costs of migration at that time.

5.2 Quantifying the Effect of Measured Costs Changes

How important were the changes in trade and migration costs in China that we measured in Section 4? We report the impact of these changes below.

5.2.1 The Effect of Lower Trade Costs

From the initial equilibrium in 2000, we solve the changes in equilibrium outcomes by using $\hat{\tau}_{ni}^{j}$ from section 4.2, and hold migration costs and productivity fixed ($\hat{\mu}_{ni}^{j} = \hat{T}_{n}^{j} = 1$ for all n and i). Table 6 displays the change in trade and migration flows, aggregate productivity and welfare, and various other outcomes. Changes in trade shares are expenditure weighted average changes across all provinces and sectors. Lower internal trade costs, not surprisingly, lower the amount of international trade as households and firms reorient their purchase decisions towards domestic suppliers. The share of expenditures allocated to producers in another province

Table 6: Effects of Trade Cost Changes

	p.p. Change in Share of			Migrant Stock		Per-Capita	Aggregate Outcomes	
	Internal Trade	External Trade	Ag. Emp.	Within Province	Between Province	Income Variation	Real GDP	Welfare
Internal Trade	9.2	-0.8	-0.3	2.3%	-2.3%	-7.3%	10.3%	10.9%
External Trade	-0.6	3.9	-1.1	4.0%	5.6%	1.8%	4.0%	3.1%
All Trade	8.2	2.8	-1.3	6.3%	3.4%	-5.0%	14.2%	13.8%
Agricultural Trade Cost Changes								
Internal	0.3	0.0	0.3	0.5%	-2.6%	1.5%	0.3%	0.8%
External	0.0	0.1	-1.1	4.5%	5.2%	-0.6%	0.3%	-0.3%
Both Ag.	0.3	0.1	-0.8	4.3%	2.3%	0.8%	0.6%	0.4%
Nonagricultural Trade Cost Changes								
Internal	8.9	-0.7	-0.5	2.1%	0.1%	-8.5%	10.0%	10.1%
External	-0.6	3.8	0.1	-0.4%	0.5%	2.6%	3.6%	3.4%
All Nonag.	7.9	2.7	-0.4	1.5%	0.2%	-5.3%	13.5%	13.4%

Notes: Displays aggregate response to various trade cost changes. All use trade cost changes as measured, though set $\hat{\tau}^j_{ni} = 1$ for certain (n,i,j) depending on the experiment. The change in internal and external trade shares are the expenditure weighted average changes in region's $\sum_{n\neq i} \pi^j_{ni}$ and π^j_{nN}. 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.

typically increase by over 9 percentage points while the share allocated to international producers falls by almost one percentage point. Lower external trade costs reveal the opposite pattern. In both cases, home shares fall.

In terms of migration, improved internal trade costs actually resulted in *fewer* workers living outside their home province. The total stock of migrants declined by over 2% (equivalent to approximately 0.5 million workers). Intuitively, internal trade costs declining disproportionately lower goods prices in poor, interior regions. This increase in real income means fewer workers, who were living in other provinces, were willing to continue to do so. On the other hand, a greater fraction of workers switched sectors within their home province. With lower international trade costs, richer coastal regions disproportionately benefit, so more workers relocate there in addition to more workers switching sectors within their home province. This migration response also matters for the gains from trade cost changes. Setting $\hat{H}^j_n = \hat{m}^{jj}_{nn} = 1$ in the welfare equation reveals the migration response accounts for roughly 10% of the gains.

The change in income, goods and land prices, and worker's location decision all have implications for aggregate welfare. We report the change in welfare and productivity (aggregate real GDP) in the last columns of Table 6. In response to lower internal trade costs, aggregate welfare dramatically increased by nearly 11%. In contrast, external trade cost reductions resulted in a much smaller gain of only 3.1%. As in our earlier analysis, internal trade costs reductions appear to be significantly more important for aggregate outcomes. The differential impacts are not due to any significant differences in the magnitude of cost reductions. To illustrate this, we simulate $\hat{\tau}_{ni}^{j} = 0.9$ for both internal and external trade costs separately: welfare increases by 7.6% from internal trade cost reductions but only 2.4% from external trade cost reductions. The main reason for the larger welfare gains from internal cost reductions is that most provinces allocate a larger fraction of their spending to goods from other provinces than from abroad.

In which sectors are trade cost changes most important? To answer this, we also investigate the results of changing trade costs in agriculture and nonagriculture separately. In the lower panels of Table 6, gains from internal cost changes in agriculture are 0.8% while the gains from external trade cost changes are actually negative, at -0.3% (largely from loses to agriculture in Shanghai and Hainan). Overall, agricultural trade cost changes over the time period we study leads to welfare gains of 0.4%. For nonagriculture, internal trade costs reductions increased aggregate welfare by over 10% and external liberalization did so by 3.4%. Overall, reductions in internal nonagricultural trade costs are, by far, the most important.

5.2.2 Lower Migration Costs

Trade liberalization accounts for only limited amount of migration. Not surprisingly, lower migration costs lead to substantially more workers living outside their home province-sector. As before, we simulate the effect of lower migration cost changes and report the effects in Table 7.

The stock of migrants increases dramatically when $\hat{\mu}_{ni}^{jk}$ is as measured. The number of inter-provincial migrants increases by over 220% – from barely more than 4% of the labour force to over 13%. This is equivalent to over 57 million workers. Within provinces, there are also substantial moves from agriculture to nonagriculture. The stock of workers with agricultural *Hukou* that have nonagricultural employment within their home province increases by nearly 22%, from over 13% of the labour force to over 16% (nearly 20 million workers). The national share

Table 7: Effects of Various Migration Cost Changes

	p.p. Change in Share of			Migrant Stock		Per-Capita	Aggregate Outcomes	
	Internal Trade	External Trade	Ag. Emp.	Within Province	Between Province	Income Variation	Real GDP	Welfare
All Changes	0.2	0.2	-8.2	21.8%	221.9%	-31.7%	12.1%	7.3%
Agriculture to Nonagriculture Migration Cost Changes								
Overall	0.1	0.1	-9.4	21.2%	191.2%	-33.5%	7.2%	4.9%
Within Prov.	0.1	-0.1	-4.8	44.0%	-10.9%	8.6%	3.7%	3.0%
Between Prov.	0.0	0.2	-7.7	-16.5%	274.4%	-37.4%	4.5%	2.7%
Between Provinces Migration Cost Changes								
Overall	0.1	0.3	-6.0	-17.1%	312.7%	-38.0%	9.3%	5.0%
Within Ag.	0.0	0.0	0.1	0.0%	49.7%	-2.8%	0.3%	0.2%
Within Nonag.	0.1	0.3	0.6	-3.4%	63.8%	-6.1%	5.7%	2.8%

