

Three Essays on Development Economics and Environmental Economics

by

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Abstract

This thesis consists of three independent essays on the fields of development economics and environmental economics. The first two papers use the same theoretical model to explain different issues in developing countries. The third paper studies the effects of population growth on the Environmental Kuznets Curve provided it exists.

China's internal migration plays an important role in explaining its recent economic success. The first paper constructs a model of labor migration, focusing on the role of selection effects in determining labor market outcomes, and then calibrates it to quantify the effects of China's labor market reforms on its outputs and inequality. I show that the removal of internal migration restrictions benefits the economy as a whole, while exacerbating inequality within both rural and urban areas.

The second paper suggests that minimum wage policy may be beneficial for a transitional economy in which labor is migrating from rural areas to urban areas when positive moving costs occur. With a moving cost wedge a modestly binding minimum wage can cause relatively low productivity urban workers to be replaced by higher productivity rural migrants, and therefore increase aggregate output. To achieve the second best outcome, government shall fully compensate the moving costs for the marginal migrant workers who move from the rural industrial sector to the urban subsistence sector and a binding minimum wage shall be imposed on the urban workers but not the migrant workers in the urban industrial sector.

The Environmental Kuznets Curve (EKC) hypothesis postulates an inverted U-shaped relationship between economic growth and many local environmental health indicators. By using an overlapping generations (OLG) model, I focus on technological effects, where the properties of the existing pollution abatement technologies could generate the inverted U-shaped EKC and other forms of growth-pollution paths for the less advanced economies. Moreover, I examine the effects of population growth on the shape of the EKC, provided that it exists. Simulations indicate positive population growth raises the height of the EKC at every level of output per worker; thus, putting an extra burden on environment quality. Empirical evidence from China partially supports the results.

Keywords: Migration; selection; minimum wage; Environmental Kuznets Curve; Technological effects; China

Dedication

I dedicate this dissertation to my family, especially...

To grandma and grandpa, for opening my eyes to the world;

To Dad and Mom, for your inspiration and support;

To Danni and Zeke, for all the time we have spent.

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Chapter 1. China's Internal Migration: A theoretical and Numerical Analysis

1.1 Introduction

China's economy has been the focus of the world in recent decades. Its economy has maintained a very high growth rate, even during the recent worldwide financial crisis. Among the efforts to explain China's achievements, many economists focus on the role of China's internal migration (Zhang and Song, 2004; Du et al, 2005; Au and Henderson, 2006). Barriers to labor mobility throughout the country have been continuously lowered since the beginning of China's economic reform in the early 1980s. Because of the substantial income differential between rural and urban areas, we have observed a flow of migrant workers from poor rural areas to rich urban ones occurring coincidentally with China's economic growth.¹

Until recently, most studies of China's internal migration and growth have been predominantly empirical. Du et al (2005) use data from the China Poverty Monitoring Survey (CPMS) and the China Rural Poverty Survey (CRPS) and find an inverted-U-

¹ China officially relaxed its labor mobility constraints in 1985. By the end of 2008, the number of migrant workers reached 140.41 million while China's real GDP of 2008 was 8.6 times as that of 1985. (China Statistical Yearbook 1986, 2009)

shaped relationship between household endowments and the likelihood of migration.² Whalley and Zhang (2007) calibrate a model with homogeneous labour in which inequality of wages is only supported by domestic migration restrictions. Although these authors offer explanations of their findings, they focus on empirical issues. In this paper, I instead build and calibrate a structural model to examine the effects of China's labor market reforms. The model generates two key predictions that are consistent with observed outcomes in China: (1) China's great success on poverty reduction has been very uneven; and (2) domestic migration enhanced China's inequality in both rural and urban areas.³

My analysis takes place in two main steps: the first is to develop a theoretical model of labor migration with heterogeneous agents, in the tradition of the well-known Roy (1951) model, which focuses on the role of selection effects in determining labor market outcomes. In doing so, my model differs in some important respects from standard analyses of migration and inequality, which are typically based on of the Harris-Todaro (1970) model. In my model, migrants confront no uncertainty concerning their urban prospects. By construction then, all movers gain. Inequality is not caused by the varying fortunes of urban job-seekers, but rather from the interaction of selection and general equilibrium wage effects.⁴

The second key step of my analysis is to follow the tradition of the applied general equilibrium literature in order to quantify the effects of China's labor market

² Du et al (2005) defines endowments as a set of variables consisting of the highest year of education, cultivated land per capita, household size, the share of household members that is laborers, the share of household members that is children, and village dummy variables that capture geographic and other community endowments that affect migration. Fitted income is used as an index of exogenous household endowments in which each endowment is weighted by its relative importance to income generation.

³ Ravallion and Chen (2007) contains an excellent review of China's economy.

⁴ Note, in traditional applications of the Roy model to labor markets, general equilibrium wage effects are abstracted from. See Borjas (1987) for an application of the Roy model to U.S. immigration.

reforms.⁵ I begin by calibrating my model's parameters to match labor market outcomes in China in 1986. The assumption is that this represents the starting date of China's relaxed labor mobility restrictions. I then simulate the effects of enhanced labor mobility by reducing the costs of migration, while holding constant the remaining parameters. I abstract from transition dynamics by assuming that a new steady state was reached by the year 2006. I find that if migration costs are inversely related to skill level, then the combination of selection and general equilibrium wage effects can explain, quantitatively, why we have observed a simultaneous increase in both urban and rural inequality. Loosely speaking, once internal migration restrictions are removed, the most skilled rural workers migrate to urban areas. This exacerbates inequality in rural areas because it makes skilled workers scarce in rural areas, which raises the relative wages of the relatively wealthiest rural residents. At the same time, the influx of rural migrants has a disproportionately negative supply-side effect on the wages of the lower end of the urban skill distribution, driving down the relative wages of the poorest urban residents. Although my model explains the within-area inequality change, it cannot explain observed rising urban-rural inequality. This primarily reflects exogenous disparities in government-directed fixed investment. Because many rural workers move from a low productivity agricultural sector to comparatively high productivity industrial sectors, the removal of migration barriers benefits the whole economy.

The rest of this paper is organized as follows. Section 1.2 briefly reviews necessary institutional background knowledge about China. Section 1.3 contains the model setup and analysis. Section 1.4 provides calibrations and simulations of my model. Section 1.5 discusses some potential policy implications. Section 1.6 concludes, and suggests some potential extensions.

⁵ Shoven and Whalley (1992) contains an overview of this methodology.

1.2 Background

This section introduces necessary institutional background knowledge about China. The facts mentioned below are either consistent with my model assumptions or the model results.

1. Model assumption: urban areas and rural areas have received very uneven capital investment from the central government.

Facts: China's central government adopted a dual-sector development strategy soon after the People's Republic of China was founded in 1949 and land reforms were completed in 1952. Rural areas were only allowed to engage in agriculture, while capital intensive heavy industries were mostly developed in cities. Consequently, China's urban areas and rural areas have received very uneven capital investment from the central government. Meanwhile, most of China's population lived in rural areas especially before economic reform started. By the time economic reform began in 1978, the agricultural sector accounted for less than 12% of total investment but employed about 80% of the total labor force. During the period 1952--1990, the value of industrial sector output increased by 65 times, whereas agricultural sector output increased by only 3 times.⁶

2: Model assumption: urban areas and rural areas have different distributions of human capital.

Facts: Because human capital differences are a key component in my model, and education has significant effects on human capital, we must consider differences between urban and rural areas in the level of education. Table 1.1 indicates this difference in 2000.⁷ Because of existing quality differences between rural and urban

⁶ Numbers are quoted from Yao (1994).

⁷ Data source: Fifth National Census conducted by Statistics China.

education, these numbers likely understate the true difference between rural and urban education.

Table 1.1. Percentage of residents with corresponding highest degree

	Elementary school or lower	Middle school	Post-secondary degree
Urban	16.83	69.20	13.97
Rural	47.62	51.67	0.71

3: Model assumption: physical labor mobility constraints first existed, and then were removed and replaced by institutional and economic barriers.

Facts: To ensure the implementation of its urban-biased investment plan, China's government imposed many restrictions on rural residents. The most famous is the Hukou (residency registration) system, which gives every Chinese her own internal "citizenship". People were forbidden to live and work in an area without government permission if they didn't own local Hukou. Hukou entitled its holders to local access to job opportunities, education and medical resources, and other social benefits which differed significantly between urban and rural areas. China's government began using this system in 1958 to control the movement of people, and it was strictly enforced until the start of the economic reform through regulations which authorized police to detain people and repatriate them to their permanent residency location. Economic reforms created incentives for migration from rural to urban areas. Beginning in the late 1980s, the increased openness of China to the rest of the world triggered another wave of expansion in the industrial sector. The huge demand for labor which resulted made legal restrictions on labor mobility no longer sustainable. The Hukou system officially remained, but its role of physical restrictions was removed. Legal constraints were replaced by institutional and economic barriers. For example, in some cities many job positions are only provided to job-seekers with local Hukous; in other cases firms must

pay the government for permission to hire a worker without local Hukou.⁸ The government officially relaxed this restriction in 1985, allowing people to live in areas in which they did not own local Hukou. However, some conditions still applied. For example, they had to apply for a temporary residency permit from local police. This system underwent further relaxation during the mid-1990s as China pursued entry to GATT (the predecessor of WTO), and promised to further liberalize the movement of labor to speed up its economic reform. In 2003, the laws on custody and repatriation were repealed.⁹ However, even with legal mobility restrictions removed, most welfare benefits are still exclusively provided to residents with local Hukous.

4: Model result: inequality has increased within both rural and urban areas over time.

Facts: Less development combined with a huge population put rural residents in a very disadvantaged position. For example, in 1950, the ratio between urban and rural nominal income per capita was about 2:1. By the time economic reform started in 1978, this ratio had increased to 2.56. By 2007 it had further increased to 3.33.¹⁰ Many economists argue that this ratio is actually underestimated because of allowances and social welfare provided exclusively to urban citizens.¹¹

The Gini coefficients for the whole of China, and for urban and rural areas, were 0.2927, 0.2504, and 0.1712 in 1981, 0.3587, 0.3221, and 0.2319 in 1990, and 0.4419, 0.3637, and 0.3263 in 2004. These facts point to not only a widening gap between urban

⁸ "In Beijing...at least 35 types of jobs would be closed to migrants. Urban employers are also required to pay a per capita fee for each migrant they hire..." See Wang and Zuo (1999).

⁹ Au and Henderson (2006) and Lu (2002) have more detailed descriptions about China's Hukou system.

¹⁰ People's Daily online resource: Special Focus: 3:33 to 1! The gap between urban and rural areas is larger than ever.

¹¹ Naughton (2007): from the mid-1960s until well into the 1990s, urban residents received the following benefits: job security; guaranteed low-price access to food grains, as well as other scarce commodities; health care; a pension and other benefits, including health care, upon retirement; primary and middle school education for their children; low-cost housing, supplied by the work unit.

and rural areas but also to inequality increases within both areas. My model focuses on the growing inequality within the rural and urban sectors. Figure 1.1 illustrates these developments.¹²

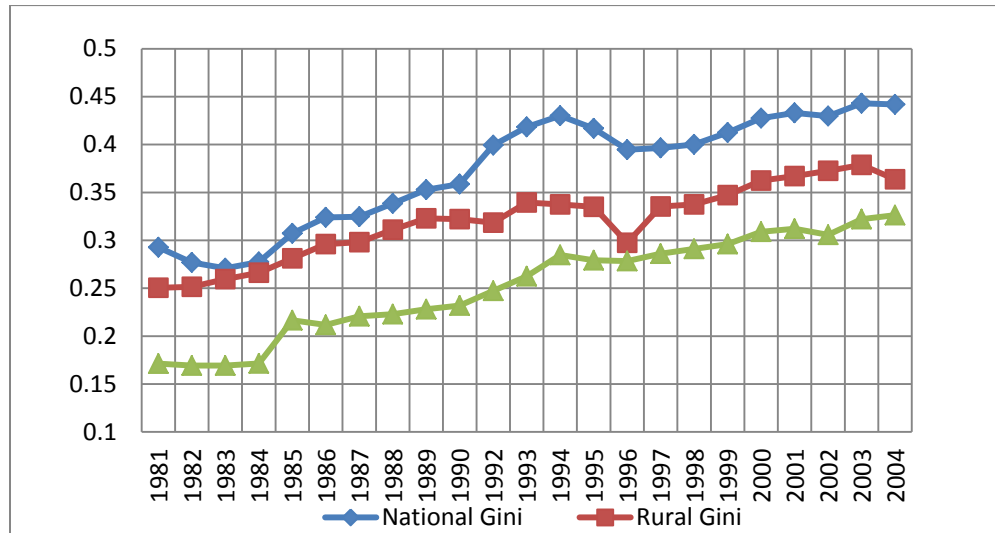


Figure 1.1. The evolution of China's Gini coefficients

5. Model result: migration flows increase with lower labor mobility constraints.

Facts: after legal mobility constraints were abandoned, more and more rural workers left home to work in urban areas.¹³ In 1999, 81% of total migrants and 89% of interprovincial migrants came from inland areas, and most inland migration (72%) was interprovincial.¹⁴ In 1996, the total number of migrant workers from rural areas was 72.22

¹² Numbers are quoted from Table 1 in Cheng (2007).

