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Labor Mobility Barriers and Rural-urban Migration in Transitional China

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Abstract:

Rural-urban migration is an inherent component of urbanization and economic development. This paper develops a model of labor migration, focusing on the role of selection effects in determining labor market outcomes. The model is then calibrated to quantify the effects of China's labor market reforms on labor market outcomes, outputs, and income. Results find that the removal of legal labor mobility constraints and lowering of migration costs benefit the overall economy in terms of GDP and total welfare, but rural-urban migration also causes a brain drain in rural areas, and decreases agricultural production while inflating the price of agricultural products. In terms of inequality, migration narrows the urban-rural labor income gap, but when considering capital income, migration actually increases urban-rural inequality.

1 Introduction

Rural-urban migration enables efficient resource allocation across regions, and is an inevitable phenomenon in the course of urbanization and economic development. However, barriers to labor mobility are common in developing economies, whether caused by institutional constraints, social norms, regional cultural and linguistic differences, information and search costs, or discrimination and psychic costs. These barriers may result in regional and sectoral misallocation of resources, geographic poverty traps and delayed growth (de Brauw et al., 2014; Jayashi and Prescott, 2008; Jalan and Ravallion, 2002).

This paper develops a multi-sector model of labor mobility and earnings, to study rural-urban migration decisions and their effects on economic development and welfare. Using China's *Hukou* system reform as the background, we calibrated the model and simulated the effects of removing legal labor mobility constraints and lowering migration costs. We argue that human capital redistribution during rural-urban migration is the key to understanding the consequences of rural-urban migration. And, besides the positive effects on productivity and income growth, we found that rural-urban migration also caused brain drain in rural regions, decreased production and inflated price of agricultural products, and widened the rural-urban income gap.

This paper makes four main contributions to the literature. First, the theoretical model of self-selection in migration based on calibration and simulations used in this study complements existing empirical research on self-selection in migration (Xing, 2014). Xing (2014) modeled rural-urban migration as a self-selection process, and then used Chinese Household Income Project (CHIP) data to estimate the effects of migration on income distributions. In this paper, we emphasize the effects of migration on human capital, labor, output and income. Second, we formalize Roy (1995)'s idea in the context of migration, and extend the model by utilizing multiple sectors to better describe the Chinese economy. The assumption of self-selection mechanism in a four-sector economy is much more realistic than the two-sector economy assumption in other theoretical studies on rural-urban migration in China. For example, Whalley and Zhang (2007) use numerical simulation methods to analyze the effect of removing migration restriction in China, based on static models of a two-sector economy. Third, since we analyze the effects of internal migration on domestic development, the work complements the literature on the microeconomic effects of migration. For example, de Brauw and Giles (2008a), de Brauw and Rozelle (2008) and Ha et al. (2009) studied the effect of migration and remittance on rural poverty reduction; Bai (2000) and Zhao et al. (2012) studied the effect of rural-urban migration on agricultural production; Zhao and Qu (2013) studied the levels and changes in wage inequality among Chinese rural-urban migrants. Meng and Zhang (2001) studied differences in occupational attainment and wages between rural migrants and urban residents. De Brauw and

Giles (2008b) studied migration opportunity on educational decisions of the youth. Finally, this paper sheds light on the effect of rural-urban migration on agricultural production and food security in China, which have far-reaching implications on sustainable development.

The rest of this paper is organized as follows. Section 2 reviews the background related to rural-urban migration in China. Section 3 presents the setup and analysis of the theoretical model utilized in this paper. Section 4 provides calibrations and simulations of the theoretical model. Section 5 concludes.

2 Background

2.1 The *Hukou* system

China's *Hukou* system (household registration system) was formally set up in 1958 to control internal migration, promote heavy industry development in urban areas and manage certain classes of "targeted people" to ensure social stability (Wang, 2005; Cai and Wang, 2008). The system classified people as rural or urban residents, keeping the rural labor force in agricultural sectors and limiting the number of people in cities who had access to low-priced food, guaranteed non-agricultural employment, basic social security and subsidized public services (Cai and Wang, 2008). In addition, police are authorized to detain 'illegal' migrants and repatriate them to their permanent residency location under the *Hukou* system, and therefore, *Hukou* system also acted as a legal restriction on internal migration which was strictly enforced until the economic reform began in 1978. The reforms made distribution and control over migration more flexible but did not fundamentally change the *Hukou* system, and various barriers remain. For example, many cities legally require rural migrants to pay a nominal fee when applying for residency, with various government-issued permits and documents required from both the sending and receiving locations. By levying a fee on each of these documents, the government artificially raises migration costs. Further, rural migrants without local *Hukou* are not entitled to social benefits such as subsidized public housing, public education, public medical insurance and government welfare payments (Richburg, 2010). Job market discrimination based on *Hukou* is also prevalent, especially in big cities[1]. Also, during large-scale layoffs in state-owned enterprises (SOEs) in the late 1990s, urban governments have implemented a series of measures to prevent rural migrants from moving in (Cai, et al. 2001).

2.2 Rural migrants

Loosening of legal mobility constraints dramatically increased rural-urban migration flows. The number of rural migrants doubled between the late 1980s and the mid-1990s (Sicular and Zhao, 2004). In 2015, there were 277.5 million migrant workers in China, accounting for about 40 percent of the urban labor force (Chinese National Bureau of Statistics, 2016).

Comparing to the labor force remaining in rural areas, rural migrant workers tend to be younger and more educated, and thus possess more human capital. In 2009, 58.4 percent of rural migrant workers were between ages 16 and 29, while the same age group only accounted for 26.4 percent of the rural labor force (China National Bureau of Statistics, 2010). Increasing numbers of rural elderly are working on farms after the migration of young family members, and rural residents ages 50 and above account for almost one third of the rural labor force. In addition, rural migrant workers on average have one more year of education than the labor force in rural areas (China National Bureau of Statistics, 2010). Lastly, rural migrant workers with relatively high human capital tend to migrate to the urban industrial sector, while those with low human

[1] Rural migrants have lower incomes, less steady jobs, less formal contracts, lower chances of working in formal sectors, longer hours and tougher working conditions (Démurger, et al, 2009; Knight and Yueh, 2004; Li, 2008; Yao, 2001; Zhao, 2005). For example, in Beijing, at least 35 types of jobs are closed to migrants, and urban employers are required to pay a per capita fee for each migrant they hire (Wang and Zuo, 1999).

capital migrate to the urban informal sector. Based on the China National Rural Survey in 2000, 63 percent of rural migrant workers in the industrial sector finished middle school, while the corresponding number in urban informal sector was 53 percent.

2.3 Uneven resource distribution in rural and urban regions

Rural and urban regions in China receive very uneven capital investments from the central government. Soon after its establishment in 1949, China's central government adopted a dual-sector development strategy. Before the economic reform in 1978, rural areas engaged basically only in agriculture, while capital-intensive heavy industries developed primarily in cities (Mao and Gong, 2009). By the reform in 1978, the agricultural sector accounted for less than 12 percent of total investments but employed about 80 percent of the total labor force. Since then, investments in fixed assets in rural areas raised to account for 28 percent of the national total, until the early 1990s, when the fraction decreased to 22 percent and has continued to fall (China National Bureau of Statistics, 2008). In 2010, investments in fixed assets in rural areas only accounted for 13 percent of the total national fixed assets investment.

After the economic reform in 1978, rural merchandise production and handicraft industry were no longer criticized as capitalism, and township and village enterprises (TVEs) thrived, employing a large amount of rural labor. In 1983, TVE employment grew to 32.35 million and production reached 102 billion yuan. The corresponding numbers were 95.45 million employees and 702 billion yuan in 1986, and 130 million employees and 1800 billion yuan in 1996 (Mao and Gong, 2009). Almost all TVEs are small in size and labor intensive, plagued with out-dated technology and machinery and low productivity, as a result of low investment levels in the rural industry as a whole.[2] Yet, low labor productivity does allow TVEs to absorb large amounts of rural surplus labor.[3]

Rural and urban areas also have different distributions of human capital. Figure 1 shows urban and rural human capital distributions measured by educational attainment in 1985 and 1995.[4] It shows that the percentage of urban residents with senior high school education or higher is much larger than of rural residents. For example, in 1995 senior high school graduates and post-secondary degree holders in urban areas were 25.7 percent and 9.1 percent, respectively, with the corresponding numbers in rural areas at 6.8 percent and 0.4 percent. In addition, due to the differences in quality of education between rural and urban areas, these numbers likely understate the true differences between rural and urban human capital.