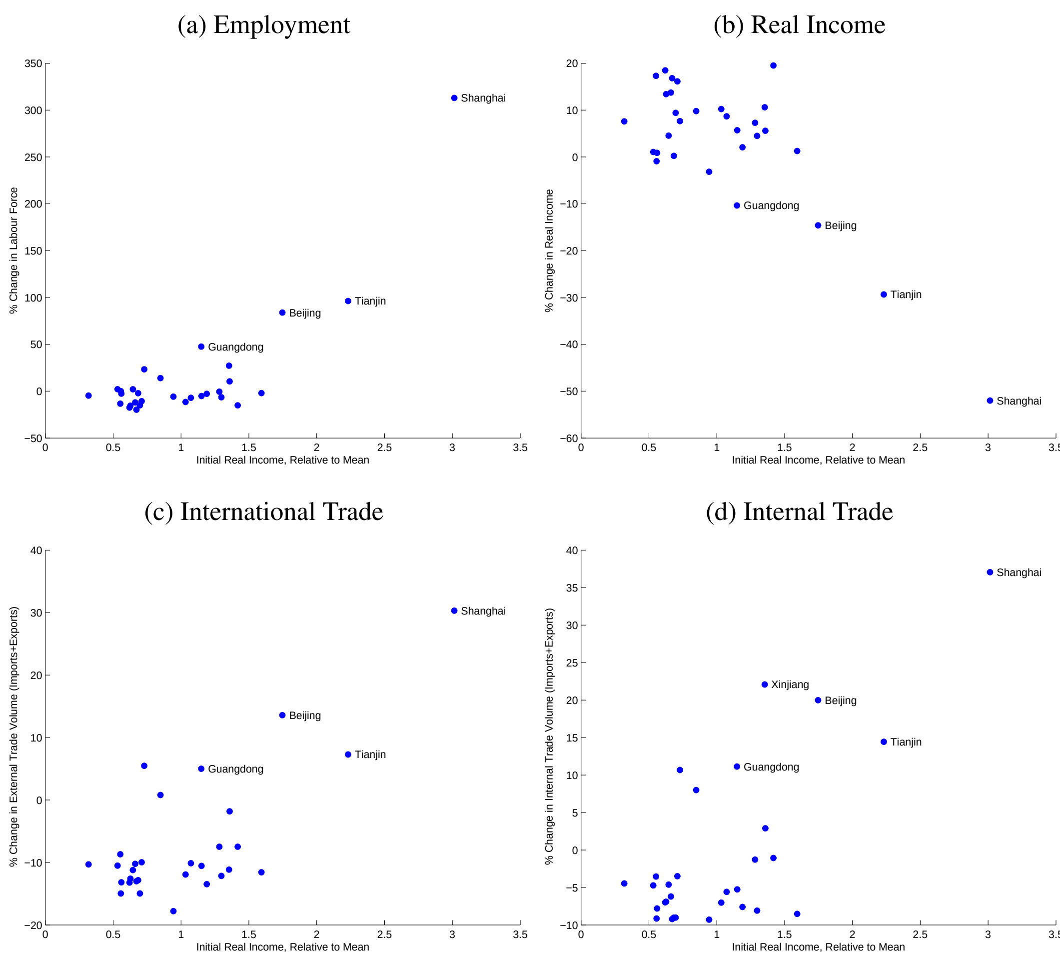
Notes: Displays aggregate response to various migration cost changes. All use migration cost changes as measured, though set $\hat{\mu}_{ni}^{kj} = 1$ for certain (n,i,j,k) depending on the experiment. The migrant stock is the number of workers living outside their province of registration. Regional income variation is the variance of log real incomes *per capita* across provinces.

of labour in agriculture declines by over 8 percentage points. Clearly, the measured changes in migration costs are extremely important determinants of worker location decisions. The large flows are also beneficial for China as a whole; real GDP and welfare rise 12.1% and 7.3%, respectively.

Regions differ in their responses, depending on whether they are a source or a destination for migrants. In Figure 2 we show various outcomes for each region. Coastal provinces, such as Shanghai, Tianjin, Beijing, and Guangdong, are the principle destinations for inter-provincial migrants. Shanghai's employment increases by over 300% in response to our measured change in migration costs, though from a relatively low base compared to the other provinces. In response, real incomes in provinces to which migrants move decline. As these are typically richer regions, regional income differences dramatically decline (by nearly a third; see Table 7).

While migration flows and real incomes respond a lot to the changes in migration costs, the effect on aggregate trade flows is muted. International and internal trade shares increase by only 0.2 percentage points (so provincial home shares π_{nn}^{j} decline by 0.4 percentage points on average). While aggregate trade is largely unresponsive, there are substantial differences between individual provinces. In Figure 2 we plot the percentage change in each province's trade volumes, both internally and internationally. Initially higher income (coastal) regions see their trade increase significantly while lower income (interior) regions see decreased volumes.

Figure 2: Regional Effects of Lower Migration Costs



Notes: Displays the percentage change in total employment and real income *per capita* by province in response to lower migration costs. Also displays the percentage change in trade volumes, both internationally and internally. All panels aggregate across both agriculture and nonagriculture within regions.

Finally, we explore changes in migration costs within and between provinces and sectors. Within-province changes (that is, only between agriculture and nonagriculture within provinces) increased welfare by 3%. Lower costs of migrating between sectors and provinces increased welfare by 2.7%. Changes that facilitate the movement of workers between sectors, whether within- or between-provinces, are therefore of roughly equal importance. Between-province cost changes within sectors are much more important for nonagriculture than agriculture.

Table 8: Effects of Various Cost Changes, With and Without Productivity Changes

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
Productivity	-0.3	-1.1	0.6	-0.1%	-7.5%	12.0%	35.2%	32.8%
Marginal Effects (changes relative to what productivity delivers)								
Internal Trade	9.2	-0.7	-0.2	2.1%	-4.5%	-11.1%	9.9%	10.6%
External Trade	-9.8	4.1	-0.4	2.1%	2.1%	1.4%	3.1%	2.9%
All Trade	8.6	-1.0	-0.5	4.2%	1.0%	-9.7%	12.6%	12.8%
Migration	-7.9	-2.3	-5.0	17.8%	151.4%	-22.7%	5.9%	4.6%
Internal Changes	9.1	-0.7	0.0	19.4%	141.3%	-32.2%	16.5%	15.9%
Everything	-0.8	3.2	-0.9	21.8%	152.0%	-32.5%	20.1%	18.7%
No Change in Productivity (consistent with Tables 6 and 7)								
Internal Trade	9.2	-0.8	-0.3	2.3%	-2.3%	-7.3%	10.3%	10.9%
External Trade	-0.6	3.9	-1.1	4.0%	5.6%	1.8%	4.0%	3.1%
All Trade	8.2	2.8	-1.3	6.3%	3.4%	-5.0%	14.2%	13.8%
Migration	0.2	0.2	-8.2	21.8%	221.9%	-31.7%	12.1%	7.3%
Internal Changes	9.2	-0.6	-8.3	24.4%	212.9%	-37.9%	23.3%	19.1%
Everything	8.2	3.0	-9.8	28.1%	230.9%	-39.0%	28.0%	22.2%

Notes: Displays aggregate response to various cost changes with and without productivity change $\hat{T}_n^j$ by region and sector. 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.