¹³ We may observe city-to-country migration flow as there are many cities in traditional rural areas and many countries in traditional urban areas in China.

¹⁴ See Zhang and Song (2003).

million. By 2006, this number had increased to 131.81 million.¹⁵ But the demography is changing: in 1996 we observed more migrant workers from eastern China than in central and western China, while 10 years later most migrant workers came from central and western China. Table 1.2 summarizes this information.¹⁶

Table 1.2. Distribution of rural labor force and migration workers

	E.China(96)	E.China(06)	C.China(96)	C.China(06)	W.China(96)	W.China(06)
Rural labor force	224.26	198.28	194.34	145.82	142.25	151.42
Migrant workers	34.04	38.46	23.43	49.18	14.74	40.35
% of migrant workers	15.18	19.40	12.06	33.72	10.36	26.65

6. Model result: rural migrant workers with high human capital move to the urban industrial sector, while those with low human capital move to the urban subsistence sector.

Facts: Another noticeable fact is the disparity in education levels between workers employed in different urban sectors. Zhang and Lei (2008) conducted a survey of 600 migrant workers in white-collar industries in Shanghai. They found that 82.8% had post-secondary degrees. Pan and Sun (2008) looked at a sample of 1200 migrant parent workers in blue-collar industries in Zhejiang province and found that most blue-collar

¹⁵ The First and Second National Agricultural Census, Statistics China (2001, 2008). The Communique of key data from Second National Agricultural Census, Statistics China (2008). Rural labor force refers to rural residents older than 16 who are capable of working; migrant workers refer to those who worked outside their home town for at least one month in 2005.

¹⁶ Numbers are in millions except percentage terms. All numbers are quoted from The First and Second National Agriculture Census conducted by Statistics China.

migrant workers had a middle school degree (82.1%), while only a few had very high or very low degrees.¹⁷ Table 1.3 compares this difference.

Table 1.3. Blue vs. White collar industries: percentage of migrant workers with corresponding highest degree obtained

	Elementary school or lower	Middle school	Post-secondary degree
White-collar	8.0	9.2	82.8
Blue-collar	14.3	82.1	3.6

1.3 Model setup

1.3.1 Model assumptions

There are two regions, rural and urban, and each region has two sectors. Rural areas possess a traditional agricultural (RA) sector and a modern industrial (RM) sector. Urban areas possess an urban modern industrial (UM) sector and an urban subsistence (US) sector. One or more sectors may be inactive at a time. All residents can be identified by a residency registration system. The rural labor force is L_r , and the urban labor force is L_u . Assume each worker possesses some human capital.¹⁸ Initial levels of human capital are determined by nature, while education and job-training yield significant increases. Each worker has his own human capital, a_i which ranges from 0 to 1. The distributions of human capital in the rural and urban populations are $p^r(a)$ and $p^u(a)$. Without differences in access to education, p^r and p^u should presumably be close to each other. However, since education resources are allocated more in urban areas

¹⁷ Those numbers are quoted from Table 1 of Zhang and Lei (2008) and Table 1 of Pan and Sun (2008).

¹⁸ Here human capital is defined as the stock of skill and knowledge embodied in the ability to perform labor, so it can be measured in terms of productivity.

and there are uneven opportunities to access to post-secondary education, p^u is assumed to exhibit first-order stochastic dominance over p^r , as shown in Figure 1.2.

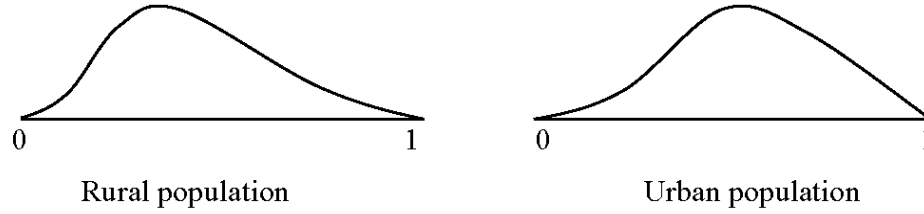


Figure 1.2. Human capital distributions

In the RA sector, labor is considered homogenous, and the production function is:

$$y_a = g(N_a) \quad (1.1)$$

where N_a is total physical labor input. Because land is limited, $g' > 0 > g''$. Farmers are paid at their marginal product of labor and the government takes all the remaining as landowner.

In the industrial sectors, I assume agents produce according to a constant-return-to-scales production functions and are paid their marginal product. Each worker's production function in UM and RM are:

$$y_i^{um} = f(N, a_i, k_u) \quad (1.2)$$

$$y_i^{rm} = h(N, a_i, k_r) \quad (1.3)$$

where a_i is the human capital possessed by worker i , and N is the physical labor input of each worker, which is normalized to 1. f and h differ in terms of productivity and resource-intensity. I assume that UM sector has higher productivity and its technology is more capital intensive. Note that I assume total capital investment in both industrial sectors is equally distributed among the workers, $k_u = K_u/L_u$ and $k_r = K_r/L_r$. The marginal product of labor, MPN_i , is increasing with a_i and k as capital and labor are

partially complements. Government allocation of investment between sectors is assumed to be exogenous and $K_u > K_r$. Manufactured goods are homogeneous.

The relative price between agricultural goods and industrial goods, P , clears the market. Manufactured goods are defined as the numeraire. The price function is:

$$P = \rho\left(\frac{y_a}{y_m}\right) \quad (1.4)$$

with $\rho'(\cdot) < 0$ and where y_a is the output of RA sector and y_m is the output of manufacturing sector.¹⁹ Since the manufacturing sector is only set up in the urban area, y_m equals the output of UM.

This starting point is designed to mimic a planned economy. There is no physical investment in rural areas, and labor mobility is strictly prohibited. Modern industry is confined to urban areas, and rural areas can only engage in traditional agriculture (i.e., rural areas only have an RA sector and urban areas only have a UM sector).

1.3.2 Restricted labor mobility

The timing of this stage corresponds to the start of economic reform, during which labor mobility was still restricted, but workers could choose freely between local job options. In rural areas, the RM sector is developed with some exogenous physical investment, which is nonetheless much less than in urban areas. Farmers are allowed to leave the RA sector, but can only work locally. Because RM has lower productivity and less physical capital per capita than UM, its MPN is smaller than in UM at any given level of human capital.

¹⁹ One possible way to endogenize it is to assume homogeneous preference over both agricultural and industrial goods (e.g. Cobb-Douglas). Given a relative price level, the consumption ratio is constant, and should be proportional to the ratio of outputs when the market clears. Thus relative price is negatively related to the ratio of outputs. Please refer to Appendix 1.A.

Inequality appears after career options are allowed, because higher human-capital workers earn no less than workers with less human capital. The equilibrium can be derived as follows: rural workers can choose to be farmers or enter the RM sector. In the RM sector, each worker produces y_i^{rm} and gets paid her MPN . As N is normalized to 1, her total income is:

$$w_{rm} = MPN^{rm}(a_i, k_r) \quad (1.5)$$

$MPN^{rm}(a_i, k_r)$ is an increasing function of both a_i and k_r which implies workers with more

human capital are more likely to work in the RM sector. Career decisions of rural workers are analyzed by comparing incomes from each sector. In equilibrium, the worker who is indifferent between working in RA or RM must possess human capital \bar{a}_r , which is determined by:

$$Pg'(N_a) = MPN^{rm}(\bar{a}_r, \frac{K_r}{N_{rm}}) \quad (1.6)$$

where $N_a = L_r \int_0^{\bar{a}_r} p^r(a_r) da_r$ is employment in the RA sector, $N_{rm} = L_r \int_{\bar{a}_r}^1 p^r(a_r) da_r$ is employment in the RM sector and K_r is the exogenous capital investment in rural areas. P is the relative price given by:

$$P = \rho\left(\frac{y_a}{y_{rm} + y_{um}}\right) \quad (1.7)$$

where the outputs of RA and RM sectors are:

$$y_a = g(L_r \int_0^{\bar{a}_r} p^r da_r) \quad (1.8)$$

$$y_{rm} = L_r \cdot \int_{\bar{a}_r}^1 h(\cdot) p^r da_r \quad (1.9)$$

and y_{um} is defined in equation (1.13). Therefore, rural workers with more human capital than \bar{a}_r choose to work in the local industrial sector.

In urban areas, the US sector emerges at this stage to employ workers who are not productive enough to enter the UM sector. In the US sector, workers provide

services for people in the UM sector. Such work ranges from domestic employment to low-skill positions in industry. In the UM sector the worker with the least human capital must be indifferent between entering UM or US. Assume her human capital is \bar{a}_u . Her wage if she works in UM is:

$$w_{um} = MPN^{um}(\bar{a}_u, k_u) \quad (1.10)$$

where $k_u = K_u/N_{um}$ is the exogenous physical investment per capita, and $N_{um} = L_u \int_{\bar{a}_u}^1 p^u(a_u) da_u$. w_{um} is an increasing function of \bar{a}_u .

In the US sector, I assume all workers work independently with a linear production function. Total output is:

$$y_{us} = w_{us} \cdot N_{us} \quad (1.11)$$

where N_{us} is employment in US, which is a function of \bar{a}_u . In this sector, everyone gets paid at w_{us} . Because w_{us} is affected by total income of the people in UM (demand) and the labor supply in US (supply), the US wage function is:

$$w_{us} = w(y_{um}, N_{us}) \quad (1.12)$$

with $w'(y_{um}) > 0$ and $w'(N_{us}) < 0$.

Output of the UM sector is:

$$y_{um} = L_u \cdot \int_{\bar{a}_u}^1 f(\cdot) p^u da_u \quad (1.13)$$

It is a function of \bar{a}_u , as is w_{us} . More specifically w_{us} is a decreasing function of \bar{a}_u , because skill doesn't matter in US. Therefore a unique value of \bar{a}_u can be inferred from the equilibrium condition:

$$w_{um}(\bar{a}_u) = w_{us}(\bar{a}_u) \quad (1.14)$$

A real root can be ensured provided that $w_{um}(\bar{a}_u = 1) > w_{us}(\bar{a}_u = 1)$ and $w_{um}(\bar{a}_u = 0) < w_{us}(\bar{a}_u = 0)$.

Now both rural and urban areas have two sectors: rural agricultural sector (RA), rural modern industrial sector (RM), urban modern industrial sector (UM) and urban subsistence sector (US). The equilibrium allocations of labor are depicted in Figure 1.3.

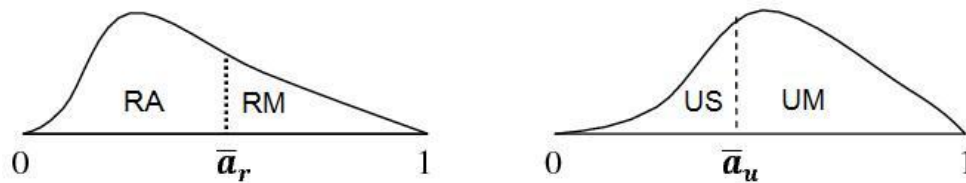


Figure 1.3. Occupation allocations without labor mobility

Wages are non-negatively related to a worker's human capital. In rural areas, workers' wages are identical as long as their human capital is less than \bar{a}_r . A rural worker's income is increasing with her human capital if she works in RM. High-ability people in rural areas who can work in local industry are better off since their incomes are higher than before. The remaining farmers suffer from relatively low marginal product of labor and low income. In urban areas, workers with more human capital are better off because there is more physical capital to work with when low productivity workers choose to leave the industry. Workers who are now in the US sector receive comparatively lower income, and are worse off. Inequality emerges within both urban and rural areas.