[2] Zen (2002) suggested that China's rural industries are more labor intensive, with a low added-value and a large bulk.

[3] A labor surplus exists when a substantial portion of the labor force contributes less to output than it requires, and therefore, its marginal product falls below its remuneration set by bargaining. A reallocation of such workers to other, competitive, sectors would eliminate the inefficiency and enhance total output (Ranis, 2008).

[4] The data is from the China's Human Capital: Measurement and Index Construction Project which is available at http://humancapital.cufe.edu.cn/rlzbzsxm/zgrlzbzsxm2017/zgrlzbzsbgsjk/zgrlzbzsxmgssj.htm. The purpose of Figure 1 is to show that the pre-migration human capital distributions are different between rural and urban regions and to provide evidence for the model assumption that the pre-migration human capital distribution function in the urban region, $p^u(h_i)$, first-order stochastically dominating $p^r(h_i)$. We used data in 1985 and 1995 because the human capital distributions drawn from data in the earlier years are less contaminated by migration, and therefore, we are more likely to measure the pre-migration human capital distributions in rural and urban regions, rather than the post-migration distributions.

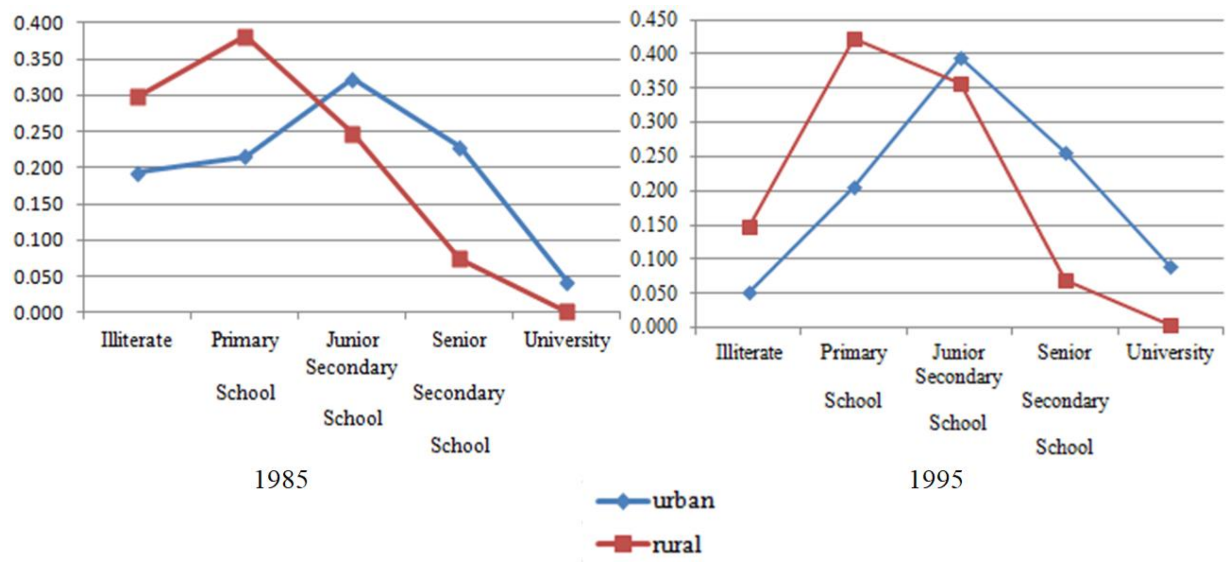

Figure 1. Urban and rural human capital distributions in 1985 and 1995

2.4 Informal sectors in China

In economic modeling, the informal sector has been defined as a type of employment that falls outside of the modern industrial sector (Lewis, 1955). For statistical purposes, the informal sector has been defined as the private unincorporated enterprises that are unregistered or small in terms of employment (the 15th International Conference of Labor Statisticians (ICLS), 1993). The informal sector is characterized by low enterprise productivity due to lacking worker skills, outdated production systems and limited management capacities. Workers in the informal sector are vulnerable, due to absence of workplace protections, job securities and social benefits. Typical occupations in the informal sectors include domestic workers, street vendors and waste pickers.

The urban informal sector in China absorbs a large amount of rural migrants and workers who were laid off of SOEs, and represents a large portion of domestic output, consumption and employment. It is estimated that approximately half of the employment in urban China belongs to the informal economy (Wu, 2009; Xue and Gao, 2012).

3 A theoretical model of self-selection and earnings of workers

3.1 Model assumptions

The model used in this paper assumes that there are two regions in the economy, a rural region and an urban region. In the rural region exists an agricultural (RA) sector and a rural industrial (RM) sector; in the urban region, there is an urban industrial (UM) sector and an urban informal (US) sector. Residents in each region can be identified by a residency registration system, with the rural labor force denoted as L^r and urban labor force as L^u.

Worker *i* is endowed with n_i units of labor and $h_i \in [0,1]$ units of human capital. Labor supply is assumed to be inelastic in each sector, so n_i is normalized to one. The probability distribution functions of human capital in the rural and urban labor forces are given by $p^r(h_i)$ and $p^u(h_i)$, respectively, with $p^u(h_i)$ first-order stochastically dominating $p^r(h_i)$, as a result of favorable educational resources in the urban region. The human capital distributions are shown in Figure 2.

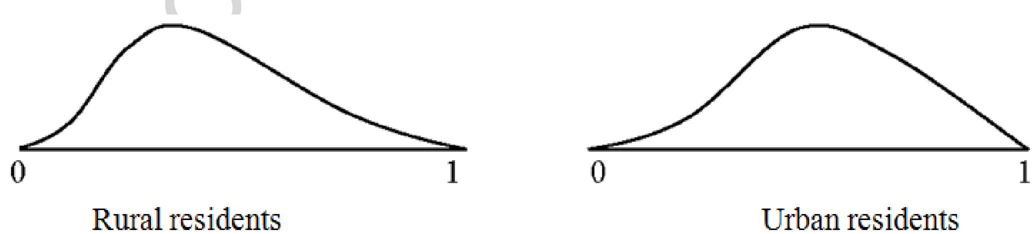

Figure 2. Human capital distributions

We assume that the aggregate capital stock in each region is exogenous, with $K^u > K^r$ resulting from favorable allocation of capital to urban region. Capital is defined as the input of production in the RM and UM sectors, and is assumed to be evenly distributed among workers in the respective sections. In the RA sector, land as input is distributed evenly among farmers, and we normalized total land to one. So, capital per worker in the RM and UM sectors and land per farmer in the RA sector are

$$k^r = \frac{K^r}{N^{rm}}$$

$$k^u = \frac{K^u}{N^{um}}$$

$$land = \frac{1}{N^a}$$

where N^{rm}, N^{um} and N^a are total employment in the RM, UM and RA sectors, respectively. In the RM and UM sectors, each worker is assumed to produce homogenous manufactured goods, using the neoclassical production functions below:

$$y_i^{rm} = f(n_i, h_i, k^r) \equiv f(h_i, k^r) \quad (1)$$

$$y_i^{um} = F(n_i, h_i, k^u) \equiv F(h_i, k^u) \quad (2)$$

where $F'(n_i, h_i, k^u) - f'(\, n_i, h_i, k^r)$ is a positive increasing function, reflecting the more advanced production technology in the UM sector. Workers in the industrial sectors earn their marginal products (MPN).

$$w_i^{rm} = MPN^{rm}(h_i, k^r)) \equiv f_n^{'}(h_i, k^r) \quad (3)$$

$$w_i^{um} = MPN^{um}(h_i, k^u) \equiv F_n^{'}(h_i, k^u) \quad (4)$$

The marginal product functions are quasiconcave, with $MPN^{rm\prime}(\cdot) > 0$, $MPN^{um\prime}(\cdot) > 0$, $MPN_{ii}^{rm''(\cdot)} \leq 0$, $MPN_{ii}^{um''(\cdot)} \leq 0$, $MPN_{ij}^{rm}{''}(\cdot) > 0$, and $MPN_{ij}^{um}{''}(\cdot) > 0$.