5.2.3 Changes in Underlying Productivity

So far we have held the underlying productivity T_n^j constant in our evaluation of the impacts of measured changes in trade and migration costs. This results in counterfactual changes in real GDP per worker and other equilibrium outcomes because there had been changes in the underlying productivity across provinces and sectors. We calibrate changes in the productivity parameter $\hat{T}_n^j$ such that, when migration and trade costs decline as measured, the resulting change in real GDP per worker in each province-sector matches the change in data between 2000 and 2005. In Appendix B, we provide the implied values by province and sector.

We now incorporate the estimated productivity changes $\hat{T}_n^j$ in our counterfactual simulations. We display the results of changing productivity, and the interaction of this with changing trade and migration costs, in Table 8. The first row of this table is distinct, and provides the effect of our calibrated $\hat{T}_n^j$ alone. Welfare rises significantly. More interestingly, trade declines as a greater fraction of spending is allocated to Chinese producers. Productivity also lowers the stock of inter-provincial migrants, with little change in the within-province between-sector migration flow.

Table 9: Decomposing China's Overall Real GDP Growth

	Relative to Initial Eq'm		Mean of All Permutations	
	Change in Real GDP	Share of Growth	Change in Real GDP	Share of Growth
Overall (All Changes)	62.4%	–	62.4%	–
Productivity Changes	35.2%	0.62	30.9%	0.56
Internal Trade Cost Changes	10.3%	0.20	9.9%	0.20
External Trade Cost Changes	4.0%	0.08	3.5%	0.07
Migration Cost Changes	12.1%	0.24	9.1%	0.18
Of the Migration Cost Changes,				
Between-Province, Within-Nonag	5.7%	0.11	4.0%	0.08
Between-Province, Within-Ag	0.3%	0.01	0.1%	0.00
Between-Province, Ag-Nonag	4.5%	0.09	2.7%	0.06
Within-Province, Ag-Nonag	3.7%	0.07	2.1%	0.04

Notes: Decomposes the change in real GDP into contributions from productivity, internal trade cost changes, external trade cost changes, and migration cost changes. The bottom panel decomposes the change due to migration cost changes into various different types of migration. The "relative to the initial equilibrium" columns correspond to Tables 6, 7, and 8. As the change in real GDP from each component depends (slightly) on the order of simulation, the last two columns report the average marginal effect of each component across all permutations of changes. Only the "mean of all permutations" contributions sum to one. Shares are calculated as $log(1+x)/log(1.624)$, where x is the contribution from each component.

The negative effect on inter-provincial migration is due to some convergence in the underlying non-agricultural productivity across provinces.

We display the marginal effects of trade and migration costs change, which are the change in the various outcome variables relative to the equilibrium with only productivity changes, in the second panel of Table 8. The marginal effects of changing trade costs are similar to our earlier results, but the impact of changes in migration costs are now smaller. The change in the stock of migrants from lower migration costs is substantially lower than our baseline, and much closer to the level actually observed. The increase in aggregate welfare is now only 4.6% compared to 7.3% when there is no change in underlying productivity. Again, the reason for the lower impacts of the migration cost reductions is that there had been some convergence in the underlying non-agricultural productivity across provinces.

5.3 Decomposing China's Recent Economic Growth

By construction, when we include the measured trade and migration costs changes along with the calibrated productivity changes, the model-implied growth in real GDP per worker for each province and sector matches the actual growth between

2000 and 2005 in the data. The corresponding growth rate of the aggregate real GDP per worker implied by the model is over 62%. We can decompose the aggregate growth into the growth due to changes in underlying productivity, changes in trade costs and changes in migration costs by including these changes into the model sequentially. However, due to the interaction between these changes, the decomposition result depends on the order we introduce these changes in the simulation. We simulate all possible sequences of changes and present the average contribution of each set of changes in Table 9.

Overall, reductions in trade and migration frictions account for nearly half of China's overall productivity growth between 2000 and 2005, with reductions in internal trade and migration costs each contributes roughly one-fifth. In stark contrast, international trade cost reductions account for only 7% of the overall growth (3.5% out of the 62.4%). Of the contribution from migration cost changes, almost half is due to changes in the cost of migrating between provinces within the nonagricultural sector, with the remainder accounted for by the cost of moving from agriculture to nonagriculture.

5.4 Potential Scope for (and Gains from) Further Reform

Our decomposition shows that reductions in trade and migration frictions and the resulting reduction in misallocation of labour had played a major role in China's growth between 2000 and 2005. How much additional scope is there for further reductions in trade and migration costs? To answer this question requires a comparison country. We choose Canada as a geographically large developed economy to benchmark trade costs and the United States to benchmark migration flows.

Let's begin with internal trade costs. We choose since Statistics Canada's internal trade data is superior to the U.S. commodity-flow survey. In particular, Albrecht and Tombe (forthcoming) estimate Canada's internal trade costs separately for a variety of sectors. Reformulating their results to be consistent with our model, we find the trade-weighted average agricultural and nonagricultural trade costs of 94.9% and 149.1%, respectively. For China, the corresponding average internal trade cost in 2007 are 288.3% and 167.0%, respectively. Lowering China's costs to

Table 10: Potential Gains of Further Trade and Migration Liberalization

	Relative to 2005 Eq'm	
	Change in Real GDP	Aggregate Welfare
Average Internal Trade Costs as in Canada	10.9%	11.8%
Between-Province Migration as in U.S.	22.8%	15.0%
Both Changes Together	37.0%	30.5%

Notes: Reports the change in real GDP and welfare that result from changing China's internal trade and migration costs such that average internal costs equal Canada's (by sector) or such that the between-province migration flows match the U.S. Percentage changes are expressed relative to the 2005 equilibrium.

Canada's level would imply $\hat{\tau}_{ni}^{ag} = \frac{1.949}{3.883} = 0.502$ and similarly $\hat{\tau}_{ni}^{na} = 0.933$. Note we change internal trade costs only and hold all else fixed. We simulate these additional changes in trade costs relative to our 2005 counterfactual equilibrium. We report the results in Table 10. We find China's real GDP and welfare could increase by a further 10.9% and 11.8% if average internal trade costs fell to Canada's level.