1.3.3 Unrestricted labor mobility

As economic reform progresses and legal barriers to domestic migration are removed, rural workers are legally allowed to move to cities. Economic and institutional constraints now replace the previous legal constraints, which makes moving costly.²⁰ That is, moving now becomes an economic decision. The cost of moving to big cities is

²⁰ Because migrant workers only work in urban area and they need to visit their family in rural area, the moving costs are assumed to be incurred each period.

not just pecuniary, but also includes loneliness, discrimination from urban residents, safety issues, etc.²¹ Assuming high-skilled people adapt to a new environment faster, the cost of moving is modeled as a decreasing function of a_i . The moving cost is also affected by the locations of rural areas, traffic conditions, and other factors. The effect of different locations and/or traffic conditions of rural areas on the migration decision is shown below in figure 1.5c. In this paper I assume human capital is the key determinant, and assume the cost of moving is $C(a_i)$ with $C'(\cdot) < 0$.²²

When a rural worker considers moving, she compares the benefits of moving to the cost. By assuming that a higher wage is the benefit she would earn if working in an urban area, her net benefit function is:

$$B(a_i) = w(a_i) - C(a_i) \quad (1.15)$$

I assume that $w_{um}(1) - C(1) - w_{rm}(1) > 0$, i.e.

$$f'_N \left(1, K_u / (L_u \int_{\bar{a}_u}^1 p^u da_r) \right) - C(1) - h'_N \left(1, K_r / (L_r \int_{\bar{a}_r}^1 p^r da_r) \right) > 0 \quad (1.16)$$

to make sure that at least the highest ability rural worker obtains a net benefit from moving to the UM sector. Because working in UM yields higher wages, rural workers consider their qualifications for positions in this sector first, given the same moving cost, if they decide to move. Employment in the urban industrial sector is now composed of urban workers and migrant rural workers.

²¹ Sjaastad (1962) breaks down the moving cost into money and non-money 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".

²² Zhang and Lei (2008) point out that there are four components in social integration for a Chinese domestic migrant: cultural integration, mental integration, identity integration and economic integration. They also construct an empirical model to test the determinants on social integration by using data on 600 new migrants to Shanghai. The coefficient of schooling years is 0.89 which implies migrants with higher education levels integrate into a new society faster.

Proposition 1.1: The migration flow to the UM sector is inversely related to the moving costs.

Proof. The rural worker moving to UM with the least human capital, a_X , must be indifferent between the benefits from staying in the rural sector and the wages earned in the UM sector. Employment in the UM sector includes urban workers and migrant workers which are:

$$N_{um} = L_u \int_{a_z}^1 p^u(a_u) da_u \quad (1.17)$$

$$N_X = L_r \int_{a_X}^1 p^r(a_r) da_r \quad (1.18)$$

where a_z is the least human capital possessed by an urban worker who stays in UM. A migrant worker from rural areas with a_X must satisfy:

$$w_X^{um} - w_X^{rm} = C(a_X) \quad (1.19)$$

where w_X^{um} is the income of the rural migrant worker with a_X who moves to UM which equals $MPN^{um}(a_X, K_u/(N_X + N_{UM}))$ and w_X^{rm} is the income of the same worker who stays in RM which is $MPN^{rm}(a_X, K_r/N_Y)$ and N_Y is the employment in RM:

$$N_Y = L_r \int_{a_Y}^{a_X} p^r(a_r) da_r \quad (1.20)$$

where a_Y is the least human capital possessed by a rural worker who stays in RM after some leave. We know that $C(a_X) > 0$ and $C'(a_X) < 0$ thus the RHS of equation (1.19) is a decreasing function on a_X . In LHS:

$$\frac{d(w_X^{um})}{d(a_X)} = MPN_{a_X}^{um} + MPN_{k_u}^{um} \cdot \frac{d(k_u)}{d(a_X)}$$

where $k_u = K_u/(N_X + N_{UM})$ and all terms are positive which implies w_X^{um} is an increasing function of a_X .

$$\frac{d(w_X^{rm})}{d(a_X)} = MPN_{a_X}^{rm} + MPN_{k_r}^{rm} \cdot \frac{d(k_r)}{d(a_X)}$$

where $k_r = K_r/N_Y$. We have $MPN_{a_X}^{rm}$ and $MPN_{k_r}^{rm}$ as positive terms but $d(k_r)/d(a_X)$ is negative. Therefore w_X^{rm} may increase or decrease with a_X . But as UM is assumed to always be attractive to high ability workers, w_X^{rm} increases slower than w_X^{um} . Therefore the LHS of equation (1.19) is an increasing function of a_X . Figure 1.4 depicts the information embodied in equation (1.19).

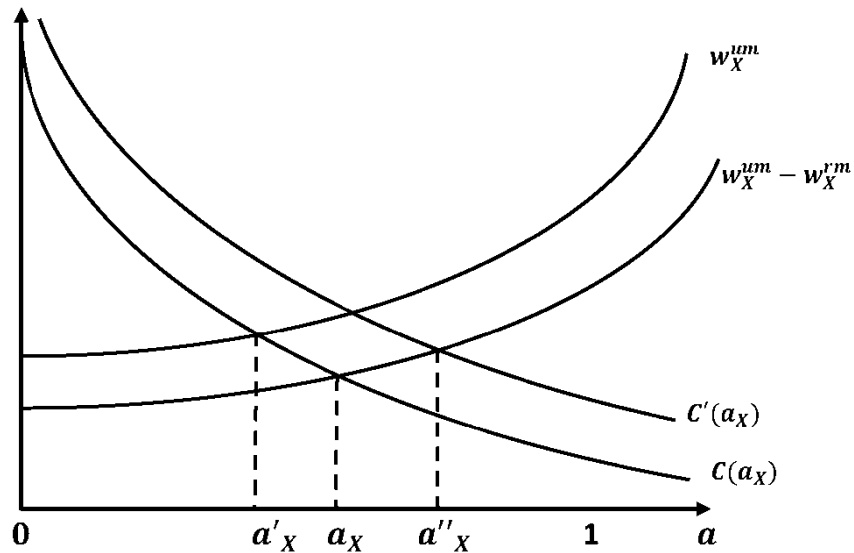


Figure 1.4. Equilibrium human capital thresholds

Intuitively, institutional and economic barriers increase the cost of moving, and local job options faced by rural workers increase the benefit of staying. Therefore, they work in the same direction on labor mobility. The equilibrium human capital of the last rural worker who would move to UM is a_X , where $w_X^{um} - w_X^{rm}$ intersects $C(a_X)$. If labor mobility across areas was allowed without setting up RM, a_X is determined by $w_X^{um} - w_a = C(a_X)$ which ends up at lower a'_X .²³ More rural workers would flow into UM. On the other hand, if the government imposes extra restrictions on the requirements of urban

²³ a_X is the wage earned by farmers which is no higher than w_X^{rm} .

job positions for rural workers, it pushes up the cost curve to $C'(a_X)$. Consequently more rural workers would stay in rural areas. Therefore, the government has multiple tools to control migration to the UM sector.

Not every job seeker is qualified to have a job in the UM sector. Many of them have to work in US. As described in Cole and Sanders (1985), US consists of "those urban employment categories that feature very low levels of productivity and earnings". US can absorb all labor which wants to work in it, thus there is no unemployment for migrant workers. This is the key difference from Harris and Todaro (1970). All US workers are assumed to be paid at w_{us} . Even though w_{us} is less than the wage earned in UM, the fact that people do stay in the city and don't go back indicates that it is still greater than the potential wage when working in rural areas. The wage difference provides the incentive for some rural workers to move to cities, even if only to get a position in US.

Proposition 1.2: There is a lower limit, $a_N \in (0,1)$, and an upper limit, $a_M \in (0,1)$, with $a_M > a_N$, on human capital with which rural workers move to the US sector. Only the rural workers with human capital between a_N and a_M move to the US sector.

Proof. Rural workers heading to the US sector must satisfy the following condition:

$$w_{us} \geq w_r + C(a_i) \quad (1.21)$$

where w_{us} and $C(a_i)$ are defined the same as before, and w_r is the wage when staying in rural areas. It may be the wage from either RA or RM, because either farmer or worker, or both, may consider moving to US. But because w_{us} is the lowest wage for the workers in UM, only those who cannot go to UM will think about going to US.

Because $C(a_i)$ is a decreasing function of human capital, w_r is a non-decreasing function of human capital and w_{us} is the same for every worker in US, Figure 1.5 illustrates the situation in which rural workers would move to US.²⁴

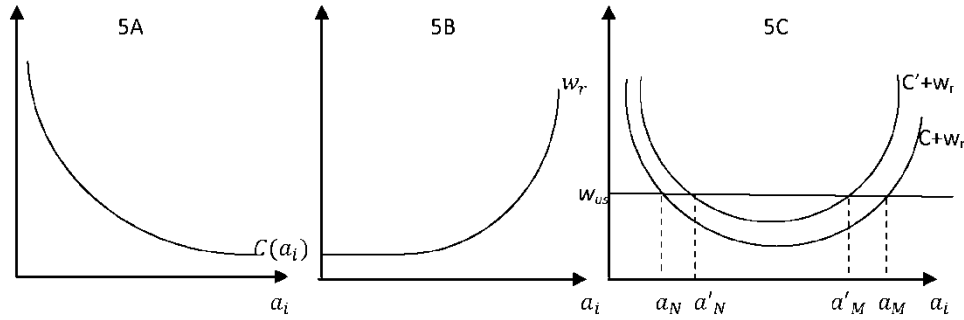


Figure 1.5. Heading to the US sector

Figure 1.5c shows that there exists an upper limit, a_M , and a lower limit, a_N , of human capital for which rural workers would move to US. It implies we would not observe extreme types of rural people in US. Those rural workers with human capital close to a_M who work in RM, but who are not skilled enough to find a job in UM sector, they can take advantage of affordable moving costs to earn higher wage in US. On the other hand, for those rural workers with human capital close to a_N who are paid much less, the wage in US will be attractive in spite of high moving costs. Figure 1.5c also indicates that a higher moving cost discourages rural workers from moving to the US sector, and so we observe more homogeneity among migrant workers in the US sector than which is induced by a lower moving cost.

²⁴ The combination of a decreasing C function plus a non-decreasing w_r function may bring about another result: overall effect is always decreasing if C dominates. The U-shaped curve also can be very asymmetric if C is much flatter than w_r . Provided w_{us} is greater than the minimum point of $w_r + C$, these two cases end up with only one intersection. In the first case, all highly skilled rural workers have an incentive to move to US; in the second case, all less smarter rural workers will move to US. These two are not consistent with the data.

Another application of figure 1.5c is to analyze migration differences between rural areas. We know that most of China's developed areas are located in the eastern and southern coastal regions, while most of its less-developed areas are located in the central and western regions. Intuitively, the moving cost for a rural worker from a county close to developed cities is lower than for someone living far away from them, assuming all other factors are the same---for example, a rural worker from Anhui province vs. a rural worker from Qinghai province---therefore, given the same wage earned in urban areas, we would observe less migration from those rural areas located far away from big cities.

Proposition 1.3: *Two different equilibrium scenarios may appear in rural areas after rural workers move to urban areas. Rural workers with human capital in excess of a_N move to the US sector. The workers with less human capital than a_N could enter RM or stay in RA. These two scenarios are depicted in Figure 1.6.*

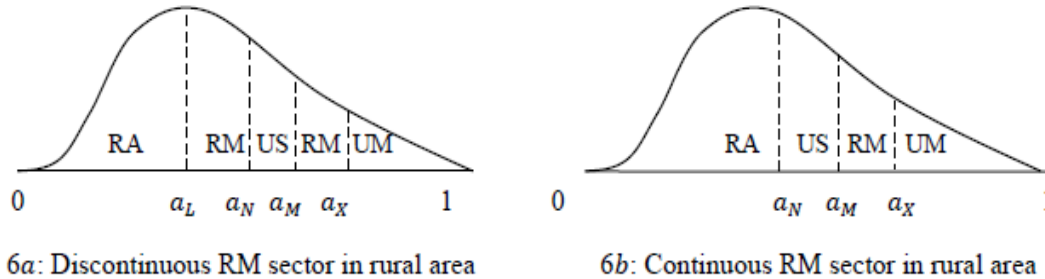


Figure 1.6. Career distribution in the rural region

The mathematical conditions for these two scenarios are showed in Appendices B and C. The intuition is as follows. Fewer rural workers move to the urban US sector when moving costs are high. This scenario is shown in Figure 1.6a. From figure 1.5c, a_N in Figure 1.6a is greater than a_N in Figure 1.6b which has lower moving costs. It implies a higher wage if the one on the boundary works in RM. This provides room for rural workers with human capital slightly less than a_N to earn higher wages in RM than staying in RA after some rural workers move to US. The rural workers with human

capital higher than a_L can enter RM after those with human capital between (a_N, a_M) , move to US. The departure of some RM workers increases the physical capital per capita for the remaining RM workers, which encourages more farmers to enter RM. Therefore we can observe two groups of human capital within which rural workers are in RM: (a_L, a_N) and (a_M, a_X) . The values of a_N , a_M and a_X identify the moving populations and their occupational choices. In rural areas, people with human capital between a_N and a_M move to US, while those with human capital greater than a_X go to the UM sector. Because people only move when they can obtain higher utility, the rural migrant workers and those former farmers who move to RM are better off. Because the supply of labor in US increases, it reduces wages in this sector, making the pre-existing urban poor worse off.