In the US sector, each worker works independently and earns w^{us}.

$$w^{us} = w(Y^{um}, N^{us}) \quad (5)$$

where N^{us} is the aggregate labor input in the US sector, and Y^{um} is the aggregate output in the UM sector. We assume $w'(Y^{um}) > 0$ and $w'(N^{us}) < 0$, as Y^{um} increases the aggregate demand for goods and services produced by the US sector, and N^{us} increases its aggregate supply. The total output in the US sector is:

$$Y^{us} = w^{us} \cdot N^{us} \quad (6)$$

In the RA sector, each farmer is assumed to produce homogenous agricultural goods, represented by a neoclassical production function with labor and land as inputs,

$$y_i^a = g(n_i,\ 1/N^a) \equiv g(1/N^a) \quad (7)$$

where $g''(\cdot) < 0 < g'(\cdot)$, and N^a is the aggregate labor input in the RA sector. Human capital does not enter the agricultural production function, and each farmer earns the same at

$$w^a = P \cdot g(1/N^a) \quad (8)$$

where $P = \rho(\frac{Y^a}{Y^m}) = \rho(\frac{Y^a}{Y^{um}+Y^{rm}})$ is the relative price of agricultural goods in terms of manufactured goods, with $\rho'(\cdot) < 0$.

3.2 Restricted labor mobility

The restricted labor mobility setup is used to describe the beginning of economic reform (1979 – mid-1980s), when labor mobility was constrained and workers could only choose between local job options. Prior to reform, in the planned economy (1949-1978) the only sectors were the rural RA sector and the urban UM sector, with all workers in each sector earning the same wages. During the first wave of economic reform and development in 1979 – mid-1980s, township and village enterprises (TVEs) thrived, and the urban unemployed formed the urban informal sector. As a result, the RM sector attracted the more productive labor in the rural region, and the US sector absorbed the less productive labor in the urban region.

Proposition 1. There exist some $\bar{h}^r \in (0,1)$ and $\bar{h}^u \in (0,1)$ such that rural residents with human capital $h_i \in [\bar{h}^r, 1]$ work in the RM sector and those with human capital $h_i \in [0, \bar{h}^r)$ work in the RA sector; urban residents with human capital $h_i \in [\bar{h}^u, 1]$ work in the UM sector, and those with human capital $h_i \in [0, \bar{h}^u)$ work in the US sector. The equilibrium allocations of labor are depicted in Figure 3.

Proof. In equilibrium, the marginal worker in the rural region is indifferent between working in the RM sector and the RA sector, and the marginal worker in the urban region is indifferent between the UM sector and the US sector.

$$P \cdot g(1/N^a) = MPN^{rm}(\bar{h}^r, \frac{K^r}{N^{rm}}) \tag{9}$$

$$MPN^{um}\left(\bar{h}^u, \frac{K^u}{N^{um}}\right) = w(Y^{um}, N^{us}) \tag{10}$$

where $\bar{h}^r$ and $\bar{h}^u$ are the levels of marginal worker human capital in rural and urban regions, respectively; $N^a = L^r \int_0^{\bar{h}^r} p^r(h^r) dh^r$ is employment in the RA sector, $N^{rm} = L^r \int_{\bar{h}^r}^1 p^r(h^r) dh^r$ is employment in the RM sector, $N^{um} = L^u \int_{\bar{h}^u}^1 p^u(h^u) dh^u$ is employment in the UM sector, and $N^{us} = L^u \int_0^{\bar{h}^u} p^u(h^u) dh^u$ is employment in the US sector. The aggregate outputs in the RA, RM, UM and US sectors, respectively, are:

$$Y^a = N^a \cdot g\left(\frac{1}{N^a}\right) = L^r \int_0^{\bar{h}^r} p^r(h^r) dh^r \cdot g\left[\frac{1}{L^r \int_0^{\bar{h}^r} p^r(h^r) dh^r}\right]$$

$$Y^{rm} = L^r \int_{\bar{h}^r}^1 f(h^r, k^r) p^r(h^r) dh^r$$

$$Y^{um} = L^u \int_{\bar{h}^u}^{1} F(h^u, k^u) p^u(h^u) dh^u$$

$$Y^{us} = w^{us} \cdot L^u \int_0^{\bar{h}^u} p^u(h^u) dh^u$$

Note that Y^a increases in $\bar{h}^r$, Y^{rm} decreases in $\bar{h}^r$, and Y^{um} is uncorrelated with $\bar{h}^r$. Therefore, $P = \rho(\frac{Y^a}{Y^{um}+Y^{rm}})$ decreases in $\bar{h}^r$, and the LHS of equation (9), which is RA sector earnings, decreases in $\bar{h}^r$, given that $g(1/N^a)$ decreases in N^a, which increases in $\bar{h}^r$. The RHS of equation (9) increases in $\bar{h}^r$, and the intersection of the two curves given by the LHS and RHS of equation (9) represents equilibrium in the rural region. Human capital at the intersection of $\bar{h}^r$ is the human capital of a marginal worker in the rural region. For rural residents with human capital of $h_i > \bar{h}^r$, earnings in the RM sector are higher than in the RA sector, leading to the choice of working in the RM sector. For rural residents with human capital of $h_i < \bar{h}^r$, earnings in the RA sector are higher than in the RM sector, leading to the choice of working in the RA sector. Hence, there exists a cutoff level of human capital, $\bar{h}^r$, such that rural residents with human capital $h_i \in [\bar{h}^r, 1]$ work in the RM sector and those with human capital $h_i \in [0, \bar{h}^r)$ work in the RA sector.

A similar argument can be made for equation (10). In equation (10), the LHS, which is UM sector earnings, increases in $\bar{h}^u$ and the RHS, which is US sector earnings, decreases in $\bar{h}^u$, as Y^{um} decreases in $\bar{h}^u$ and N^{us} increases in $\bar{h}^u$. The intersection of the two curves, given by the LHS and RHS of equation (10), represents equilibrium in urban regions. The human capital at the intersection, $\bar{h}^u$, is the marginal worker human capital in the urban region. For urban residents with human capital of $h_i > \bar{h}^u$, earnings in the UM sector will be higher than in the US sector, encouraging the choice to work in the UM sector. For rural residents with human capital of $h_i < \bar{h}^u$, earnings in the US sector are higher than in the UM sector, leading to the choice to work in the US sector. Hence, there exists a cutoff level of human capital, $\bar{h}^u$, such that rural residents with human capital $h_i \in [\bar{h}^u, 1]$ work in the UM sector, and those with human capital $h_i \in [0, \bar{h}^u)$ work in the US sector.

qed.

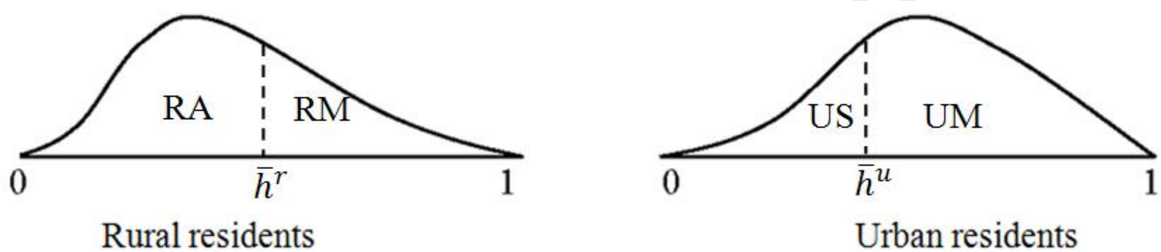

Figure 3. Equilibrium human capital distribution under the restricted labor mobility regime

3.3 Unrestricted labor mobility

As economic reform progresses and legal barriers to internal migration are removed, rural residents have become legally allowed to migrate to urban regions. However, migration is costly, as economic and institutional constraints remain. The cost of migration includes monetary and non-monetary costs, such as separation from family and community and discrimination.[5]

Assuming high-skilled workers more quickly adapt to a new environment, the cost of migration is modeled as a decreasing function of h_i, labeled $C(h_i)$, with $C'(h_i) < 0, C''(h_i) > 0, C(0) = \infty, C(1) = 0, C'(0) = -\infty,$ and $C'(1) = 0$.[6] When considering migration, a rural

[5] Sjaastad (1962) breaks down moving cost into monetary and non-monetary costs. "The former include the out-of-pocket expenses of movement, while the latter include foregone earnings and the 'psychic' costs of changing one's environment". Zhao (1999) called them "explicit costs" which also include the costs imposed by government and "implicit psychic cost".