Next, consider lowering migration costs in China such that migration flows are on par with developed economies. For this exercise, we can use the United States, as high quality migration data (through the Census) exists. The share of individuals living outside of their state of birth is roughly one-third in the United States – substantially more than the 9.5% who live outside their *Hukou* province in in China in 2005. To quantify the consequences of China's relatively low inter-provincial migration rate, we choose a constant change in $\hat{\mu}_{ni}^{jk}$ for all province pairs such that the share of workers living outside their *Hukou* province is one-third. We find $\hat{\mu}_{ni}^{jk} = 2.51$ for all $n \neq i$ will deliver this share (note we do not change migration costs within provinces between sectors). This implies that, to reach the U.S. level of labour mobility, the after-migration cost portion of inter-provincial migrant workers' income have to be two and half times as high as the current proportion. The resulting increase in real GDP and welfare is 22.8% and 15.0%, respectively.

The scope for and gains from further policy reform are therefore large. Both changes together deliver real GDP gains of 37% and welfare gains of nearly 31%.

6 Conclusion

China experienced rapid GDP growth between 2000 and 2005. There is a widely held belief that the main reason for this rapid growth is the external trade liberalization associated with China joining the WTO in 2001. This resulted in export expansion supported by a large increase in the supply of cheap migrant workers, hense the growth. Internal policy reforms undertaken by the Chinese government during the same period have not received as much attention. We find these reforms helped reduce the costs of both internal trade and migration. Using a general equilibrium model featuring internal trade, international trade, and worker migration across regions and sectors, we quantify the effect of changes in trade and migration costs on China's aggregate productivity growth and welfare. We find that reductions in internal trade and migration costs account for 38% of the aggregate labour productivity growth in China between 2000 and 2005. In contrast, reductions in external trade costs account for only 7% of the aggregate labour productivity growth during the same period. We also find that the internal reforms helped to reduce regional income differences in China, while external trade liberalization had the opposite effect. Finally, despite the reductions, internal trade and migration costs in China are still much higher than those in developed countries such as Canada and the U.S. Further reforms that lower these costs to developed country levels would yield substantial increases in China's aggregate productivity and welfare.

While our results may lead one to conclude international liberalization matters little for aggregate outcomes, we should point out the contribution of trade liberalization that we quantify is the effect of trade-induced resource reallocation. We have shown that internal trade liberalization results in a much larger reallocation effect than external trade liberalization does. However, external trade liberalization may also contribute to productivity growth through other channels that we have not studied in this paper. Two channels that we think are particularly relevant for China are FDI and the associated technology transfers (as in Ramondo and Rodriguez-Clare, 2013) and the influence of international liberalization on internal policy reforms. We leave the study of these issues to future research.

References

Aguayo-Tellez, Ernesto and Marc-Andreas Muendler, "Globalization and Formal-Sector Migration in Brazil," 2009.

Ahlfeldt, Gabriel, Stephen Redding, Daniel Sturm, and Nikolaus Wolf, "The Economics of Density: Evidence from the Berlin Wall," *CEP Discussion Paper*, 2012, *1154*.

Albrecht, Lukas and Trevor Tombe, "Internal Trade, Productivity, and Interconnected Industries: A Quantitative Analysis," *Canadian Journal of Economics*, forthcoming.

Allen, Treb and Costas Arkolakis, "Trade and the Topography of the Spatial Economy," *The Quarterly Journal of Economics*, 2014, *129* (3), 1085–1140.

Bai, Chong-en, Yingjuan Du, Zhigang Tao, and Sarah Tong, "Local Protectionism and Regional Specialization: Evidence from China's Industries," *Journal of International Economics*, 2004, *63* (2), 397–417.

Banerjee, Abhijit V. and Esther Duflo, "Growth Theory through the Lens of Development Economics," in Philippe Aghion and Steven Durlauf, eds., *Handbook of Economic Growth*, Vol. 1 of *Handbook of Economic Growth*, Elsevier, June 2005, chapter 7, pp. 473–552.

Bartelsman, Eric, John Haltiwanger, and Stefano Scarpetta, "Cross-Country Differences in Productivity: The Role of Allocation and Selection," *American Economic Review*, 2013, *103* (1), 305–334.

Bernard, Andrew B., Jonathan Eaton, J. Bradford Jensen, and Samuel Kortum, "Plants and Productivity in International Trade," *American Economic Review*, 2003, *93* (4), 1268–1290.

Brandt, Loren and Carsten Holz, "Spatial Price Differences in China: Estimates and Implications," *Economic Development and Cultural Change*, 2006, *55* (1), 43–86.

_ **, Trevor Tombe, and Xiadong Zhu**, "Factor Market Distortions Across Time, Space, and Sectors in China," *Review of Economic Dynamics*, 2013, *16* (1), 39–58.

Bryan, Gharad and Melanie Morten, "Economic Development and the Spatial Allocation of Labor: Evidence from Indonesia," 2015.

Cai, Fang, Alberta Park, and Yaohui Zhao, "The China Labor Market in the Reform Era," in Loren Brandt and Thomas Rawski, eds., *China's Great Economic Transformation*, Cambridge University Press, 2008.

Caliendo, Lorenzo, Fernando Parro, Esteban Rossi-Hansberg, and Pierre-Daniel Sarte, "The Impact of Regional and Sectoral Productivity Changes on the U.S. Economy," 2013.

_ , Maximiliano Dvorkin, and Fernando Parro, "The Impact of Trade on Labor Market Dynamics," *Working Paper*, 2015.

Caselli, Francesco, "Accounting for Cross-Country Income Differences," in Philippe Aghion and Steven Durlauf, eds., *Handbook of Economic Growth*, Vol. 1 of *Handbook of Economic Growth*, Elsevier, June 2005, chapter 9, pp. 679–741.

_ and Wilbur John Coleman, "The U.S. Structural Transformation and Regional Convergence: A Reinterpretation," *Journal of Political Economy*, 2001, *109* (3), 584–616.

Chan, Kam Wing, "The Household Registration System and Migrant Labor in China: Notes on a Debate," *Population and Development Review*, 2010, *36* (2), 357–364.

Cortes, Guido Matias Cortes and Giovanni Gallipoli, "The Barriers to Occupational Mobility: An Aggregate Analysis," 2014.

Cosar, Kerem and Pablo Fajgelbaum, "Internal Geography, International Trade, and Regional Outcomes," 2012.

Dekle, Robert, Jonathan Eaton, and Samuel Kortum, "Unbalanced Trade," *American Economic Review*, 2007, *97* (2), 351–355.