More rural workers can afford to move to the US sector when moving costs are low. This scenario is shown in Figure 1.6b. The marginal worker staying in rural areas possesses less human capital than when moving costs are high. Because of the low human capital endowments, of those who remain in rural areas, after those with human capital (a_N, a_M) move to cities, investment cannot support wages in RM higher than those obtained by farming. In rural areas, people with skills lower than a_N work in the agricultural sector. People with human capital between a_N and a_M move to US. Those with human capital between (a_M, a_X) stay in RM and those with human capital greater than a_X will go to the UM sector. All rural workers with greater human capital than a_N are better off. But because the supply of labor in the US sector increases more than in the first case, it reduces incomes in this sector.

1.4 Quantitative analysis

In this section, I use specific functional forms that are consistent with the previous assumptions in order to calibrate my model using 1986 as a benchmark for when China removed its labor mobility constraints. I then use the calibrated model to simulate the effects of lowering labor mobility constraints on the aggregate level and distribution of China's output. The labor allocation thresholds $(a_r, a_N, a_M, a_X, a_Z)$ are the

model's key endogenous variables. The values of free parameters are either based on observed data ($L_u, L_r, K_u, K_r, \alpha_u, \alpha_r, \beta_u, \beta_r, A$), standardized (c_r, z_{rm}, z_a) or derived from theories which are consistent with the data (c_u, z_{um}, a, γ).

1.4.1 Parameters and functions

In 1986, the urban labor force was 132.92 million, while the rural labor force was 379.90 million. The labor force ratio was 1:2.87. The RA sector employed 304.68 million workers, which was 60% of total labor force. In urban areas, the industrial sector employed 68.98 million workers, while non-industrial workers numbered 63.94 million. The total value of industrial output was 1119.4 billion Yuan, among which rural industry contributed 238.08 billion Yuan. Total investment in urban areas was 211.945 billion Yuan, while rural investment was 82.017 billion Yuan. The investment ratio was 2.68. In 1986, the incomes per capita in urban and rural China were 1303.19 and 490.27 Yuan.²⁵ Accordingly, I assume that $L_u = 133$, $L_r = 380$, $K_u = 212$ and $K_r = 82$.²⁶ This information is summarized in Table 1.4.

Table 1.4. Facts and parameters

	Urban sector	Rural sector	Parameter or fact to match
Labor force	132.92 million	379.90 million	$L_u = 133, L_r = 380$
Industrial employment	68.98 million	75.22 million	UM employs 52% of urban labor force
Non-industrial employment	63.94 million	304.68 million	RA employs 60% of total labor force
Investment	211.945 billion	82.017 billion	$K_u = 212$ and $K_r = 82$
Industrial output	881.32 billion	238.08 billion	The output ratio is 3.7
Income per capita	1303.19	490.27	The income ratio is 2.66:1

²⁵ The income per capita = (total consumption+savings)/population. Please refer to table 1 in Guo (2004).

²⁶ Because there is no data on China's capital stock across periods, I use investment flow to approximate capital stock. I understand we need very strong economic assumptions to do this approximation, such as assuming the depreciation rate, δ , is very high close to 1 so as $K=I/\delta$ at steady state.

I assume human capital in both urban and rural areas follows a triangular distribution on the domain $a \in (0,1)$. The rural distribution peaks at c_r , and the urban distribution peaks at c_u .²⁷

The manufacturing sector uses a Cobb-Douglas production function:

$$y_{im} = z_{im} \cdot a_i \cdot N^{\alpha_i} \cdot k_i^{\beta_i} \quad (1.22)$$

RM is more labor intensive and has less value-added than UM.²⁸ Moreover Jin and Du (1997) estimated the productivity of China's rural industry in the 1980s. In 1986, capital incomes and total wages were 24.50 and 24.18 billion Yuan, thus α_r is roughly equal to β_r .²⁹ Given a CRTS production function, they are both assumed to be 0.5. Sharma (2007) estimates a Cobb-Douglas production function along with a time trend to capture the effect of technological progress after the reforms in 1978 using a cointegration and Error-Correction modeling framework for the 1952-1998 period. He found that the output elasticity for labor was about 0.37 under the assumption of constant returns to scale for all of China. Since rural industry accounted for roughly 1/5 of total industry, $\alpha_u = 1/3$ and $\beta_u = 2/3$.³⁰ z_{rm} and z_{um} are free parameters in my model. Each worker's physical labor, N , is normalized to 1 in both sectors.

The relative price function is derived in Appendix 1.A:

$$P = \frac{y_{um} + y_{rm}}{A \cdot y_a} \quad (1.23)$$

²⁷ The pdf of a triangle distribution is triangle shaped and it is $2(x - A)/((B - A)(C - A))$ if $A \leq x \leq C$ and it is $2(B - x)/((B - A)(B - C))$ if $C \leq x \leq B$ where A is the lower limit, B is the upper limit and C is the mode.

²⁸ Zen (2002) suggested that China's rural industry is more labor intensive, has a lower added-value and large bulk.

²⁹ Please refer to Table 3.3 in Jin and Du (1997).

³⁰ The urban capital share is $0.63 - (0.5 \cdot 1/5) = 0.53$ and the urban labor share is $0.37 - (0.5 \cdot 1/5) = 0.27$. The ratio is roughly 2.

Because in 1986 the ratio between the value of industrial goods and agricultural goods was about 1.62 in China, I assume $A = 1.6$.³¹

The wage in US sector is assumed to be $\ln w_{us} = \gamma \ln y_{um} - \eta \ln N_{us}$. Using data from 1986 to 2008, I ran a regression of $\ln \Delta y_{um}$ on $\ln(\Delta N_{us})$ and $\ln(\Delta w_{us})$ and have $\eta = 1.23\gamma$.³² Accordingly, the wage function is assumed to be:

$$w_{us} = \frac{(y_{um})^\gamma}{(N_{us})^{1.23\gamma}} \quad (1.24)$$

The production function of RA is:

$$y_a = z_a \cdot N_A^a \quad (1.25)$$

Total labor incomes of urban and rural areas are:

$$IU = N_{us} \cdot w_{us} + L_u \int z_{um} \cdot p^u \cdot MPN_{um} da_u \quad (1.26)$$

$$IR = N_{RA} \cdot w_a \cdot p + L_r \int z_{rm} \cdot p^r \cdot MPN_{rm} da_r \quad (1.27)$$

The values of free parameters are calibrated using the equation system containing equation (1.6) and (1.14) along with the following four equations.

$$L_r \int_0^{a_r} p^r da_r = 0.6(L_r + L_u) \quad (1.28)$$

$$\int_{a_z}^1 p^u da_u = 0.52 \quad (1.29)$$

$$y_{um} = 3.7y_{rm} \quad (1.30)$$

$$\frac{IU}{L_u} = 2.66 \frac{IR}{L_r} \quad (1.31)$$

³¹ In 1986, the shares of agriculture and industry were 26.9% and 43.7%. (China Statistical Yearbook 2006)

³² The coefficients of $\ln(\Delta N_{us})$ and $\ln(\Delta w_{us})$ are 1.23 and 0.71 with P-values 1.49E-08 and 8.90E-06. Adjusted R² is 0.9494.

Equation (1.28) and (1.29) are matching the facts in China's labor market as shown in Table 1.4. Equation (1.30) reflects the 1986 output ratio between UM and RM. Equation (31) reflects income disparity in 1986. Notice, however, we have 9 unknowns, $c_r, c_u, a_r, a_z, z_{rm}, z_{um}, z_a, a$ and γ , which is more than the number of equations. As my model is a comparison study between China's urban and rural areas, based on the results of my experiments I assign the values to rural parameters: $c_r = 0.3$ and $z_{rm} = 0.2$.³³ Moreover, as the value of z_a doesn't affect the outcomes except y_a and p , I normalize its value to 1. After solving this system of equations, the values of the free parameters are: $c_u = 0.6867$, $z_{um} = 0.4057$, $a = 0.6091$ and $\gamma = 1.3410$. From the results, we see that p^u has first-order stochastic dominance over p^r as $c_u > c_r$. Also UM has better TFP as $z_{um} > z_{rm}$. They are both consistent with the assumptions.

1.4.2 Restricted labor mobility

Using the above parameter values and functional forms, the equilibrium outcomes at the time when the labor mobility constraints are removed are shown in Table 1.5.

Table 1.5. Equilibrium outcomes: restricted labor with career options

a_z	a_r	y_{um}	y_{rm}	y_a	P	MPN^{RA}	w_a	w_{us}	N_{rm}	N_{um}	N_{ra}
0.5741	0.6353	43.095	11.647	32.779	1.0438	0.0649	0.0677	0.1638	72.2	69.16	307.8

In urban areas, workers with human capital higher than 0.5741 enter UM, and the UM employment is 69.16, which is 52% of urban labor force. In rural areas, workers with human capital higher than 0.6363 enter RM and the RM employment is 72.2 million. The RA sector employs 307.8 million, which is 60% of the total labor force. The farmers' income is 0.0677. As the capital available to every RM worker is 1.136, even the most

³³ To standardize the values of c_r and z_{rm} , they must bring about real roots to the equation system; those real roots and parameters must be consistent with all assumptions; and the values should be simple.

efficient worker in RM can only make 0.1066. The wage in the US sector is 0.1638. The total labor incomes in rural and urban sectors are 26.66 million and 24.82 million respectively and the labor incomes per capita in rural and urban sectors are 0.0702 and 0.1866 respectively.

1.4.3 Unrestricted labor mobility

Because workers are now free to move between labor markets, all variables are pooled into one equation system. The moving cost function is assumed to be:

$$C(a) = c_F + \frac{1}{c_V \cdot a^2} \quad (1.32)$$

where c_F is the fixed moving cost.³⁴

I compare outcomes with different cost functions to examine the effects of different ways of changing the moving costs. One way is to change the fixed cost and the other way is to change the variable cost. In the real world, the former is possible by directly reducing the head fees on migrant workers; the latter can be done by denouncing negative reports of living and working environments in urban areas.³⁵ I substitute the specific functions into the system including equation (1.C10), (1.C11), (1.C12) and (1.C13). Table 1.6 reports the equilibrium outcomes given different cost parameters.³⁶

³⁴ The moving cost function has two parts. The second term is used to approximate non-money costs, though "it would be difficult to quantify these costs" (Sjaastad (1962)).

³⁵ Zhao (1999) stated that the costs are "related to the psychological adjustments that have to be made when changing one's home and work environment..."

³⁶ 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 amount to about 30% of the earnings difference between migrants and rural nonfarm workers. In my simulations, when $c_F = 0.01$ and $c_V = 150$, c_F is 31.2% of the earnings difference between w_{us} and w_a .

Table 1.6. Equilibrium outcomes: unrestricted labor with career options

c_F, c_V	a_Z	a_N	a_M	a_X	y_{um}	y_{rm}	y_a
0.02, 150	0.6351	0.5594	0.5931	0.6774	58.74	6.63	30.58
0.01, 150	0.6313	0.5499	0.5994	0.6730	62.73	6.20	30.27
0.02, 205	0.6290	0.5531	0.5963	0.6771	60.18	6.49	30.37
0, ∞	0.6111	0.5214	0.6111	0.6654	73.65	5.33	28.95
c_F, c_V	w_a	$MPN_{a_N}^{rm}$	$MPN_{a_M}^{rm}$	$MPN_{a_X}^{rm}$	$MPN_{a_X}^{um}$	$MPN_{a_Z}^{um}$	w_{us}
0.02, 150	0.0906	0.0877	0.0930	0.1062	0.1407	0.1319	0.1319
0.01, 150	0.0971	0.0924	0.1007	0.1130	0.1377	0.1292	0.1292
0.02, 205	0.0935	0.0887	0.0957	0.1086	0.1393	0.1294	0.1294
0, ∞	0.1198	0.1005	0.1198	0.1305	0.1305	0.1198	0.1198
c_F, c_V	P	N_{RA}	N_{rm}	N_{um}	N_{us}	M_{UM}	M_{US}
0.02, 150	1.336	274.62	33.34	111.37	93.64	56.49	15.52
0.01, 150	1.423	270.04	29.08	113.86	100.03	58.06	22.83
0.02, 205	1.372	271.55	31.85	112.98	96.62	56.61	19.98
0, ∞	1.706	250.93	21.33	121.43	119.31	60.76	46.97

I begin with high moving costs $c_F = 0.02$, $c_V = 150$. The urban workers with human capital higher than 0.6351 enter UM, and the rest go to US. In rural areas, workers are divided into four groups: workers with human capital less than 0.5594 stay in RA, and its proportion of the total labor force drops from 60% to 53.53%; workers with human capital between 0.5594 and 0.5931 move to the US sector; rural workers with human capital between 0.5931 and 0.6774 stay in RM; while workers with human capital greater than 0.6774 move to UM. The migration flows to UM and US are 56.49 million and 15.52 million, respectively. US wage is 0.1319 while the wages in RM range from 0.0930 to 0.1062.