[6] Zhang and Lei (2008) point out that there are four components to social integration for a Chinese domestic migrant: cultural integration, mental integration, identity integration and economic integration. They also constructed an empirical model to test the determinants of social integration, using data on 600 new migrants to Shanghai. The coefficient of years of schooling was 0.89, which implies migrants with higher education levels integrate into a new environment faster.

resident compares the costs and benefits. The net benefit of migration is the difference between earning gain and migration cost. We assume that the migration cost is 'reasonable', in the sense that it is not too high, so that rural migrants work in both the UM and US sectors, and not too low, so that rural residents work in both the RA and RM sectors.

Lemma 1. There exists some $\boldsymbol{h_X} \in (\mathbf{0}, \mathbf{1})$ such that rural residents with human capital $\boldsymbol{h_i} \in (\boldsymbol{h_X}, \mathbf{1}]$ migrate and work in the UM sector.

Proof. For a rural resident with human capital of h_i, the net benefit of migrating to the urban region is

$$[\max(w_i^{um}, w_i^{us}) - \max(w_i^{rm}, w_i^{a})] - C(h_i)$$

where the first term is earning gain and the second is migration cost.

Given the employment in each sector, w_i^{um} increases in h_i, and w_i^{us} is uncorrelated with h_i. Therefore, only rural residents with human capital higher than some cutoff level, h_Q, will choose the UM sector over the US sector after migration. Now, only consider rural residents with human capital $h_i \geq h_Q$. For them, the net benefit of migrating to an urban region becomes

$$[w_i^{um} - \max(w_i^{rm}, w_i^{a})] - C(h_i).$$

Based on the assumptions of the production functions of manufactured goods, earning gain is an increasing function of h_i, and migration cost decreases in h_i. Thus, the net benefit of migrating to the UM sector increases in h_i. Since $C(0) = \infty$ and $C(1) = 0$, there must exist some $h_X \geq h_Q$, such that rural resident with human capital of h_X have a net benefit of migrating to the UM sector of zero. Therefore, there exists some $h_X \in (0,1)$ in that rural residents with human capital of $h_i \in (h_X, 1]$ choose to migrate and work in the UM sector.

qed.

Lemma 2. There exist some $\boldsymbol{h_N}, \boldsymbol{h_M} \in (\mathbf{0}, \mathbf{1})$ such that $\mathbf{0} < \boldsymbol{h_N} < \boldsymbol{h_M} < 1$, and rural residents with human capital $\boldsymbol{h_i} \in (\boldsymbol{h_N}, \boldsymbol{h_M})$ migrate and work in the US sector.

Proof. For a rural resident with human capital of h_i, the net benefit of migrating to the urban region is

$$[\max(w_i^{um}, w_i^{us}) - \max(w_i^{rm}, w_i^{a})] - C(h_i)$$

where the first term is earning gain and the second is migration cost. Given the employment in each sector, w_i^{um} increases in h_i and w_i^{us} is uncorrelated with h_i. Therefore, only rural residents with human capital lower than some cutoff level, h_Q, will choose the US sector over the UM sector if they migrate. Now, only consider rural residents with human capital $h_i \leq h_Q$. For them, the net benefit of migrating to an urban region becomes

$$[w_i^{us} - \max(w_i^{rm}, w_i^{a})] - C(h_i).$$

Given the employment in each sector, w_i^{rm} increases in h_i and w_X^{us} and w_X^{a} are uncorrelated with h_i. Thus, the earning gain is first constant and then decreases in h_i; it is continuous and concave. The migration cost is continuous and strictly convex, and decreases in h_i, with $C(0) = \infty$ and $C(1) = 0$. Therefore, the net benefit of migrating to the UM sector is continuous and strictly concave. It is first negative for $h_i = 0$, then increases as migration cost decreases, and then after hitting its peak decreases as w_i^{rm} increases. Thus, for a reasonable migration cost, two distinct values of human capital exist, $h_N < h_M$, which makes the net benefit of migrating to the urban region and working in the UM sector zero. For rural residents with human capital $h_i \in (h_N, h_M)$, the net benefit of migrating to an urban region and working in the UM sector is positive.

qed.

Proposition 2. There exist some h_N, h_M and h_X such that $0 < h_N < h_M < h_X < 1$, where rural residents with human capital $h_i \in (h_N, h_M)$ migrate and work in the US sector, and rural residents with human capital $h_i \in (h_X, 1]$ migrate and work in the UM sector.

Proof. Lemmas 1 and 2 already prove that rural residents with human capital $h_i \in (h_N, h_M)$ migrate and work in the US sector and rural residents with human capital $h_i \in (h_X, 1]$ migrate and work in the UM sector. Now, we need to prove $h_M < h_X$. The marginal rural resident with human capital h_M is indifferent between working in the RM sector and moving to the US sector, and the marginal rural resident with human capital h_X is indifferent between working in the RM sector and moving to the UM sector.

$$w_M^{us} - C(h_M) = w_M^{rm} > w_M^{um} - C(h_M)$$

$$w_X^{um} - C(h_X) = w_X^{rm} > w_X^{us} - C(h_X).$$

Because $C'(h_i) < 0$, and w_i^{us} is constant in h_i, for given employment in each sector, we have

$$\begin{aligned} w_X^{um} - C(h_X) &> w_X^{us} - C(h_X) \\ &= w_M^{us} - C(h_X) \\ &= [w_M^{us} - C(h_M)] + [C(h_M) - C(h_X)] \\ &> [w_M^{um} - C(h_M)] + [C(h_M) - C(h_X)] \\ &= w_M^{um} - C(h_X) \end{aligned}$$

Therefore, $w_X^{um} > w_M^{um}$. Because w_i^{um} is an increasing function of h_i, we have $h_X > h_M$.

qed.

Proposition 3: There are two equilibrium allocations of non-migrant labor in the rural region under the unrestricted labor mobility regime. At the first equilibrium, rural residents with human capital $\boldsymbol{h_i} \in [\mathbf{0}, \boldsymbol{h_N}]$ work in the RA sector, and those with human capital $\boldsymbol{h_i} \in [\boldsymbol{h_M}, \boldsymbol{h_X}]$ work in the RM sector. At the second equilibrium, rural residents with human capital $\boldsymbol{h_i} \in [\mathbf{0}, \boldsymbol{h_N}]$ work in the RA or RM sector, and those with human capital $\boldsymbol{h_i} \in [\boldsymbol{h_M}, \boldsymbol{h_X}]$ work in the RM sector. These two equilibria are depicted in Figure 4.

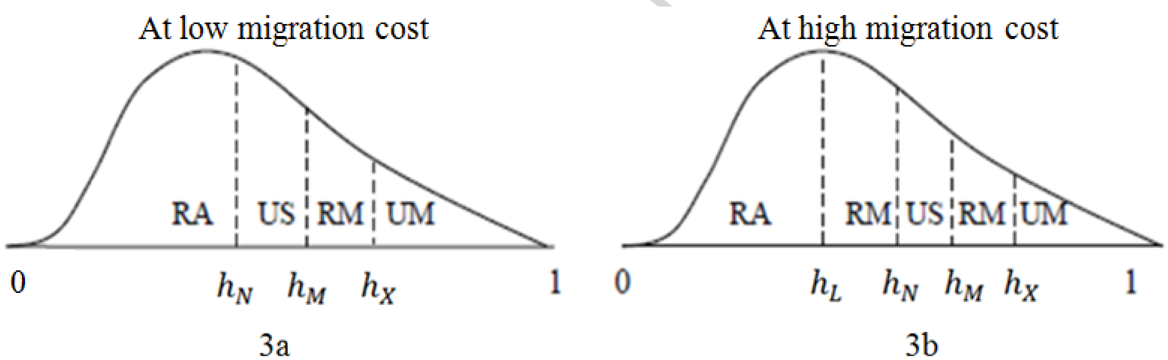

Figure 4. Equilibrium human capital distributions in the rural region under the unrestricted labor mobility regime