Dix-Carneiro, Rafael and Brian Kovak, "Trade Reform and Regional Dynamics: Evidence from 25 Years of Brazilian Matched Employer-Employee Data," 2014.

Eaton, Jonathan and Samuel Kortum, "Technology, Geography, and Trade," *Econometrica*, 2002, *70* (5), 1741–1779.

Ghani, Ejaz, Arti Grover Goswami, and William R. Kerr, "Highway to Success: The Impact of the Golden Quadrilateral Project for the Location and Performance of Indian Manufacturing," *NBER Working Paper*, 2012, (18524).

Hall, Robert E. and Charles I. Jones, "Why Do Some Countries Produce So Much More Output Per Worker Than Others?," *The Quarterly Journal of Economics*, 1999, *114* (1), 83–116.

Hanson, Gordon, "North American Economic Integration and Industry Location," *Oxford Review of Economic Policy*, 1998, *14* (2), 30–44.

Head, Keith and John Ries, "Increasing Returns versus National Product Differentiation as an Explanation for the Pattern of U.S.-Canada Trade," *American Economic Review*, 2001, *91* (4), 858–876.

_ **and Thierry Mayer**, "Gravity Equations: Workhorse,Toolkit, and Cookbook," in Gita Gopinath, Alhanan Helpman, and Kenneth Rogoff, eds., *Handbook of International Economics*, Vol. 4 2014. Chapter 3.

Hering, Laura and Rodrigo Paillacar, "How does market access shape internal migration?," 2012.

Hsieh, Chang-Tai and Peter J. Klenow, "Misallocation and Manufacturing TFP in China and India," *The Quarterly Journal of Economics*, 2009, *124* (4), 1403–1448.

Hsieh, Chang-Tai, Erik Hurst, Charles Jones, and Peter Klenow, "The Allocation of Talent and U.S. Economic Growth," 2013.

Klenow, Peter J. and Andres Rodriguez-Clare, "Economic growth: A review essay," *Journal of Monetary Economics*, 1997, *40* (3), 597–617.

Li, Shantong, *2002 Nian Zhongguo Diqu Kuozhan Touru Chanchubiao (2002 China Extended Regional Input-Output Tables)*, Beiing:: Economic Science Press, 2010.

Lin, Jusin, Gewei Wang, and Yaohui Zhao, "Regional Inequality and Labor Transfers in China," *Economic Development and Cultural Change*, 2004, *52* (2), 587–603.

McCaig, Brian and Nina Pavcnik, "Export markets and labor allocation in a poor country," 2012.

Morten, Melanie and Jaqueline Oliveira, "Migration, roads and labor market integration: Evidence from a planned capital city," 2014.

Novy, Dennis, "Gravity Redux: Measuring International Trade Costs With Panel Data," *Economic Inquiry*, 2013, *51* (1), 101–121.

Parro, Fernando, "Capital-Skill Complementarity and the Skill Premium in a Quantitative Model of Trade," *American Economic Journal: Macroeconomics*, 2013, *5* (2), 72–117.

Poncet, Sandra, "A Fragmented China: Measure and Determinants of Chinese Domestic Market Disintegration," *Review of International Economics*, 2005, *13* (3), 409–430.

_ , "Provincial migration dynamics in China: Borders, costs and economic motivations," *Regional Science and Urban Economics*, 2006, *36* (3), 385–398.

Ramondo, Natalia and Andres Rodriguez-Clare, "Trade, Multinational Production, and the Gains from Openness," *Journal of Political Economy*, 2013, *121* (2), 273 – 322.

Redding, Stephen J., "Goods Trade, Factor Mobility and Welfare," *Working Paper*, 2015.

Restuccia, Diego and Richard Rogerson, "Policy Distortions and Aggregate Productivity with Heterogeneous Plants," *Review of Economic Dynamics*, 2008, *11* (4), 707–720.

_ **and** _ , "Misallocation and productivity," *Review of Economic Dynamics*, 2013, *16* (1), 1–10.

Simonovska, Ina and Michael E. Waugh, "The Elasticity of Trade: Estimates and Evidence," Working Paper 16796, National Bureau of Economic Research 2011.

Tombe, Trevor, "The Missing Food Problem: Trade, Agriculture, and International Productivity Differences," *American Economic Journal: Macroeconomics*, 2015, *7* (3), 1–33.

Waugh, Michael E., "International Trade and Income Differences," *American Economic Review*, 2010, *100* (5).

Young, Alwyn, "The Razor's Edge: Distortions and Incremental Reform in the People's Republic of China," *Quarterly Journal of Economics*, 2000, *115* (4), 1091–1135.

Zhang, Yaxiong and Shuchang Qi, *2002, 2007 Nian Zhongguo Qiqujian Touru Chanchubiao (2002 and 2007 China Inter-Regional Input-Output Tables)*, Beiing:: China Statistical Press, 2012.

Zhu, Xiaodong, "Understanding China's Growth: Past, Present, and Future," *Journal of Economic Perspectives*, 2012, *26* (4), 103–24.

Appendix

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 nonagriculture'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 nonagricultural Hukou) currently working in province i and employed in sector k (agricultural or nonagricultural). 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 regional 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 nonagriculture. 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 either 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).

In the following tables, we report various summary measures of trade, real incomes, migration, employment, and other metrics for all provinces and sectors. We further provide the calibrated equilibrium values for real incomes per effective worker and the number of effective workers in each province and sector. See Section 3.7.4 for details.

Table 12: Selected Region-Specific Initial Calibrated Values

	Hukou Registrations, $\bar{L}_n^j$		Real Income per Effective Worker, V_n^j		Effective Workers, H_n^j	
Province	Ag	Nonag	Ag	Nonag	Ag	Nonag
Anhui	24.40	11.76	0.17	0.84	36.39	17.45
Beijing	1.43	3.39	0.26	1.77	1.77	5.87
Chongqing	10.97	6.09	0.16	0.97	16.77	9.10
Fujian	12.45	3.54	0.31	2.90	15.99	6.05
Gansu	7.43	4.55	0.12	0.76	12.61	6.66
Guangdong	23.30	4.45	0.17	4.69	37.57	8.12
Guangxi	18.01	8.82	0.14	0.76	29.26	12.81
Guizhou	15.31	6.01	0.08	0.51	24.62	8.96
Hainan	1.99	1.23	0.36	0.78	3.83	1.87
Hebei	19.40	15.25	0.25	1.21	31.20	22.82
Heilongjiang	8.49	8.31	0.10	1.59	31.65	11.41
Henan	39.02	18.41	0.17	0.99	64.22	26.68
Hubei	14.35	12.03	0.23	1.23	24.26	17.38
Hunan	25.44	12.18	0.14	0.99	40.91	17.39
Inner Mongolia	6.25	3.87	0.31	1.10	9.79	5.97
Jiangsu	20.24	14.66	0.17	1.96	48.60	21.49
Jiangxi	13.02	8.61	0.22	0.74	18.94	12.63
Jilin	5.65	5.28	0.37	1.21	9.64	7.67
Liaoning	7.87	9.97	0.34	1.63	13.34	14.94
Ningxia	1.78	0.91	0.11	1.02	3.50	1.36
Qinghai	1.53	0.86	0.12	1.14	2.82	1.24
Shandong	29.08	17.47	0.23	1.63	48.05	26.24
Shanghai	1.99	3.01	0.13	4.15	3.32	4.78
Shaanxi	11.62	6.82	0.11	0.79	18.70	10.19
Shanxi	8.20	5.89	0.11	0.92	13.31	8.94
Sichuan	31.31	16.51	0.18	0.80	47.18	24.15
Tianjin	1.14	2.62	0.26	2.14	1.87	4.02
Xinjiang	4.00	2.00	0.31	2.25	7.28	3.04
Yunnan	18.18	4.32	0.08	1.44	35.45	6.43
Zhejiang	23.34	2.55	0.22	6.28	24.09	4.68