The two ways of decreasing moving cost yield different results.³⁷ In the case of changing the fixed moving cost, c_F drops to 0.01, while c_V remains at 150. This stimulates migration flows to UM and US, which increase by 2.7% and 47.14% respectively. The US workers are worse off, since the US wage decreases by 2.05% to 0.1292. In the case of changing the variable moving cost, c_V changes to 205 while c_F remains at 0.02. This affects the migrations to UM and US to differently: the migration flow to UM increases very little (by 0.23% to 56.62), while the migration flow to US increases significantly (by 28.79% to 27.22). The effect on a_Z depends on the migration flows to both UM and US: the migration of workers to UM pushes urban workers out of UM, but migration to US decreases the wage, thus inducing more urban workers to go back to UM. In my simulations, the first effect is dominant, so that more urban workers join US as a_Z decreases from 0.6351 to 0.6313 and to 0.6290. When the fixed moving cost decreases, rural workers with a_N equal to 0.5499 earn 0.0972 in RA. This is higher than the wage of workers who enter RM, which is 0.0924. When the variable cost increases, rural workers with a_N , which is equal to 0.5430, earn 0.0935 in RA. Again, this is higher than the wage of workers who enter RM at 0.0887. Therefore, no farmers would move to RM after former RM workers move to urban areas. These two cases are both equilibrium outcomes.

The last case, with $c_F = 0$ and $c_V = \infty$, implies no moving cost across the country. In this condition, people with the same amount of human capital would earn the same wage. If the workers' human capital is not sufficiently high to make the owner enter the industrial sector, workers will stay in either the RA or US sectors, and wages will be 0.1198 for both. The migration flow to UM is 60.76, which is only slightly higher than that for the two cases above, while the migration flow to US will increase dramatically to 46.97---more than double that of the other two cases. Therefore, with a decreasing moving cost we would expect that more rural workers would move to the US sector, rather than to the UM sector.

³⁷ I control the moving cost so that both ways of decreasing moving cost have the same effects on the median rural worker with human capital of 0.4226.

The impact of removing the labor mobility constraints on the aggregate economy is shown in Tables 1.7 and 1.8. The price of industrial goods is normalized to 1. Moreover, y_a , y_m and y_{us} are the values of outputs of the agricultural sector, the industrial sector and the US sector, respectively. The value of y_a is the product of the agricultural output and the price level. When labor is prohibited from moving, the total output is 99.41. The effects of reducing the moving costs on the output values are shown in Table 1.7.

Table 1.7. The effects on output

	y_a	y_m	y_{us}	Total value	% change
Restricted Labor	34.21	54.74	10.46	99.41	
$c_F=0.02, c_V=150$	48.85	65.37	12.35	118.57	19.27%
$c_F=0.01, c_V=150$	43.08	68.93	12.92	124.93	25.67%
$c_F=0.02, c_V=205$	42.67	66.67	12.50	120.83	21.55%
$c_F=0, c_V=\infty$	49.37	78.98	14.30	142.65	35.78%

With regards to the change of inequality, I compare the income of workers with human capital equal to 0.8 with that of the majority in each area. This illustrates the intra-area inequality change, and by calculating the Gini coefficient, the inter-area inequality change based on labor incomes is shown. The changing inequality situations are summarized in Table 1.8.³⁸

³⁸ Because I lack data about the number of capital owners, I assume the ratio between the incomes of capital owners and US workers is r , given that the income is equally distributed among capital owners. A reasonable range of r would be around 1, as equality of payments was part of China's planned economy.

Table 1.8. The effects of removing labor constraint on inequalities

Income	Rural inequality change			Urban inequality change			Gini
	$\alpha_r=0.8$	farmer	ratio	capital	US worker	ratio	
Restricted Labor	0.0853	0.0677	1.26	28.73	0.1638	r	0.2871
$c_F=0.02, c_V=150$	0.1662	0.0906	1.83	39.16	0.1319	1.69r	0.1344
$c_F=0.01, c_V=150$	0.1637	0.0972	1.68	41.82	0.1292	1.85r	0.1127
$c_F=0.02, c_V=205$	0.1646	0.0935	1.76	40.11	0.1294	1.77r	0.1136
$c_F=0, c_V=\infty$	0.1569	0.1198	1.31	49.10	0.1198	2.34r	0.0463

In rural areas, when labor is immobile, workers with $a = 0.8$ earns 1.26 times more than farmers. After labor becomes mobile, when $c_F = 0.02$ and $c_V = 150$, the rural workers move to UM and the gap increases to 1.83. In urban areas, when labor is immobile, workers with $a = 0.8$ earns 1.39 times more than the US workers. After labor becomes mobile, the gap decreases to 1.26. The inequality seems to be better in urban areas. This result changes when we consider the capital owners' income. The total income of capital owners, when labor is immobile, is 28.73, but after labor is free to move their incomes rise dramatically to 39.16. The gap between incomes is thus 1.69 times wider, which is the main reason for the inequality increase in urban areas. Although we observe higher inequality within both rural and urban areas after labor becomes mobile, the overall situation is better in terms of labor income. The Gini coefficient, based only on labor income, was 0.2871 with labor restrictions, while the value decreased to 0.1344, 0.1127, 0.1136 and 0.0463, respectively. This suggests that labor income is not the main reason for social inequality in China.

Because $c_F = 0.01$ and $c_V = 150$ approximate the moving costs in 1995, Table 1.9 compares the model output and data for the same year.³⁹ Moreover, the table

³⁹ To be consistent with the parameter in 1986, when computing I_U/I_R , income per capita = (total consumption + savings)/population. The data on migration is from the first agricultural census conducted in 1996.

compares the first order difference between 1986 and 1995, indicating the contribution made by lowering labor mobility constraints to the changes in China's economy.

Table 1.9. Comparison between the model and data

	1. $\Delta(\frac{N_a}{N_{total}})$	2. $\Delta(\frac{N_m}{N_{total}})$	3. $\Delta(\frac{N_{us}}{N_{total}})$	4. $\frac{M_{total}}{N_{total}}$	5. $\frac{P_{1995}}{P_{1986}}$
Model	-7.4%	0.3%	7.1%	21.3%	1.36
Data	-8.0%	1.1%	6.9%	12.9%	1.28
	6. $\frac{\Delta y_a}{\Delta y_{total}}$	7. $\frac{\Delta y_m}{\Delta y_{total}}$	8. $\frac{\Delta y_{us}}{\Delta y_{total}}$	9. $\frac{I_U}{I_R}$	10. Gini
Model	34.74%	55.59%	9.67%	1.47	0.1127
Data	8.85%	76.30%	14.85%	3.34	0.4169

Because output of the US sector is measured by industrial goods, I adjust the data by applying the industry price index to the service sector. Model predictions for the labor market are close to the data, except for the prediction of a higher migration rate (21.3%). Model predictions for output changes are slightly different from the data. Besides the significant changes in labor force, capital investment, technology, and many other fundamentals that are beyond my static model, have also changed. Another important explanation for the difference is the price scissors used by China's government to manually set relatively lower prices for agricultural goods.⁴⁰ Although no well-accepted measurement is available for the distorted relative prices in China, the data indicate that relative prices increased by 59% from 1978 to 1990. Given that the effect of price scissors persists in China, it would be reasonable to assume that the relative price was less than 40% of the market price at the beginning of economic reform. If 40% is accurate, the model outputs of 6, 7, and 8 in Table 9 are 17.56%, 70.23% and 12.21%, respectively. If the relative price was 20%, model outputs become 9.62%, 76.99% and 13.39%, respectively, which are very close to the data. Moreover, we can see that the urban-rural labor income disparity shrinks in my model, while in the real world the gap

⁴⁰ Please refer to Lin and Yu (2009) for more information about the evolution of price scissors in China.

between income of urban residents and rural residents becomes wider. By looking at the Gini coefficient, we can also conclude that the labor-income gap between the two areas is smaller after the labor market opens, and thus labor income is not the main source of social inequality. Many economists have tried to explain the urban-rural income disparity from different perspectives. For example, Yang (1999) argues that "urban biased policies and institutions, including labor mobility restrictions, welfare systems, and financial policies of inflation subsidies and investment credits to the urban sector, are responsible for the long-term rural-urban divide and the recent increases in disparity".

1.4.4 Welfare Change

After removing the labor mobility constraint, a redistribution of the labor force occurs in both rural and urban areas, as shown in Figure 1.7. Table 1.10 shows the effects of removing the labor mobility constraint on incomes of rural workers and urban workers. The moving costs are assumed to be $c_F = 0.01$ and $c_V = 150$, the same as in Table 1.9.

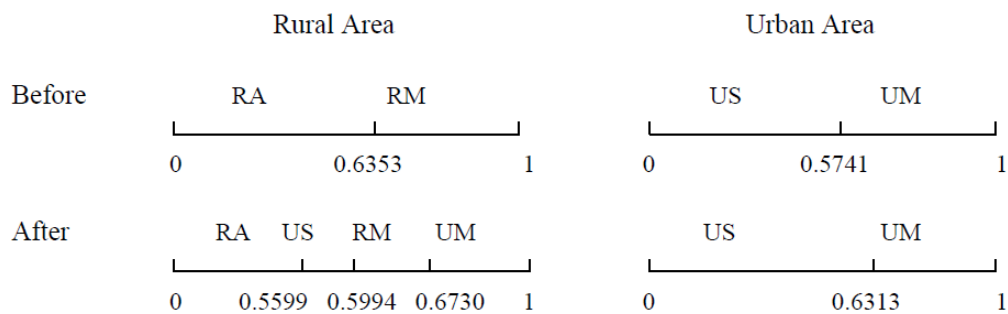


Figure 1.7. Career distributions before and after the labor mobility constraint is removed

Table 1.10. Welfare change after the labor mobility constraint is removed

Rural workers human capital (millions of workers, % in local labor force)					
	0-0.5499 (270.04, 71.06%)	0.5499-0.5993 (22.83, 6.01%)	0.5993-0.6353 (14.93, 3.93%)	0.6353-0.6730 (14.15, 3.72%)	0.6730-1 (58.05, 15.28%)
Before	0.0677	0.0677	0.0677	0.0677-0.0717	0.0717-0.1066
After	0.0972	0.0972-0.1007	0.1007-0.1067	0.1067-0.1130	0.1130-0.1880
% Δ	43.52	43.52-48.67	48.67-57.59	57.59	57.59-76.40
Urban workers human capital (millions of workers, % in local labor force)					
	0-0.5741 (63.84, 48.00%)	0.5741-0.6313 (13.36, 10.05%)	0.6313-1 (55.80, 41.96%)		
Before	0.1638	0.1638-0.1802	0.1802-0.2854		
After	0.1292	0.1292	0.1292-0.2047		
% Δ	-21.12	(-28.27)-(-21.12)	-28.27		

Table 1.10 shows the positive effects of the free labor market on the welfare of rural workers, and the negative effects on the welfare of urban workers. Even though all urban workers are hurt by the removal of the labor mobility constraint, rural workers gain far more than the urban workers' losses. Farmers gain the least if they stay in RA. The rural workers who move to the UM sector gain the most, and the previous urban UM workers are hurt the most.

1.5 Policy implication

The removal of the labor mobility constraints would help China's economic growth at the cost of inequality. If the government aims to balance the trade-off between economic growth and inequality, it must determine the optimal labor mobility constraints for rural workers. From my calibrations, removal of the labor mobility constraints would have positive effects on the development of the whole economy, though the effects

would be very uneven. Low moving constraints allow more rural workers to move to the urban sectors, thus hurting the RA outputs. The urban sectors would expand after the moving barrier is lowered, but the urban workers would be worse off because both w_{us} and k_u would decrease. Even though a low barrier of moving would hurt the rural sectors, it would benefit the rural workers. Moreover, the overall inequality would be better off in terms of wage incomes. Removal of labor mobility constraints would help the development of the whole economy, and the decreasing gap between urban and rural workers' incomes would come at the cost of the urban workers' living standards.

The government can use policies to affect different components of the moving cost. The fixed cost could be changed by directly reducing the head fees on migrant workers, or directly subsidizing their transportation costs or accommodation costs, etc. The variable cost could be increased by denouncing negative reports of the living and working conditions in urban areas, which are more related to the "psychological adjustments". The different ways of changing the moving costs would have different effects on the economy, because a uniform extra moving cost would have a stronger negative effect on all types of rural workers, compared to changing the variable cost, which would have a greater effect on the low-ability rural workers. The increased negative effect on all types of rural workers would have a negative impact on both types of migration flows, while the greater effect on the less efficient rural workers would have stronger effect on flow to US than to UM. Even though both ways of changing the moving costs would lead to changes in the total economy, the decrease in fixed cost would lead to a greater increase. Since both ways have similar effects on inequality, controlling the fixed moving cost would be better, in terms of developing the real sectors. Another advantage of controlling the fixed moving cost is from its precision as a result of being measurable, unlike the variable moving cost which is difficult to accurately quantify.