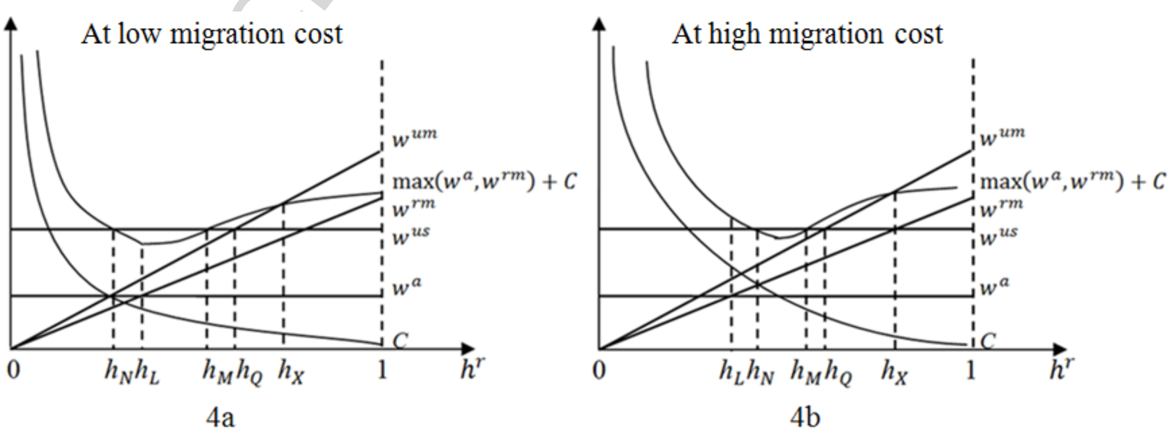

Figure 5. Migration cost and equilibrium earning distribution for rural residents under the unrestricted labor mobility regime

The mathematical conditions for the above two equilibria are showed in Appendices A and B. Migration cost is the main cause of multiple equilibria. Low migration costs lead to the first equilibrium as in Figure 4a; otherwise, if migration cost is high the second equilibrium as in Figure 4b will exist. The relationships between migration cost and human capital distribution in the rural region are shown in Figure 5. Figure 5 shows the migration cost and earning distribution in different sectors at equilibrium employment levels, revealing that rural residents have no incentive to deviate from the equilibrium allocation. Figure 5a shows the case with low migration cost, and Figure 5b with high migration cost. In both Figures 5a and 5b, the horizontal axis is human capital level.

At the equilibrium employment levels, w^{us} and w^{a} are horizontal, w^{um} and w^{rm} are upward sloping and concave, and migration cost is downward sloping and strictly convex. Therefore, maximum earning in rural sectors, $w^{r} = \max(w^{rm}, w^{a})$, is first horizontal and then upward sloping, with a kink at h_L; maximum earning in urban sectors, $w^{u} = \max(w^{um}, w^{us})$, is also first horizontal and then upward sloping, with a kink at h_Q. Rural residents compare w^{u} and $w^{r} + C$ to determine whether to migrate; the latter is a curve first downward sloping and then upward sloping.

In Figure 5a, the migration cost is low; $w^{r} + C$ first intersects with the horizontal part of the w^{u} curve at h_N and h_M, with $h_N < h_L < h_M$, and then intersects the upward sloping part of the w^{u} curve at h_X, with $h_Q < h_X < 1$. As a result, rural residents with human capital $h_i \in [0, h_N]$ work in the RA sector, those with human capital $h_i \in (h_N, h_M)$ migrate and work in the US sector, those with human capital $h_i \in [h_M, h_X]$ work in the RM sector, and those with human capital $h_i \in (h_M, 1]$ migrate and work in the UM sector. In Figure 5b, the migration cost is high; $w^r + C$ first intersects w^u curve's horizontal part at h_N and h_M, with $h_L < h_N < h_M$, and then intersects the upward sloping part of the w^u curve at h_X, with $h_Q < h_X < 1$. As a result, rural residents with human capital $h_i \in [0, h_L)$ work in the RA sector, those with human capital $h_i \in (h_N, h_M)$ migrate and work in the US sector, those with human capital $h_i \in [h_L, h_N]$ and $h_i \in [h_M, h_X]$ work in the RM sector, and those with human capital $h_i \in (h_M, 1]$ migrate and work in the UM sector. There are other possible equilibria which are unrealistic, so they have been ruled out. For example, with extreme low migration cost, $w^r + C$ only intersects w^u curve's horizontal part at h_N, with $h_N < h_L$, and as a result, there are no rural workers in the RM sector. To the contrary, with extreme high migration cost, $w^r + C$ only intersects w^u curve's upward sloping part at h_X, with $h_Q < h_X < 1$, and as a result, there are no rural migrant workers in the US sector.

4 Quantitative analysis

In this section, specific functional forms consistent with model assumptions are used to calibrate the model, using 1986 as a benchmark time, when China started to relax labor mobility restrictions. The calibrated model is then used to simulate the effects of lowering labor mobility constraints on the distribution of labor force, human capital, output and income.

4.1 Calibration

We assume both industrial sectors use Cobb-Douglas production functions with constant returns to scale of the following form:

$$y_i^{jm} = z^{jm} \cdot h_i \cdot (n_i)^{\alpha_j} \cdot \left(k^j\right)^{1-\alpha_j} \qquad (11)$$

where $j = r, u$, and i indexes individual worker. According to Jin and Du (1997)'s estimation of China's rural industry productivity in the 1980s, α_r was roughly equal to 0.5 in 1986.[7] According to Sharma (2007)'s estimation of China's growth accounting during the 1952-1998 period, the output elasticity for labor was about 0.37. Since the rural industry accounted for roughly 1/5 of total industry, $\alpha_u = 1/3$.[8] Thus, we set $\alpha_r = 0.5$ and $\alpha_u = 1/3$.

We assume that human capital in both urban and rural regions follows triangular distributions on the domain $h_i \in [0,1]$. The rural distribution peaks at c^r, and the urban distribution peaks at c^u, with $c^r < c^u$.[9] We standardized c^r at 0.3, with each worker's physical labor, n_i, normalized to 1 in both sectors. z^{rm} and z^{um} are exogenous parameters in our model, and we standardize z^{rm} at 0.2.

The relative price function is assumed as:

$$P = \frac{Y^{um} + Y^{rm}}{A \cdot Y^{a}} \tag{12}$$

Because in 1986, the ratio between the value of manufactured goods and agricultural goods was 1.6 in China, we assume $A = 1.6$.[10]

The wage in the US sector is assumed to be

$$ln\ w^{us} = \gamma ln\ Y^{um} - \eta ln N^{us}.$$

[7] Please refer to Table 3.3 in Jin and Du (1997).

[8] The urban capital share is 0.63 - (0.5·1/5) = 0.53, and the urban labor share is 0.37 - (0.5·1/5) = 0.27. The ratio is roughly 2.

[9] The probability distribution function of a triangular distribution is triangle shaped; it is $2(x - A)/((B - A)(C - A))$ if $A \le x \le C$, and is $2(B - x)/((B - A)(B - C))$ if $C \le x \le B$, where A is the lower limit, B is the upper limit and C is the mode.

[10] In 1986, the shares of agricultural and industrial outputs in overall GDP were 26.9 percent and 43.7 percent, respectively (China Statistical Yearbook 2006).