Notes: Lists the values for the region-specific initial values. Some are calibrated while others are directly observables from data. See section 3.7 for details.

Table 11: 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 the model's calibration that was not provided in the main text, and (3) details behind estimating the Head-Ries method of estimating trade costs adjusted for asymmetries.

Proofs of Propositions

Our proofs omit sector super-scripts.

Proposition 1: *Given real incomes for each region V_i, migration costs between all regional pairs μ_{ij}, and heterogeneous productivity distributed $F_z(x)$, the share of region i workers that migrate to region j is*

$$m_{ij} = \frac{\left(V_j \mu_{ij}\right)^{\kappa}}{\sum_{k=1}^{N} \left(V_k \mu_{ik}\right)^{\kappa}}.$$

Proof: The share of people from region i that migrate to region j is the probability that each individual's potential payoff from region j exceeds that from any other region. Specifically,

$$m_{ij} \equiv Pr\left(\mu_{ij} z_j V_j \geq \max_{k \neq j} \{\mu_{ik} z_k V_k\}\right).$$

Since $Pr(z_j \leq x) \equiv e^{-(\tilde{\gamma}x)^{-\kappa}}$ by assumption of Frechet distributed worker productivity, we have $Pr(\mu_{ij} z_j V_j \leq x) = Pr(z_j \leq x/\mu_{ij} V_j) = e^{-(\tilde{\gamma}x/\mu_{ij}V_j)^{-\kappa}}$. The distribution of net income across workers from i in region j is therefore also Frechet. Similarly, the distribution of the highest net real income in all other regions is described by

$$\begin{aligned} Pr\left(\max_{k \neq j} \{\mu_{ik} z_k V_k\} \leq x\right) &= \prod_{k \neq j} Pr\left(\mu_{ik} z_k V_k \leq x\right), \\ &= \prod_{k \neq j} Pr\left(z_k \leq x/\mu_{ik} V_k\right), \\ &= \prod_{k \neq j} e^{-(\tilde{\gamma}x/\mu_{ik}V_k)^{-\kappa}}, \\ &= e^{-\left(\tilde{\gamma}x/\left(\sum_{k \neq j}(\mu_{ik}V_k)^{\kappa}\right)^{1/\kappa}\right)^{-\kappa}}, \end{aligned}$$

which is also Frechet.

Returning to the original m_{ij} expression, let $X = \mu_{ij} z_j V_j$ and $Y = \max_{k \neq j} \{\mu_{ik} z_k V_k\}$, which are Frechet distributed with parameters $s_X = \mu_{ij} V_j / \tilde{\gamma}$ and $s_Y = \left(\sum_{k \neq j} \left(\mu_{ik} V_k\right)^{\kappa}\right)^{1/\kappa} / \tilde{\gamma}$. By the Law of

Total Probability,

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

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

$$\begin{aligned} m_{ij} &= 1 + \int_{u=\infty}^{u=0} e^{-(s_X^\kappa + s_Y^\kappa) u} s_X^\kappa du, \\ &= 1 - s_Y^\kappa \int_0^\infty e^{-(s_X^\kappa + s_Y^\kappa) u} du, \\ &= 1 - \frac{s_Y^\kappa}{s_X^\kappa + s_Y^\kappa} = \frac{\left(\mu_{ij} V_j\right)^\kappa}{\sum_{k=1}^N \left(V_k \mu_{ik}\right)^\kappa}, \end{aligned}$$

which is the result. ■

Proposition* 2*: *If worker productivity z_i is distributed Frechet with variance parameter κ, and agents are able to migrate between regions at cost μ_{ij}, then the expected real income net of migration costs for workers from region i is*

$$V_i^0 = V_i m_{ii}^{-1/\kappa},$$

and aggregate average real income (welfare) is therefore

$$W = \sum_{i=1}^N \lambda_i^0 V_i m_{ii}^{-1/\kappa},$$

where $\lambda_i^0 = \frac{L_i^0}{\sum_{j=1}^N L_j^0}$ is the share registered in region i.

Proof: A worker from region i has heterogeneous productivity across all potential regions in China. These productivity are i.i.d. $Frechet(\kappa, \tilde{\gamma}^{-1})$ across all workers and regions with a mean of 1. Each worker will reside in the location that maximizes real income net of migration costs $\mu_{ij} z_j V_j$. The probability that a given person's welfare is below x is the probability that *no* region gives utility above x. The probability that region $j's$ payoff for a person from region i is below x is $e^{-\left(\tilde{\gamma}x/\mu_{ij}V_j\right)^{-\kappa}}$. The probability that they are all below x is the product of this across all potential regions,

$$F_{U_i}(x) = \prod_{j=1}^N e^{-\left(\tilde{\gamma}x/\mu_{ij}V_j\right)^{-\kappa}} = e^{-\left(\tilde{\gamma}x/\left[\sum_{j=1}^N \left(\mu_{ij}V_j\right)^\kappa\right]^{1/\kappa}\right)^{-\kappa}}.$$

To get our result, note that if $X \sim Frechet(\kappa, \tilde{\gamma}^{-1})$ then $Pr(X < x) \equiv F(x) = e^{-(\tilde{\gamma}x/s)^{-\kappa}}$ and $E[X] = s$. So, the utility of workers from region i after migration decisions – distributed according to $F_{U_i}(x)$ above – is Frechet with $E[U_i] = \left[\sum_{j=1}^{N}\left(\mu_{ij}V_j\right)^{\kappa}\right]^{1/\kappa}$. As real income and welfare are synonymous, $V_i^0 \equiv E[U_i]$. From proposition 1, $m_{ii} = \frac{V_i^{\kappa}}{\sum_{j=1}^{N}(\mu_{ik}V_k)^{\kappa}}$ and therefore $V_i^0 = V_i m_{ii}^{-1/\kappa}$. Aggregate welfare is the mean across all regions of registration, weighted by registration population shares $\lambda_i^0 = L_i^0/\sum_{j=1}^{N} L_j^0$, $W = \sum_{i=1}^{N} \lambda_i^0 V_i m_{ii}^{-1/\kappa}$. ■

Proposition 3: *The total supply of effective labour in region n is*

$$H_n = \sum_{i=1}^{N} \mu_{in} m_{in}^{\frac{\kappa-1}{\kappa}} L_i^0.$$

Moreover, $h_{in} = \mu_{in} m_{in}^{-1/\kappa}$ *is the average units of effective labour for workers from region n that work in region i, and therefore* $H_n = \sum_{i=1}^{N} h_{in} m_{in} L_i^0$.