Because China still had 36 million rural poor population by 2010, how to help them out of poverty is very important for China's economic development.⁴¹ Although my model results suggest that rural workers are better off with the removing of labor mobility constraints, the outputs of rural sectors are hurt, given the same investment profile. It implies that the increase in rural incomes comes mainly from the expansion of the urban sectors. This increase is vulnerable to the constraints on labor mobility. Therefore, how can we help the rural poor and shrink the gap between the rural and urban areas sustainably?

Investing more in rural education is crucial for changing the distribution of human capital in the rural population. With better education, more rural people would be qualified for industrial positions, which would stimulate the rural economy and income per capita. Still, much time would be needed to see an effect. Another, more efficient way to affect rural growth is to directly and constantly increase investment in the RM sector. This would increase the demand for rural workers and increase their incomes. Moreover, as shown in my model, the US sector is a channel for redistributing total social wealth, implying that a more complete service business should be developed in both rural and urban areas to make the channel smoother. More rural workers with low human capital should be involved in developing the rural service (RS) sector. Typically, the transfer of most production lines to rural areas would take advantage of the low labor cost. To help more of the rural poor in the agricultural sector, more advanced technologies must be introduced to increase MPN, or a large amount of labor must be released from the agricultural sector. The released labor can then be absorbed either domestically or internationally. Domestically, labor-intensive industries could be encouraged, such as the hand-made craft sector that requires no/low physical investment. Furthermore, the government could remove some rural people from the rural economy, for example, by recruiting more soldiers from the rural areas. Internationally, the government should actively contact countries that have a shortage of labor and

⁴¹ The number is quoted from China's Human Resource, by State Council Information Office of PRC.

export labor to them, since the labor export would give domestic workers more job opportunities.

1.6 Conclusion

This paper develops a model with heterogeneous agents, endogenous internal migration, and endogenous labor markets, and calibrates it to analyze the effects of a key component of China's recent economic reform, namely, the gradual removal of internal labor mobility constraints, on its economic development and inequality issues within the country's urban and rural areas. Because China's government adopted an urban-biased investment strategy, investment decisions are assumed to be exogenous in the model. This paper primarily focuses on intra-regional inequality. The model features heterogeneous workers who look for jobs in two regions (urban and rural areas) and across four sectors (urban modern industrial sector (UM), urban subsistence sector (US), rural modern industrial sector (RM), and rural traditional agricultural sector (RA)). In equilibrium, high-ability rural workers go to the UM sector, while workers who stay in the RM sector may come from two discontinuous groups. All workers who are between the two groups have an incentive to move to the US sector after the legal labor mobility constraints are removed. The heterogeneity of labor increases inequality in both rural and urban regions, even though many rural residents are better off than before. Calibrations show the positive contribution from allowing domestic migration on developing the whole economy, even though the effects are very uneven. The calibrations also suggest an enhancement of inequality within both rural and urban areas. Among the various ways of helping the rural poor, investing more in education, increasing capital investment in rural areas, developing the RS sector, and finding other channels to absorb the abundant rural labor force would all be suitable strategies for promoting the sustainable growth of China's rural economy.

Although most stylized facts related to China's internal migration can be explained from my model, it has several weaknesses that point to possible extensions in future research. Firstly, the economy in my model is assumed to fully follow market

principles. In the real world, however, China is still transitioning from a planned economy to a market economy, though it has already changed from a closed economy to a large open economy during the process of marketization.⁴² For example, my model does not capture the price distortion occurring at the beginning of China's economic reform or some features of an open economy.⁴³ Second, my model is static, while in reality people think not only about their current benefits but also about their future welfare. Also, this static model cannot explain the urban-rural inequality change. Third, though I mention that human capital can be influenced by education and job training, I do not assume options for the agents to accumulate human capital. Because urban areas have better education resources, another incentive is present for rural workers to move. Such issues are studied in Lucas (2004). Fourth, since no unemployment is present, no uncertainty exists in my model, which is not entirely consistent with the actual China's economy. 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 by using a search model. These authors all provide good hints on how to incorporate unemployment into the present model.

⁴² China began its economic reform in 1979 and declared its market economy in 1992. As of February 2008, China's market economy status has not yet been recognized by the US or the EU, though it has been recognized by 77 other countries.

⁴³ The price scissors between industrial goods and agricultural goods existed in China until 1992 when the country declared itself as a market economy. See Lin and Yu(2009).

1.7 References

- Andofatto, D., 2008. Search Models of Unemployment. *The New Palgrave Dictionary of Economics*, 2nd edition.
- Au, C., Henderson, J., 2006. How Migration Restrictions Limit Agglomeration and Productivity in China. *Journal of Development Economics*. 80(2), 350--388.
- Borjas, G., 1987. Self-Selection and the Earnings of Immigrants. *The American Economic Review*. 77, 531--553.
- Cheng, Y., 2007. The Evolution of China's Gini Coefficient and Its Decomposition Between Urban and Rural Areas After Economic Reform (in Chinese: Gaige Yilai Chengxiang Zhongti Gini Xishu de Yanbian Jiqi Chengxiang Fenjie). *China's Social Science (Zhongguo Shehui Kexue)*. 4.
- Cole, W., Sanders, R., 1985. Internal Migration and Urban Employment in the Third World. *The American Economic Review*, 75(3), 481--494.
- Cooper, R., 1985. Worker Asymmetric Information and Involuntary Unemployment. *Journal of Labor Economics*. 3(2), 188--208.
- Du, Y., Park, A., Wang, S., 2005. Migration and Rural Poverty in China. *Journal of Comparative Economics*. 33, 688--709.
- Guo, X., 2004. A New Estimation of the Income Gap Between Rural and Urban Areas (in Chinese: Chenxiang Shouru Chaju de Xinguiji). *Shanghai Economic Study (Shanghai Jinji Yanjiu)*. 12.
- Harris, J., Todaro, M., 1970. Migration, Unemployment and Development: A Two-sector Analysis. *The American Economic Review*. 60(1), 126--142.
- Jin, H., Du, Z., 1997. Productivity of China's Rural Industry in the 1980's. *Chinese Economics Research Center (CERC) working papers*. 1997-06.
- Kung, J., Lin, Y., 2007. The Decline of Township-and-village Enterprises in China's Economic Transition. *World Development*. 35(4), 569--584.
- Krusekopf, C., 2002. Diversity in Land-tenure Arrangements Under the Household Responsibility System In China. *China Economic Review*. 13, 297--312.
- Lin, J., Yu, M., 2009. The Political Economic Analysis of China's Price Scissors: Theory Model and Empirical Evidence (in Chinese: Wogou Jiage Jiandaocha de Zhengzhi Jingjixue Fenxi: Lilun Moxin Yu Jiliang Shizheng). *Economic Study (Jingji Yanjiu)*, 1, 422--456.
- Lu, Y., 2002. China's Hukou System After 1949: Structure and Evolution (in Chinese: 1949 Nian Hou De Zhonggou Huji Zhidu: Jiegou Yu Bianqian). *Journal of Peking University (Beijing Daxue Xuebao)*. 2.

- Lucas, R., 2004. Life Earnings and Rural-Urban Migration. *Journal of Political Economy*. 112(1), S29--S59.
- Naughton, B., 2007. *The Chinese Economy: Transitions and Growth*. MIT Press. Cambridge.
- Pan, X., Sun, G., 2008. A Survey and Analysis on the Education of the Children of Migrant Workers (in Chinese: Jincheng Mingong Zinu Jiating Jiaoyu De Diaocha Yu Fenxi). *Journal of the Party School of CPC Hangzhou (Zhonggong Hangzhou Shiwei Dangxiao Xuebao)*. 4.
- Ravallion, M., and Chen, S., 2007. China's (uneven) progress against poverty. *Journal of Development Economics*. 82, 1--42.
- Roy, A.D., 1951. Some Thoughts on the Distribution of Earnings. *Oxford Economic Papers*. 3, 1352--146.
- Sharma, H., 2007. Sources of Economic Growth in China, 1952-1998. *Issues in Political Economy*, 17.
- Shoven, J., and Whalley, J. 1992. *Applying General Equilibrium*. Cambridge University Press.
- Sjaastad, L., 1962. The Costs and Returns of Human Migration. *The Journal of Political Economy*. 70(5), 80--93.
- Wang, F., Zuo, X., 1999. Inside China's Cities: Institutional Barriers and Opportunities for Urban Migrants. *The American Economic Review*. 89, 276--280.
- Whalley, J., Zhang, S., 2007. A Numerical Simulation Analysis of (Hukou) Labour Mobility Restrictions in China. *Journal of Development Economics*. 83, 392--410.
- Yang, D., 1999. Urban-Biased Policies and Rising Income Inequality in China. *The American Economic Review*. 89(2), 306--310
- Yao, S., 1994. *Agricultural Reforms and Grain Production in Rural China*. Palgrave Macmillan.
- Zen, F., 2002. On the Interaction of Urbanization and Industry Structure (in Chinese: Lun Chengshihua Yu Chanye Jiegou De Hudong Guanxi). *Economic Review (Jingji Zhongheng)*, 10.
- Zhang, K., Song, S., 2003. Rural--urban Migration and Urbanization in China: Evidence from time-series and cross-section analyses. *China Economic Review*. 14, 386--400.
- Zhao, Y., 1999. Labor Migration and Earnings Differences: The Case of Rural China. *Economic Development and Cultural Change*. 47(4), 767--782.

Zhang, W., Lei, K., 2008. The Analysis of the Structure, Status Quo and Determinants of a New Urban Migrant's Social Integration (in Chinese: Chengshi Xinyimin Shehui Ronghe). Sociology Study (Shehuixue Yanjiu). 5.

1.8 Appendices

Appendix 1.A: relative price formation

Assume the homogeneous utility function over agricultural and industrial goods is:

$$U(x_A, x_M) = x_A^a x_M^b \quad (1.A1)$$

With different income levels m_i and a normalized price of industrial goods, the optimal consumption of each person is:

$$x_A^* = \frac{q}{a+b} \frac{m_i}{P} \quad (1.A2)$$

$$x_M^* = \frac{b}{a+b} m_i \quad (1.A3)$$

We have:

$$\frac{x_A^*}{x_M^*} = \frac{a}{b \cdot P} \quad (1.A4)$$

To clear the market, x_A^*/x_M^* must equal y_a/y_M which gives us:

$$P = \frac{a}{b} \left(\frac{y_a}{y_M} \right)^{-1} \quad (1.A5)$$

Generalizing it I assume the relative price forming function as equation 1.4.

Appendix 1.B: mathematical equilibrium in figure 1.6a

Mathematically, employment levels in the urban sectors, N_{US} and N_{UM} are defined as:

$$N_{US} = L_r \int_{a_N}^{a_M} p^r(a_r) da_r + L_u \int_0^{a_Z} p^u(a_u) da_u \quad (1.B1)$$

$$N_{UM} = L_r \int_{a_X}^1 p^r(a_r) da_r + L_u \int_{a_Z}^1 p^u(a_u) da_u \quad (1.B2)$$

Because some previous farmers would move to RM, the employment levels in rural areas now change. Now a farmer with human capital a_L is indifferent between working in RA or RM, and the employment levels in RA and RM are:

$$N_{RA} = L_r \int_0^{a_L} p^r(a_r) da_r \quad (1.B3)$$

$$N_{RM} = L_r \int_{a_L}^{a_N} p^r(a_r) da_r + L_r \int_{a_M}^{a_X} p^r(a_r) da_r \quad (1.B4)$$

The relative price, P , is defined as:

$$P = \rho\left(\frac{y_a}{y_{um} + y_{rm}}\right) \quad (1.B5)$$

where y_a , y_{rm} and y_{um} are defined as:

$$y_a = g(N_{RA}) \quad (1.B6)$$

$$y_{rm} = L_r \int_{a_L}^{a_N} h\left(a_r, \frac{K_u}{N_{RM}}\right) p^r da_r + L_r \int_{a_M}^{a_X} h\left(a_r, \frac{K_u}{N_{RM}}\right) p^r da_r \quad (1.B7)$$

$$y_{um} = L_r \int_{a_X}^1 f\left(a_r, \frac{K_u}{N_{UM}}\right) p^r da_r + L_u \int_{a_Z}^1 f\left(a_u, \frac{K_u}{N_{UM}}\right) p^u(a_u) da_u \quad (1.B8)$$