Using 1986 to 2008 data from the China National Bureau of Statistics, we ran a regression of the equation above, and obtained $\eta = 1.23\gamma$. Accordingly, the wage function is assumed to be:

$$w^{us} = \frac{(Y^{um})^{\gamma}}{(N^{us})^{1.23\gamma}} \tag{13}$$

The aggregate production function of the RA sector is:

$$Y^{a} = (N^{a})^{\alpha} \tag{14}$$

In 1986, the urban labor force was 132.92 million and the rural labor force was 379.90 million. Thus, we assume that $L^{u} = 133$ and $L^{r} = 380$. Capital stock data is not readily available, so we used the standard perpetual inventory approach to estimate the quantity of capital stocks in 1986. There are two sources of investment data from the China National Bureau of Statistics: investment in fixed assets (IFA) and gross fixed capital formation (GFCF). GFCF is a more accurate measure of changes in China's reproducible capital stock, but is not disaggregated into rural and urban regions or different types of investment, whereas the series of IFA data is. So, we assume that the shares of investment in structures and buildings and machinery and equipment in GFCF are the same as IFA, and disaggregate information from the IFA to break down aggregate GFCF into urban and rural GFCFs. The nominal GFCF was converted into real GFCF using an implicit GFCF deflator, and following Bai, Hsieh and Qian (2006), we assumed that the depreciation rate was 8 percent for structures and buildings and 24 percent for machinery and equipment. Since we only need to consider capital stocks in 1986, the choice of initial capital stock in 1952 does not matter much, because of depreciation. We changed the initial capital stock from zero to 175 billion yuan; the rural capital stock in 1986 does not change, while the urban capital stock only increases by one. From our estimation, the urban and rural capital stocks were $K^{u} = 937$ and $K^{r} = 350$.

The RA sector employed 304.68 million workers, which was 60 percent of the total labor force.

$$L^r \int_0^{\bar{h}^r} p^r dh^r = 0.6(L^r + L^u) \quad (15)$$

In urban areas, the industrial sector employed 68.98 million workers, accounting for 52 percent of the urban labor force,

$$\int_{\bar{h}^u}^1 p^u dh^u = 0.52. \quad (16)$$

The total value of industrial output was 1119.4 billion yuan, among which the rural industry contributed 238.08 billion yuan. Therefore, the ratio of urban and rural industrial outputs is 3.7.

$$Y^{um} = 3.7Y^{rm}. \quad (17)$$

In 1986, the labor income per capita in urban and rural China were 1303.19 and 490.27 yuan, respectively, and thus the urban-rural labor income per capita ratio was 2.66.[11]

$$\frac{I^u}{L^u} = 2.66\frac{I^r}{L^r} \quad (18)$$

where $I^u = N^{us} \cdot w^{us} + L^u \int z^{um} \cdot p^u \cdot MPN^{um} dh^u$ and $I^r = N^a \cdot w^a + L^r \int z^{rm} \cdot p^r \cdot MPN^{rm} dh^r$.

The values of the remaining exogenous parameters were calibrated using the equation system containing equations (9), (10), (15), (16), (17) and (18).[12] After solving this system of equations, the exogenous parameter values were $c^u = 0.6867$, $z^{um} = 0.4057$, $a = 0.6091$ and $\gamma = 1.3410$. From the results, we can see that p^u has first-order stochastic dominance over p^r

[11] Labor income per capita = (consumption+savings)/population. Please refer to Table 1 in Guo (2004).

[12] We used this system of six equations to solve for six unknowns. Among them, c^u, z^{um}, a and γ are exogenous parameters, and $\bar{h}^u$ and $\bar{h}^r$ are endogenous variables.

as $c^u > c^r$, and the total factor productivity is higher in the UM sector than the RM sector, as $z^{um} > z^{rm}$. These findings are consistent with model assumptions.

4.2 Simulation

Using the above parameter values and functional forms, the equilibrium outcomes are simulated before and after the removal of labor mobility restrictions. The simulation results are shown in Table 1.

Table 1. Equilibrium simulation outcomes

	Restricted labor mobility	**Unrestricted labor mobility**			**Note**
Parameter values					
(C_F, C_V)		(0.02, 150)	(0.01, 150)	(0.02, 305)	fixed and variable costs of migration
Human capital distribution					
$\bar{h}^u(h_Z)$	0.5741	0.5973	0.5919	0.5877	cut-off levels for urban workers entering the UM sector
h_N		0.5259	0.5185	0.5168	cut-off levels for rural workers entering the US sector
$\bar{h}^r(h_M)$	0.6353	0.5752	0.573	0.5738	cut-off levels for rural workers entering the RM sector
h_X		0.6508	0.6446	0.6468	cut-off levels for rural workers entering the UM sector
Employment and Migration					
N^{um}	69.16	130.1019	133.7278	133.824	employment in the UM sector
N^{us}	63.84	93.1679	94.7334	95.0397	employment in the US sector
N^{rm}	72.2	31.7651	30.3788	30.8884	employment in the RM sector
N^a	307.8	257.965	254.16	253.2479	employment in the RA sector
M^{um}		66.2074	68.5785	67.7172	migration flow to the UM sector
M^{us}		24.0624	26.8827	28.1465	migration flow to the US sector
M^{total}		90.2698	95.4612	95.8637	total migration flow
Outputs and Incomes					
Y^{um}	89.034	113.795	114.329	114.284	output in the UM sector
Y^{us}	21.607	21.531	21.296	21.203	output in the US sector
Y^{rm}	24.063	12.901	12.533	12.668	output in the RM sector
Y^a	32.779	29.436	29.170	29.107	output in the RA sector
$P \cdot Y^a$	70.686	79.184	79.288	79.344	value of output in the RA sector

GDP	205.390	227.411	227.445	227.499	GDP
Y^u/L^u	0.832	1.017	1.020	1.019	urban GDP per capita
Y^r/L^r	0.249	0.242	0.242	0.242	rural GDP per capita
I^u/L^u	0.386	0.258	0.252	0.251	urban labor income per capita
I^r/L^r	0.145	0.202	0.206	0.205	rural labor income per capita
$Gini_L^{ur}$	0.223	0.049	0.041	0.040	urban-rural Gini in labor income
$Gini^{ur}$	0.279	0.336	0.337	0.336	urban-rural Gini in total income
Price level					
P	2.156	2.690	2.718	2.726	relative price of agricultural output

Note: Numbers are from authors' simulation results.

The equilibrium conditions under the restricted labor mobility regime are represented in equations (9) and (10). Column 2 of Table 1 reports the equilibrium outcomes. Workers in the urban region with human capital higher than 0.574 work in the UM sector, which has employment of 69.16 units, or 52 percent of the urban labor force. In the rural region, workers with human capital higher than 0.635 work in the RM sector, which employs 72.2 units of workers. RA employment is 307.8, or 60 percent of the total labor force.

The national GDP is 205.39 units, with the UM and RA sectors contributing the most to GDP in the urban and rural regions, respectively. The per capita labor income of urban residents is 2.66 times of that of rural residents, and the urban-rural Gini coefficient is 0.223 in terms of labor income.

The migration cost function for after the labor mobility restrictions are removed is assumed to be:

$$C(h_i) = c_F + \frac{1}{c_v \cdot (h_i)^2} \tag{19}$$

where c_F is the fixed migration cost and c_v is the parameter in the variable migration cost.[13]

Now, we compare the outcomes of different cost functions to examine the effects of each method of changing migration costs: changing fixed costs and changing variable costs. To make the changes in migration costs comparable, we controlled the total change in migration costs so both methods of decreasing costs have the same effects on the rural worker at the 75th percentile, with human capital of 0.582.[14] The migration cost parameters were chosen such that the costs are relatively low, and the equilibrium conditions are equations (A10), (A11), (A12) and (A13).[15]

Table 1 columns 3, 4 and 5 report simulation results. Column 3 shows the benchmarks under the unrestricted labor mobility regime, and columns 4 and 5 show the results of reducing fixed and variable migration costs. At a relatively high migration cost, $c_F = 0.02$, $c_V = 150$, urban workers with human capital higher than 0.597 work in the UM sector, and the rest work in the US sector. The removal of labor mobility restrictions induces a brain drain effect on the rural labor market: those with human capital less than 0.526 stay in the RA sector, which employs 50.3 percent of the total labor force, those with human capital between 0.526 and 0.575 migrate to the US sector, those with human capital between 0.575 and 0.651 stay in the RM sector, and those with human capital greater than 0.651 migrate to the UM sector. The total migration flow to the urban sectors is 90.27, 73.3 percent of whom enter the UM sector. GDP increases to 227.411, 59.5 percent of which comes from the urban sectors.

[13] The migrating cost function has two parts, with the second term used to approximate non-monetary costs, though "it would be difficult to quantify these costs" (Sjaastad, 1962). Zhao (1999) stated that non-monetary costs are "related to the psychological adjustments that have to be made when changing one's home and work environment".