Proof: Worker productivity follows a Frechet distribution with mean 1. The productivity of workers from region i that work in region j will follow a different distribution. By the multiplication rule of probabilities,

$$Pr\left(z_j \leq x \mid \mu_{ij}V_j z_j \geq \max_{k\neq j}\{\mu_{ik}V_k z_k\}\right) = \frac{Pr\left[\left(z_j \leq x\right) \cap \left(\mu_{ij}V_j z_j \geq \max_{k\neq j}\{\mu_{ik}V_k z_k\}\right)\right]}{Pr\left(\mu_{ij}V_j z_j \geq \max_{k\neq j}\{\mu_{ik}V_k z_k\}\right)}. \quad (23)$$

From Proposition 1, the probability of a worker from i to work in region j (the denominator of the above) is m_{ij}. The numerator is

$$Pr\left[\left(z_j \leq x\right) \cap \left(\mu_{ij}V_j z_j \geq \max_{k\neq j}\{\mu_{ik}V_k z_k\}\right)\right] = Pr\left[\max_{k\neq j}\{\mu_{ik}V_k z_k\} \leq \mu_{ij}V_j z_j \leq \mu_{ij}V_j x\right].$$

We saw in Proposition 1 that $X = \mu_{ij}V_j z_j$ and $Y = \max_{k\neq j}\{\mu_{ik}V_k z_k\}$ are both Frechet distributed random variables. Denote their CDFs $F(x)$ and $G(y)$, with means $\mu_{ij}V_j$ and $\left(\sum_{k\neq i}(\mu_{ik}V_k)^{\kappa}\right)^{1/\kappa}$, respectively. To ease notation, define $B = \left(\sum_{k\neq i}(\mu_{ik}V_k)^{\kappa}\right)^{1/\kappa}$. Given a particular value for Y,

$$\begin{aligned} Pr\left[y \leq \mu_{ij}V_j z_j \leq \mu_{ij}V_j x\right] &= Pr\left[\mu_{ij}V_j z_j \leq \mu_{ij}V_j x\right] - Pr\left[\mu_{ij}V_j z_j \leq y\right], \\ &= F\left(\mu_{ij}V_j x\right) - F(y). \end{aligned}$$

Hence, by the Law of Total Probability,

$$\begin{aligned} Pr\left[\max_{k\neq j}\{\mu_{ik}V_k z_k\} \leq \mu_{ij}V_j z_j \leq \mu_{ij}V_j x\right] &= \int_0^{\mu_{ij}V_j z_j}\left[F\left(\mu_{ij}V_j x\right) - F(y)\right] dG(y), \\ &= G\left(\mu_{ij}V_j x\right) F\left(\mu_{ij}V_j x\right) - \int_0^{\mu_{ij}V_j x} F(y) dG(y). \end{aligned}$$

Solve for the first term,

$$
\begin{aligned}
G\left(\mu_{ij}V_jx\right)F\left(\mu_{ij}V_jx\right) &= e^{-\left(\tilde{\gamma}\frac{\mu_{ij}V_jx}{B}\right)^{-\kappa}} e^{-(\tilde{\gamma}x)^{-\kappa}}, \\
&= e^{-(\tilde{\gamma}x)^{-\kappa}\left[\frac{B^{\kappa}}{\left(\mu_{ij}V_j\right)^{\kappa}}+1\right]}, \\
&= e^{-(\tilde{\gamma}x)^{-\kappa}\left[\frac{\sum_{k=1}^{N}\left(\mu_{ik}V_k\right)^{\kappa}}{\left(\mu_{ij}V_j\right)^{\kappa}}\right]}, \\
&= e^{-(\tilde{\gamma}x)^{-\kappa}/m_{ij}},
\end{aligned}
$$

where the last line follows from equation 9.

Next, to solve the second term, find the PDF of Y $(dG(y))$. Since $G(y)$ is Frechet with mean B,

$$
dG(y) = \frac{\tilde{\gamma}\kappa}{B}\left(\frac{\tilde{\gamma}y}{B}\right)^{-\kappa-1} e^{-(\tilde{\gamma}y/B)^{-\kappa}}.
$$

With this, and defining $A \equiv \sum_{k=1}^{N}\left(\mu_{ik}V_k\right)^{\kappa}$ with some algebra, we have

$$
\int_0^{\mu_{ij}V_jx} F(y)dG(y) = \left(\frac{B}{A}\right)^{\kappa} e^{-\left(\tilde{\gamma}\frac{\mu_{ij}V_jx}{A}\right)^{-\kappa}}.
$$

So, using these two results,

$$
Pr\left[\max_{k\neq j}\left\{\mu_{ik}V_kz_k\right\} \leq \mu_{ij}V_jz_j \leq \mu_{ij}V_jx\right] = m_{ij}e^{-\left(\tilde{\gamma}x/\left(A/\mu_{ij}V_j\right)\right)^{-\kappa}}.
$$

The m_{ij} therefore cancels out (recalled equation 23), and the conditional distribution of z_j is

$$
Pr\left(z_j \leq x \mid \mu_{ij}V_jz_j \geq \max_{k\neq j}\left\{\mu_{ik}V_kz_k\right\}\right) = e^{-\left(\tilde{\gamma}x/\left(A/\mu_{ij}V_j\right)\right)^{-\kappa}},
$$

which is Frechet with mean $A/\mu_{ij}V_j = m_{ij}^{-1/\kappa}$.