At equilibrium, the rural worker with a_L must be indifferent between farming and working in RM; that is:

$$h'_N\left(a_L, \frac{K_r}{N_{RM}}\right) = P \cdot g'(N_{RA}) \quad (1.B9)$$

For the rural worker with a_N who is indifferent between working in RM and US:

$$h'_N\left(a_N, \frac{K_r}{N_{RM}}\right) = w_{us}(y_{um}, N_{US}) - C(a_N) \quad (1.B10)$$

For the rural worker with a_M who is indifferent between working in RM and US:

$$h'_N\left(a_M, \frac{K_r}{N_{RM}}\right) = w_{us}(y_{um}, N_{US}) - C(a_M) \quad (1.B11)$$

For the rural worker with a_X who is indifferent between working in RM and UM:

$$h'_N \left(a_X, \frac{K_r}{N_{RM}} \right) = f'_N \left(a_X, \frac{K_u}{N_{UM}} \right) - C(a_X) \quad (1.B12)$$

For the urban worker with a_Z who is indifferent between working in US and UM:

$$w_{us}(y_{um}, N_{US}) = f'_N \left(a_Z, \frac{K_u}{N_{UM}} \right) \quad (1.B13)$$

With the expression of P which is shown in equation B5, the equation system with equation B9, B10, B11, B12 and B13 determines the values of a_L , a_N , a_M , a_X , a_Z . To make extra labor enter RM, at equilibrium the solutions must satisfy:

$$h'_N \left(a_N, \frac{K_r}{N_{RM}} \right) \geq P \cdot g'(N_{RA}) \quad (1.B14)$$

Appendix 1.C: mathematical equilibrium in figure 1.6b

N_{RM} is the employment in RM:

$$N_{RM} = L_r \int_{a_M}^{a_X} p^r(a_r) da_r \quad (1.C1)$$

The wage of farmers is:

$$w = P \cdot g'(N_{RA}) \quad (1.C2)$$

where P is the relative price which is determined by:

$$P = \rho \left(\frac{y_a}{y_{um} + y_{rm}} \right) \quad (1.C3)$$

where y_a , y_{rm} , and y_{um} are the equilibrium outputs of RA, RM and UM sectors, which are defined in equation 1.C7, 1.C8, and 1.C9.

The employment levels of RA, US and UM are:

$$N_{RA} = L_r \int_0^{a_N} p^r(a_r) da_r \quad (1.C4)$$

$$N_{US} = L_r \int_{a_N}^{a_M} p^r(a_r) da_r + L_u \int_0^{a_Z} p^u(a_u) da_u \quad (1.C5)$$

$$N_{UM} = L_r \int_{a_X}^1 p^r(a_r) da_r + L_u \int_{a_Z}^1 p^u(a_u) da_u \quad (1.C6)$$

The outputs of RA, RM and UM are:

$$y_a = g(N_{RA}) \quad (1.C7)$$

$$y_{rm} = L_r \int_{a_M}^{a_X} h\left(a_r, \frac{K_u}{N_{RM}}\right) p^r da_r \quad (1.C8)$$

$$y_{um} = L_r \int_{a_X}^1 f\left(a_r, \frac{K_u}{N_{UM}}\right) p^r da_r + L_u \int_{a_Z}^1 f\left(a_u, \frac{K_u}{N_{UM}}\right) p^u(a_u) da_u \quad (1.C9)$$

The rural worker with a_N must be indifferent between working in agricultural and US; that is:

$$P \cdot g'(N_{RA}) = w_{us}(y_{um}, N_{US}) - C(a_N) \quad (1.C10)$$

The rural worker with a_M must be indifferent between working in RM and US; that is:

$$h'_N\left(a_M, \frac{K_r}{N_{RM}}\right) = w_{us}(y_{um}, N_{US}) - C(a_M) \quad (1.C11)$$

The rural worker with a_X must be indifferent between working in RM and UM; that is:

$$h'_N\left(a_X, \frac{K_r}{N_{RM}}\right) = f'_N\left(a_X, \frac{K_u}{N_{UM}}\right) - C(a_X) \quad (1.C12)$$

The urban worker with a_Z must be indifferent between working in US and UM; that is:

$$w_{us}(y_{um}, N_{US}) = f'_N\left(a_Z, \frac{K_u}{N_{UM}}\right) \quad (1.C13)$$

Because my employment functions and output functions are all of a_N , a_M , a_X and a_Z , the equilibrium values are determined by solving the equation system containing 1.C10, 1.C11, 1.C12, and 1.C13. To make no extra labor enter RM, at equilibrium the solutions must satisfy:

$$h'_N\left(a_N, \frac{K_r}{N_{RM}}\right) \leq P \cdot g'(N_{RA}) \quad (1.C14)$$

Chapter 2. The Economic Effects of Minimum Wage Policy

2.1 Introduction

Nowadays minimum wage policy has been popularly used in both developed and developing countries, even though it serves different purposes. As pointed out by Watanabe (1976), developed countries intend to use minimum wages to provide an acceptable living standard for their marginal workers, while developing countries intend to use minimum wages to adjust their social inequalities. It is commonly agreed that minimum wages increase unemployment and reduce output when workers are homogenous and labor markets are perfectly competitive in the presence of perfect information. Absent these restrictive assumptions, however, many economists draw different conclusions. For example, some have shown that minimum wages might be Pareto optimal if the labor market is not competitive (Boal & Ransom (1997), Strobl & Walsh (2007), and Ashenfelter, Farber & Ransom (2010) have shown that minimum wages decrease unemployment in a monopsony market); if workers are not homogeneous (Drazen (1986) suggested that, with heterogeneous workers, minimum wage may be Pareto optimal if a higher wage would be preferred to the market clearing wage, even though unemployment is produced); and if there is no perfect information (Broadway & Cuff (2001) argued that minimum wage may be optimal because it can be combined with the institutional features of a typical welfare system to fix the government's asymmetric information problem with respect to workers' abilities).

In this paper, I study the effects of minimum wages on a transitional economy, such as China, in which migration flows from rural to urban areas occur with positive moving costs. There are three main results from my analysis. First, minimum wage is a useful instrument for the government to control migration flows. Second, regarding social inequality adjustments, a minimum wage leads to improvements in urban areas, but to a

worsening in both rural areas and the country as a whole. Third, a minimum wage may be optimal due to the moving friction: a moving cost wedge induces a modestly binding minimum wage to cause relatively low productivity urban workers to be replaced by higher productivity rural migrants. To show these results, I construct a theoretical model, focusing on the selection effects on determining the labor market outcomes, and then compare the outcomes with minimum wages to the status quo ante. Theory indicates that minimum wage policy has different effects on migration flows to formal sector, depending on the level at which it is set. When its value is low, minimum wage induces fewer urban workers but more migrant workers to work in the urban modern industrial sector. However, when its value is high, migrant workers are also constrained from entering the urban industrial sector. The effects on the urban informal sector are unclear. I then calibrate my theoretical model by using data from China to simulate the effects of minimum wages. I begin by calibrating my model's parameters to match labor market outcomes in China in 2006. By using 2006 as benchmark, the calibrated model predicts that when the minimum wage is not high enough to constrain qualified rural workers from moving to the urban industry sector, it benefits the whole economy; otherwise, it has negative effects on economic growth. The calibration also predicts worse inequality in rural areas but less inequality in urban areas, given the same investment profile. To achieve the second best outcome, government shall fully compensate the moving costs for the marginal migrant workers from the rural industrial sector to the urban subsistence sector, and the minimum wage shall not be binding for migrant workers in the urban industrial sector.

A minimum-wage system was officially introduced in China's Labor Law in 1994. It stated that the minimum wage should be set to ensure that the lowest wage earned by a worker be sufficient to support her basic needs. The Labor Law was an attempt to protect workers by specifying the form of payment, maximum hours, and overtime rates. In reality, it functioned more like a set of recommendations than binding policy, because there was no solid punishment for firms that did not abide by it. Although the minimum wage increased several times after 1994, the average income of low-skilled workers fell further behind the average urban income. Between 1994 and 2004, the average annual income of civil servants in Dongguan City increased by as much as 340%, from 8,000 RMB to more than 35,000 RMB; during the same period, average wages in the leather

and shoe industry stayed between 6,000 RMB to 10,000 RMB, and only increased by a total of 71%.⁴⁴ The Provisions on Minimum Wages was enacted in 2003 by the Ministry of Labor and Social Security, as an attempt to strengthen the protection of low-skill workers provided by the minimum-wage system. It required that the minimum wage be readjusted at least every two years according to such factors as the cost of basic necessities for employees and their dependents, as well as the local consumer price index. The readjustment was frozen in 2009 due to the worldwide recession. In 2010, following the recovery of China's economy and due to shortages of migrant workers, 30 of China's 31 provinces and direct-controlled municipalities announced increases in their minimum wages, at different rates. For example, Shanghai has China's highest minimum wage at 1120 RMB per month---an increase of 16.7%; in Guangdong province it increased by 21.1%; Hainan province saw the greatest increase at 37%.⁴⁵ But these wages are still very low when compared with the local average wage. For example, the average wage in Shanghai was 3759 RMB in 2009, while its minimum wage in 2010 was only 30% of that.⁴⁶

This paper analyzes the effects of minimum wage policy by using China as an example. Followed by the introduction, the rest of this paper is organized as follows. Section 2.2 contains the basic model setup and analysis. Section 2.3 analyzes the effects of minimum wage policy. Section 2.4 provides calibrations and simulations of my model. Section 2.5 discusses some potential policy implications. Section 2.6 concludes, and suggests some potential extensions.

⁴⁴ More information can be found in Wages in China, published on China Labor Bulletin on Feb 19th, 2008

⁴⁵ The information is published on the official website of The Central People's Government of The People's Republic of China.

⁴⁶ Numbers are quoted from the Shanghai Statistical Yearbook 2010

2.2 Model setup

2.2.1 Model assumptions

I construct a model with two regions, rural and urban, and four sectors to facilitate internal migration. Each region has two sectors. Rural areas possess a traditional agricultural (RA) sector and a modern industrial (RM) sector. Urban areas possess a former urban modern industrial (UM) sector and an informal urban subsistence (US) sector. The RM sector is developed with some exogenous physical capital investment, which is significantly less than is invested in urban areas. All residents can be identified by a residency registration system. The rural labor force is L_r , and the urban labor force is L_u , and I assume that L_r is much greater than L_u . I also assume that each worker possesses some human capital.⁴⁷ Initial levels of human capital are determined by nature, while education and job-training yield significant increases. Each worker has his own human capital, a_i which ranges from 0 to 1. The distributions of human capital in the rural and urban populations are p^r and p^u , respectively. Since education resources are allocated more in urban areas and there are uneven opportunities to access to post-secondary education, p^u is assumed to exhibit first-order stochastic dominance over p^r .

In the RA sector, labor is considered homogenous, and the production function is:

$$y_a = g(N_a) \quad (2.1)$$

where N_a is total physical labor input. I assume $g' > 0 > g''$. Farmers are paid at their marginal product of labor (MPNs) and the government, as the landowner, takes all the remaining output.

⁴⁷ Here human capital is defined as the stock of skill and knowledge embodied in the ability to perform labor, so it can be measured in terms of productivity.

In the industrial sectors, I assume agents work individually and the produce functions are CRTS. Workers are paid their marginal product. Each worker's production function in UM and RM are:

$$y_i^{um} = f(N, a_i, k_u) \quad (2.2)$$

$$y_i^{rm} = h(N, a_i, k_r) \quad (2.3)$$

where a_i is the human capital possessed by worker i , and N is the physical labor input of each worker, which is normalized to 1. Note that I assume total capital investment in both industrial sectors is equally distributed among the workers, $k_u = K_u/L_u$ and $k_r = K_r/L_r$. The marginal product of labor, MPN_i , is increasing with a_i and k as capital and labor are complements. Government allocation of investment between sectors is assumed to be exogenous and $K_u > K_r$. Manufactured goods are homogeneous.

The relative price between agricultural goods and industrial goods, P , clears the market. Manufactured goods are defined as the numeraire. The price function is:

$$P = \rho\left(\frac{y_a}{y_{um}}\right) \quad (2.4)$$

with $\rho'(\cdot) < 0$.⁴⁸

2.2.2 The best outcomes

The first best outcome occurs when all resources are mobile across sectors, and there is thus no difference between urban and rural areas. In the first best case, capital goes to the sector with higher returns between industrial sector and agricultural sector.

⁴⁸ One possible way to endogenize it is to assume homogeneous preference over both agricultural and industrial goods (e.g. Cobb-Douglas). Given a relative price level, the consumption ratio is constant, and should be proportional to the ratio of outputs when the market clears. Thus relative price is negatively related to the ratio of outputs. Please refer to Appendix 2.A.