[14] Our theoretical model predicts that only rural workers with high human capital will migrate. So, we chose rural workers at the 75th percentile to reflect how the two ways of changing migration costs have roughly the same cost effect on the rural workers who actually migrate.

[15] Because of a lack of data, it is difficult to calibrate c_F and c_V. Zhao (1999) showed that, in 1995, the explicit migrant costs amounted to about 30 percent of the earnings difference between rural migrants and farmers. In our simulation, when $c_F = 0.01$ and $c_V = 150$, c_F was 30 percent of the earnings difference between w^{us} and w^a.

Comparing to the restricted labor mobility regime, during the unrestricted regime the output in the UM sector increased the most, because of the increase in labor input. The output in the US sector remained roughly the same, though employment increased by 46 percent. The outputs in both rural sectors decreased, though in the RA sector the value of output increased, because of the 24.8 percent appreciation of agricultural products. Migration enables rural migrants to earn more, which narrows the labor income gap between urban and rural regions. The urban-rural Gini coefficient decreased to 0.049 in terms of labor income, however, when capital income was considered the urban-rural Gini coefficient increased from 0.279 to 0.336.

Results found that the two methods for decreasing migration costs had similar effects, reinforcing the change from the restricted labor mobility regime to an unrestricted regime. Though the total migration flow is about the same in both, it seems that rural workers with lower human capital are more sensitive to changes in variable cost. This may be because the variable cost is already very low for those with high human capital.

In sum, the transition from a restricted labor mobility regime to an unrestricted regime in China increased GDP and overall productivity, through more efficient allocation of human capital and labor. The relaxation of labor mobility restrictions enables rural workers to earn more by migrating, which narrows the urban-rural labor income gap. But, these results come at a cost. The outflow of rural workers causes agricultural output decreases and price increases, and brain drain in the rural labor market also causes a shrink in the RM sector. Furthermore, when taking capital income into consideration, the urban-rural Gini coefficient actually increases, because of the higher returns to capital in the UM sector.

4.3 Welfare Analysis

The removal of labor mobility restrictions results in a redistribution of human capital and labor, as well as output and income. In this subsection, we utilize a simulation to analyze these effects on worker welfare. The migration cost parameters are assumed to be $c_F = 0.01$ and $c_V = 150$. Table 2 shows the results. The welfare effect was found to be positive for all rural workers and negative for all urban workers. Rural workers with high human capital gained the most, and urban workers in the UM sectors hurt the most, due to largest rural migrant influx. Overall, the gain of rural workers outweighed the loss of urban workers, and the welfare effect was positive for the nation as a whole.

Table 2. Welfare change caused by the removal of labor mobility restrictions

Panel A. Workers from rural region

Human capital	0~0.5185	0.5185~0.573	0.573~0.6353	0.6353~0.6446	0.6446~1
Change in occupation	RA→RA	RA→US	RA→RM	RM→RM	RM→UM
# of workers	254.160	26.883	26.757	3.621	68.579
% of workers in local labor force	66.88%	7.07%	7.04%	0.95%	18.05%
Welfare before removal	0.1399	0.1399	0.1399	0.1399~0.1419	0.1419~0.2202
Welfare after removal	0.190	0.190~0.1945	0.1945~0.2156	0.2156~0.2188	0.2188~0.3631
%△ in welfare	35.81%	35.81%~39.03%	39.03%~54.11%	54.11%~54.19%	54.19%~64.90%

Panel B. Workers from urban region

Human capital	0~0.5741	0.5741~0.5919	0.5919~1
Change in occupation	US→US	UM→US	UM→UM
# of workers	63.840	4.011	65.149
% of workers in local labor force	48%	3.02%	48.98%
Welfare before	0.3385	0.3385~0.3489	0.3489~0.5895

removal			
Welfare after removal	0.2248	0.2248	0.2248~0.3798
%△ in welfare	–33.59%	–33.59%~–35.57%	–35.57%

Note: Numbers are from authors' simulation results.

4.4 Comparison of simulation results with real data

Table 3 shows a comparison between the estimated results and the real data. Since migration costs at $c_F = 0.01$ and $c_V = 150$ approximate what the costs were in 1995, we used data from 1995. The estimated results from our theoretical model are close to the real data. The estimated ratio of relative price of agricultural products in 1995 and 1986 are quite similar to the real data (at 1.26 and 1.28, respectively). The estimated ratio of change in manufactured output to change in total output is somewhat lower than the real data (62.4 percent, compared to 76.3 percent from the real data). This is because our theoretical model only focused on the impact of labor mobility restrictions, without considering the growth in capital and technology in the industrial sectors. Our estimated migration rate is somewhat higher than the real data (18.6 percent, compared to 12.9 percent). A possible reason is that our theoretical model did not take permanent migration into account and considered all migration as temporary. The estimated ratio of urban-rural income per capita was slightly higher than the real data (4.22 compared to 3.34). This is because our theoretical model assumed that all returns to capital from the industrial sectors are distributed as income.

Table 3. Comparison between the estimated outcomes and the real data

	Model	Data	Note
$\frac{P^{1995}}{P^{1986}}$	1.26	1.28	ratio of relative price of agricultural products in 1995 to that in 1986
$\frac{\Delta Y^m}{\Delta GDP}$	62.41%	76.30%	ratio of manufactured output change to total output change from 1986 to 1995

$\frac{M^{total}}{N^{total}}$	18.6%	12.9%	migration rate
$\frac{Y^u/L^u}{Y^r/L^r}$	4.22	3.34	ratio of urban income per capita to rural income per capita

Note: Numbers are calculated based on authors' simulation results and data from China statistical yearbook 2006 and first agricultural census.

5 Conclusions

Rural-urban migration is an inherent part of the economic development process. This paper developed a rural-urban migration model with heterogeneous agents, endogenous migration and endogenous labor markets. In the model, heterogeneous workers look for jobs in two regions (urban and rural regions) and across four sectors (urban industrial sector (UM), urban informal sector (US), rural industrial sector (RM), and rural agricultural sector (RA)). In equilibrium, high-ability rural workers will migrate to the UM sector after legal labor mobility constraints are removed, and former farmers with relatively high human capital will migrate to the US sector. The model was then calibrated to analyze the effects of a key component of China's recent economic reform, namely, the gradual removal of labor mobility constraints.

Calibration and simulations of the model suggest that rural-urban migration is a two-edged sword: it increases GDP and total welfare, but also causes a brain drain in rural regions, decreases agricultural production while raising the price of agricultural products, and increases rural-urban income inequality. In addition, not everyone gains equally as a result of the removal of labor mobility restrictions. Results found that rural workers who migrated to the UM sector gained the most, while UM workers suffered the most from the influx of rural migrants. Reducing migration costs reinforces the effect of the removal of labor mobility restrictions.

Although most stylized facts related to China's rural-urban migration can be explained by our model, it has several limitations that point to possible extensions in future research. First, though we mentioned that human capital can be influenced by education, the accumulation of human capital was not explicitly modeled here. Also, better educational resources in the urban region can act as another incentive for rural residents to migrate, as studied in Lucas (2004) and Stark (2004). Second, our model is based on individual decisions instead of family decisions, thus we cannot address the effect of migration on family members, such as the effect of remittances (see Zhao (1999) for a study on migration decisions within rural households). Third, since no unemployment is present in our model, there is no uncertainty. Many economists have presented reasons for unemployment. For example, Harris and Todaro (1970) proposed a random job selection process over an excess labor supply, Cooper (1985) studied involuntary unemployment from asymmetric information, and Andolfatto (2008) analyzed unemployment using a search model. These authors all provide a good basis for incorporating unemployment into the present model.