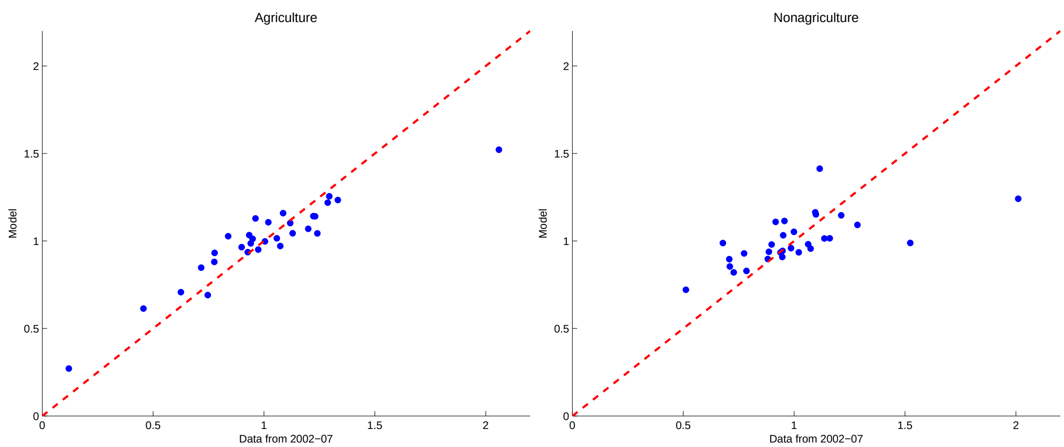
Finally, since all migrants incur a migration cost modeled as a real resource cost (a time loss, or a direct productivity reduction), the average units of effective labour of migrants net of the migration cost is $h_{in} = \mu_{in}m_{in}^{-1/\kappa}$ and our result follows. ■

Calibrating Changes in Underlying Productivity

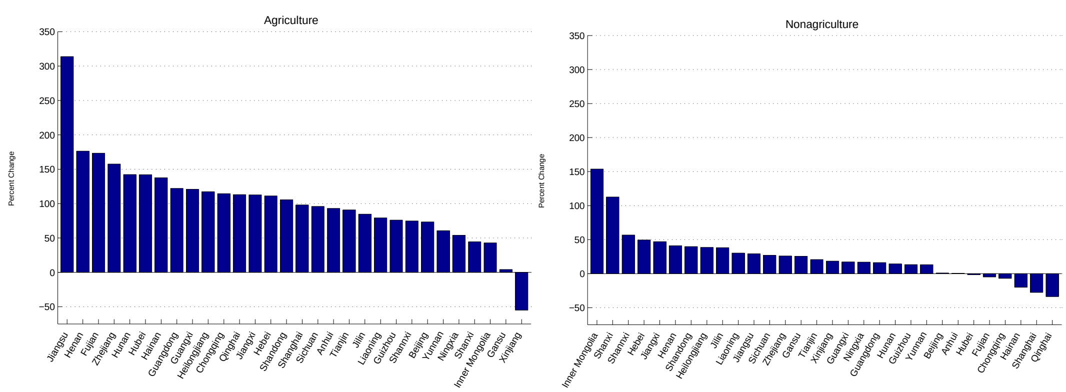
Finally, we calibrate the change in sectoral productivity (and capital accumulation) $\hat{T}_n^j$ such that observed real GDP changes match the data. Simulating only migration cost and trade cost reductions results in counterfactual changes in real incomes (per effective worker) across provinces. These changes, not surprisingly, do not match what we measure for $\hat{V}_n^j$ from data. We compare the model outcomes to data in Figure 3 (a). In the model, changes in productivity $\hat{T}_n^j$ make up the difference. We calibrate changes in provincial the productivity parameter $\hat{T}_n^j$ such that, when migration and trade costs decline as measured, the resulting real income per effective worker changes match data. The necessary values for $\hat{T}_n^j$ are displayed in Figure 3 (b).

Figure 3: Calibrating Productivity Changes $\hat{T}_n^j$

(a) Real Income Changes Per Effective Worker $\hat{V}_n^j$, when $\hat{T}_n^j = 1$



(b) Implied Change in $\hat{T}_n^{j\;1/\theta(\beta^j+\eta^j)}$ to Match Data



Notes: Compares the model-implied change in real income per effective worker $\hat{V}_n^j$ when underlying productivity is constant to real income changes from data. Both are expressed relative to the mean. To match data, we require changes in productivity parameters $\hat{T}_n^j$ as displayed in the bottom panel. We re-scale with the exponent $1/\theta(\beta^j + \eta^j)$, as productivity per effective worker in autarky is proportional to $T_n^{j\;1/\theta(\beta^j+\eta^j)}$.

Estimating Trade Costs

We begin with a standard Head-Ries index of trade costs. From equation 22 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 nonagriculture. 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.

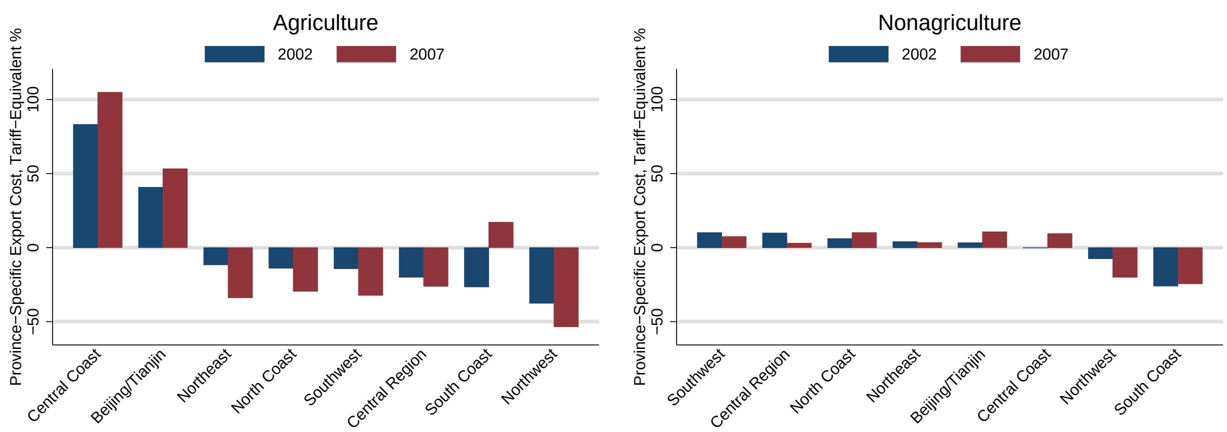
If trade costs have only a symmetric and exporter-specific component, and if the symmetric component is well proxied by geographic distance, then we can estimate t_i^j from

$$ln\left(\pi_{ni}^{j}/\pi_{nn}^{j}\right)=\delta^{j}ln\left(d_{ni}\right)+\iota_n^j+\eta_i^j+\varepsilon_{ni}^{j}, \tag{24}$$

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 4. 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 nonagricultural 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.

Figure 4: 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 Nonagriculture, 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).