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Appendices

Appendix A. Mathematical conditions for equilibrium in Figure 4a

Suppose that in equilibrium, h_Z is the human capital of the marginal urban resident who is indifferent between working in the US and UM sectors. From Proposition 2, the equilibrium employment level in each sector is given by:

$$N^a = L^r \int_0^{h_N} p^r(h^r)dh^r \quad \text{(A1)}$$

$$N^{rm} = L^r \int_{h_M}^{h_X} p^r(h^r)dh^r \quad \text{(A2)}$$

$$N^{us} = L^r \int_{h_N}^{h_M} p^r(h^r)dh^r + L^u \int_0^{h_Z} p^u(h^u)dh^u \quad \text{(A3)}$$

$$N^{um} = L^r \int_{h_X}^{1} p^r(h^r)dh^r + L^u \int_{h_Z}^{1} p^u(h^u)dh^u \quad \text{(A4)}$$

The equilibrium outputs in each sector are:

$$Y^a = N^a g(1/N^a) \quad \text{(A5)}$$

$$Y^{rm} = L^r \int_{h_M}^{h_X} f\left(h^r, \frac{K^u}{N^{rm}}\right) p^r(h^r)dh^r \quad \text{(A6)}$$

$$Y^{us} = w^{us} \cdot N^{us} \quad \text{(A7)}$$

$$Y^{um} = L^r \int_{h_X}^{1} F(h^r, \frac{K^u}{N^{um}}) p^r(h^r)dh^r + L^u \int_{h_Z}^{1} F(h^u, \frac{K^u}{N^{um}}) p^u(h^u)dh^u \quad \text{(A8)}$$

The relative price is determined by:

$$P = \rho(\frac{Y^a}{Y^{um} + Y^{rm}}) \quad \text{(A9)}$$

where Y^a, Y^{rm}, and Y^{um} are the equilibrium outputs in the RA, RM and UM sectors, as defined in equation (A5), (A6), and (A8).

In equilibrium, the rural resident with human capital of h_N must be indifferent between working in the RA sector and moving to the US sector:

$$w_N^a = w^{us} - C(h_N) > w_N^{rm}$$

$$P \cdot \mathrm{g}(1/N^{a}) = w^{us}(Y^{um}, N^{us}) - C(h_N) > f_n'\left(h_N, \frac{K^r}{N^{rm}}\right) \qquad \text{(A10)}$$

where $f_n'(\cdot)$ is the partial derivative of the production function in the RM sector with respect to n_i. In equilibrium, the rural resident with human capital of h_M must be indifferent between working in the RM sector and moving to the US sector:

$$w_M^{rm} = w^{us} - C(h_M) > w_M^{a}$$

$$f_n'\left(h_M, \frac{K^r}{N^{rm}}\right) = w^{us}(Y^{um}, N^{us}) - C(h_M) > P \cdot \mathrm{g}(1/N^{a}) \qquad \text{(A11)}$$

In equilibrium, the rural resident with human capital of h_X must be indifferent between working in the RM sector and moving to the UM sector:

$$w_X^{rm} = w_X^{um} - C(h_{\mathrm{X}})$$

$$f_n'\left(h_X, \frac{K^r}{N^{rm}}\right) = F_n'\left(h_X, \frac{K^u}{N^{um}}\right) - C(h_X) \qquad \text{(A12)}$$

where $F_n'(\cdot)$ is the partial derivative of the production function in the RM sector with respect to n_i. In equilibrium, the urban resident with human capital of h_Z is indifferent between working in the US and UM sectors:

$$w_Z^{us} = w_Z^{um}$$

$$w^{us}(Y^{um}, N^{us}) = F_n'\left(h_Z, \frac{K^u}{N^{um}}\right) \qquad \text{(A13)}$$

Because all the equilibrium conditions in equations (A10), (A11), (A12), and (A13) are expressed in terms of a_N, a_M, a_X and a_Z, the equilibrium values are determined by solving the this equation system.

Appendix B. Mathematical conditions for equilibrium in Figure 4*b*

Suppose that in equilibrium, h_Z is the human capital of the marginal urban resident who is indifferent between working in the US and UM sectors. From Proposition 2, the equilibrium employment level in each sector is given by:

$$N^{a} = L^{r}\int_0^{h_L} p^{r}(h^{r})\,dh^{r} \qquad \text{(B1)}$$

$$N^{rm} = L^{r}\left[\int_{h_L}^{h_N} p^{r}(h^{r})dh^{r} + \int_{h_M}^{h_X} p^{r}(h^{r})dh^{r}\right] \qquad \text{(B2)}$$

$$N^{us} = L^{r}\int_{h_N}^{h_M} p^{r}(h^{r})dh^{r} + L^{u}\int_0^{h_Z} p^{u}(h^{u})dh^{u} \qquad \text{(B3)}$$

$$N^{um} = L^{r}\int_{h_X}^{1} p^{r}(h^{r})dh^{r} + L^{u}\int_{h_Z}^{1} p^{u}(h^{u})dh^{u} \qquad \text{(B4)}$$

The equilibrium outputs in each sector are:

$$Y^{a} = N^{a} g(1/N^{a}) \qquad \text{(B5)}$$

$$Y^{rm} = L^{r}\left[\int_{h_L}^{h_N} f\left(h^{r}, \frac{K^u}{N^{rm}}\right) p^{r}(h^{r})dh^{r} + \int_{h_M}^{h_X} f\left(h^{r}, \frac{K^u}{N^{rm}}\right) p^{r}(h^{r})dh^{r}\right] \qquad \text{(B6)}$$

$$Y^{us} = w^{us} \cdot N^{us} \qquad \text{(B7)}$$

$$Y^{um} = L^{r}\int_{h_X}^{1} F(h^{r}, \frac{K^u}{N^{um}}) p^{r}(h^{r})dh^{r} + L^{u}\int_{h_Z}^{1} F(h^{u}, \frac{K^u}{N^{um}}) p^{u}(h^{u})dh^{u} \qquad \text{(B8)}$$

The relative price is determined by:

$$P = \rho\left(\frac{Y^{a}}{Y^{um} + Y^{rm}}\right) \qquad \text{(B9)}$$

where Y^{a}, Y^{rm}, and Y^{um} are the equilibrium outputs in the RA, RM and UM sectors, as defined in equation (B5), (B6), and (B8).

In equilibrium, the rural resident with human capital of h_L is indifferent between working in the RA and RM sectors:

$$w_L^{a} = w_L^{rm}$$

$$P \cdot \mathrm{g}(1/N^{a}) = f_n'\left(h_L, \frac{K^r}{N^{rm}}\right) \tag{B10}$$

where $f_n'(\cdot)$ is the partial derivative of the production function in the RM sector with respect to n_i. In equilibrium, the rural resident with human capital of h_N must be indifferent between working in the RM sector and moving to the US sector:

$$w_N^{rm} = w^{us} - C(h_N) > w_N^{a}$$

$$f_n'\left(h_N, \frac{K^r}{N^{rm}}\right) = w^{us}(Y^{um}, N^{us}) - C(h_N) > P \cdot \mathrm{g}(1/N^{a}) \tag{B11}$$

In equilibrium, the rural resident with human capital of h_M must be indifferent between working in the RM sector and moving to the US sector:

$$w_M^{rm} = w^{us} - C(h_M)$$

$$f_n'\left(h_M, \frac{K^r}{N^{rm}}\right) = w^{us}(Y^{um}, N^{us}) - C(h_M) \tag{B12}$$

In equilibrium, the rural resident with human capital of h_X must be indifferent between working in the RM sector and moving to the UM sector:

$$w_X^{rm} = w_X^{um} - C(h_X)$$

$$f_n'\left(h_X, \frac{K^r}{N^{rm}}\right) = F_n'\left(h_X, \frac{K^u}{N^{um}}\right) - C(h_X) \tag{B13}$$

where $F_n'(\cdot)$ is the partial derivative of the production function in the RM sector with respect to n_i. In equilibrium, the urban resident with human capital of h_Z is indifferent between working in the US and UM sectors:

$$w_Z^{us} = w_Z^{um}$$

$$w^{us}(Y^{um}, N^{us}) = F_n'\left(h_Z, \frac{K^u}{N^{um}}\right) \tag{B14}$$

Because all the equilibrium conditions in equations (B10), (B11), (B12), (B13) and (A14) are expressed in terms of a_L, a_N, a_M, a_X and a_Z, the equilibrium values are determined by solving the this equation system.

Highlights

- We develop a labor mobility model to study rural-urban migration and its effects in China.
- We calibrate the model and simulate the effects of lowering labor mobility barriers.
- We find that rural-urban migration benefits the economy in terms of GDP and total welfare.
- Rural-urban migration causes a brain drain in rural region and widens income gap.
- Rural-urban migration decreases agricultural production and inflates its price.