There is a boundary of human capital in that those workers with higher human capital work in the manufacturing sector and those with lower human capital work in the agricultural sector. Since in my model labor is the only flexible factor and there are many practical constraints, the first best case is not possible in the real world at least in the near future, and thus it will not be discussed in detail.

The second best outcome occurs with only one constraint: that is, capital is predetermined. In the second best case, the difference between urban and rural areas exists since investment profiles are quite different. To induce the second best outcome, the moving costs must be assumed away. If the US sector is assumed to be a channel to reallocate social wealth and produce no real outputs, and the utility functions are based on real outputs only, the second best outcome must satisfy several conditions. First, agents' utilities are maximized given the outputs of manufactured goods and agricultural goods. Second, workers with the same human capital are treated equally. That is, either they are all in the same sector or they are all out of that sector, since labor is totally mobile. Third, in the second best outcome the marginal products of labor for the same worker must be equalized across UM and RM sectors, which determines the labor allocation. This may imply an urban-to-rural migration flow to the RM sector if it requires more workers.

Based on my model setup, the second best outcome may be derived in a simple way. Because of the properties of the production functions in modern industry sectors, there are two opposite effects when an extra worker enters. On the one hand, labor increases, contributing positively to total outputs. On the other hand, the extra workers decrease the capital available to each worker, which has a negative effect on output. Therefore the total output may be maximized at a certain cut-off level of human capital. At this cut-off level of human capital, once the ratio between manufacturing goods and agricultural goods exceeds the optimal ratio of subjective demands which is determined by equating the marginal utilities of consuming each good, some workers must switch from the industrial sector to the agricultural sector until the output ratio is optimal. Otherwise, the second-best outcome is induced. Numerical analysis cannot be done without specific assumptions on functional forms. I discuss this further in Section 2.4.

The equilibrium outcome that we may observe in the real world is the market equilibrium. Besides the constraint imposed on the second best case, the market equilibrium also experiences positive moving costs. This is the main focus of this paper.

2.2.3 The market equilibrium outcome

To determine the market equilibrium outcome, moving costs must be considered since migrant workers are subject to them in the real world. The costs of moving to big cities are not just pecuniary, but also include psychological discomfort, such as loneliness, discrimination from urban residents, safety issues, etc.⁴⁹ Assuming high-skilled people adapt to a new environment faster, the cost of moving is modeled as a decreasing function of a_i .⁵⁰ I assume the annuitized cost of moving is $C(a_i)$ with $C'(\cdot) < 0$.⁵¹

When a rural worker considers moving, she compares the benefits of moving to the cost. By assuming that a higher wage is the benefit she would earn if working in an urban area, her net benefit function is:

$$B(a_i) = w(a_i) - C(a_i) \quad (2.5)$$

I assume that $w_{um}(1) - C(1) - w_{rm}(1) > 0$, i.e.

⁴⁹ Sjaastad (1962) breaks down the moving cost into money and non-money 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".

⁵⁰ The moving cost is also affected by the locations of rural areas, traffic conditions, and other factors, while I focus on the effects of human capital.

⁵¹ Zhang and Lei (2008) point out that there are four components in social integration for a Chinese domestic migrant: cultural integration, mental integration, identity integration and economic integration. They also construct an empirical model to test the determinants on social integration by using data on 600 new migrants to Shanghai. The coefficient of schooling years is 0.89 which implies migrants with higher education levels integrate into a new society faster.

$$f'_N \left(1, K_u / (L_u \int_{\bar{a}_u}^1 p^u da_r) \right) - C(1) - h'_N \left(1, K_r / (L_r \int_{\bar{a}_r}^1 p^r da_r) \right) > 0 \quad (2.6)$$

to make sure that at least the highest ability rural worker obtains a net benefit from moving to the UM sector. Because working in UM yields higher wages, rural workers consider their qualifications for positions in this sector first, given the same moving cost, if they decide to move. Employment in the urban industrial sector is now composed of urban workers and migrant rural workers.

Proposition 2.1: The migration flow to the UM sector is inversely related to the moving costs.

Proof. The rural worker moving to UM with the least human capital, a_X , must be indifferent between the benefits from staying in the rural sector and the wages earned in the UM sector. Employment in the UM sector includes urban workers and migrant workers which are:

$$N_{um} = L_u \int_{a_z}^1 p^u(a_u) da_u \quad (2.7)$$

$$N_X = L_r \int_{a_X}^1 p^r(a_r) da_r \quad (2.8)$$

where a_z is the least human capital possessed by an urban worker who stays in UM. A migrant worker from rural areas with a_X must satisfy:

$$w_X^{um} - w_X^{rm} = C(a_X) \quad (2.9)$$

where w_X^{um} is the income of the rural migrant worker with a_X who moves to UM which equals $MPN^{um}(a_X, K_u / (N_X + N_{UM}))$ and w_X^{rm} is the income of the same worker who stays in RM which is $MPN^{rm}(a_X, K_r / N_{RM})$ and N_{RM} is the employment in RM:

$$N_{RM} = L_r \int_{a_M}^{a_X} p^r(a_r) da_r \quad (2.10)$$

where a_M is the least human capital possessed by a rural worker who stays in RM. We know that $C(a_X) > 0$ and $C'(a_X) < 0$ thus the RHS of equation (2.9) is a decreasing function on a_X . In LHS:

$$\frac{d(w_X^{um})}{d(a_X)} = MPN_{a_X}^{um} + MPN_{k_u}^{um} \cdot \frac{d(k_u)}{d(a_X)}$$

where $k_u = K_u / (N_X + N_{UM})$ and all terms are positive which implies w_X^{um} is an increasing function of a_X .

$$\frac{d(w_X^{rm})}{d(a_X)} = MPN_{a_X}^{rm} + MPN_{k_r}^{rm} \cdot \frac{d(k_r)}{d(a_X)}$$

where $k_r = K_r / N_{RM}$. We have $MPN_{a_X}^{rm}$ and $MPN_{k_r}^{rm}$ as positive terms but $d(k_r) / d(a_X)$ is negative. Therefore w_X^{rm} may increase or decrease with a_X . But as UM is assumed to always be attractive to high ability workers, w_X^{rm} increases slower than w_X^{um} . Therefore the LHS of equation (2.9) is an increasing function of a_X . Figure 2.1 depicts the information embodied in equation (2.9).

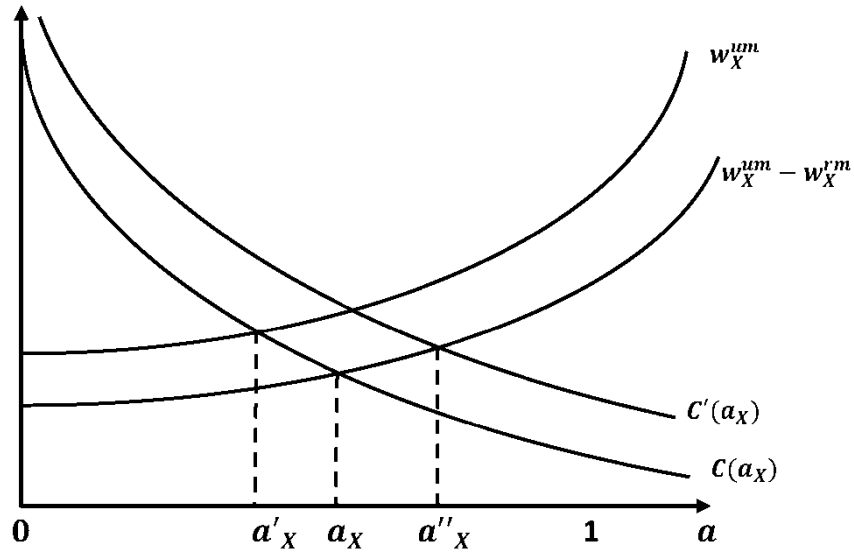


Figure 2.1. Equilibrium human capital thresholds

Intuitively, institutional and economic barriers increase the cost of moving, and local job options faced by rural workers increase the benefit of staying. Therefore, they work in the same direction on labor mobility. The equilibrium human capital of the last rural worker who would move to UM is a_X , where $w_X^{um} - w_X^{rm}$ intersects $C(a_X)$. If labor mobility across areas was allowed without setting up RM, a_X is determined by $w_X^{um} - w_a = C(a_X)$ which ends up at lower a'_X .⁵² More rural workers would flow into UM. On the other hand, if the government imposes extra restrictions on the requirements of urban job positions for rural workers, it pushes up the cost curve to $C'(a_X)$. Consequently more rural workers would stay in rural areas. Therefore, the government has multiple tools to control migration to the UM sector.

Not every job seeker is qualified to have a job in the UM sector. Many of them have to work in US. As described in Cole and Sanders (1985), US consists of "those urban employment categories that feature very low levels of productivity and earnings". US can absorb all labor which wants to work in it, thus there is no unemployment for migrant workers. This is the key difference from Harris and Todaro (1970). All US workers are assumed to be paid at w_{us} . Even though w_{us} is less than the wage earned in UM, the fact that people do stay in the city and don't go back indicates that it is still greater than the potential wage when working in rural areas. The wage difference provides the incentive for some rural workers to move to cities, even if only to get a position in US.

Proposition 2.2: There is a lower limit, $a_N \in (0,1)$, and an upper limit, $a_M \in (0,1)$, with $a_M > a_N$, on human capital with which rural workers move to the US sector. Only the rural workers with human capital between a_N and a_M move to the US sector.

⁵² a_X is the wage earned by farmers which is no higher than w_X^{rm} .

Proof. Rural workers heading to the US sector must satisfy the following condition:

$$w_{us} \geq w_r + C(a_i) \quad (2.11)$$

where w_{us} and $C(a_i)$ are defined the same as before, and w_r is the wage when staying in rural areas. It may be the wage from either RA or RM, because either farmer or worker, or both, may consider moving to US. But because w_{us} is the lowest wage for the workers in UM, only those who cannot go to UM will think about going to US.

Because $C(a_i)$ is a decreasing function of human capital, w_r is a non-decreasing function of human capital and w_{us} is the same for every worker in US, Figure 2.2 illustrates the situation in which rural workers would move to US.⁵³

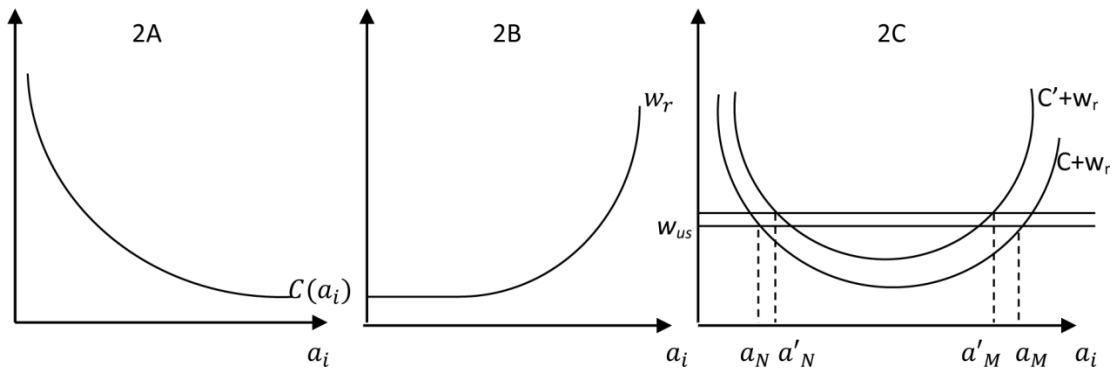


Figure 2.2. Heading to the US sector

Figure 2.2c shows that there exists an upper limit, a_M , and a lower limit, a_N , of human capital for which rural workers would move to US. It implies we would not

⁵³ The combination of a decreasing C function plus a non-decreasing w_r function may bring about another result: overall effect is always decreasing if C dominates. The U-shaped curve also can be very asymmetric if C is much flatter than w_r . Provided w_{us} is greater than the minimum point of $w_r + C$, these two cases end up with only one intersection. In the first case, all highly skilled rural workers have an incentive to move to US; in the second case, all less smarter rural workers will move to US. These two are not consistent with the data.

observe extreme types of rural people in US. Those rural workers with human capital close to a_M who work in RM, but who are not skilled enough to find a job in UM sector, they can take advantage of affordable moving costs to earn higher wage in US. On the other hand, for those rural workers with human capital close to a_N who are paid much less, the wage in US will be attractive in spite of high moving costs. Figure 2.2c also indicates that a higher moving cost discourages rural workers from moving to the US sector, and so we observe more homogeneity among migrant workers in the US sector.

Another application of figure 2.2c is to analyze migration differences between rural areas. Using China as an example, we know that most of China's developed areas are located in the eastern and southern coastal regions, while most of its less-developed areas are located in the central and western regions. Intuitively, the moving cost for a rural worker from a county close to developed cities is lower than for someone living far away from them, assuming all other factors are the same---for example, a rural worker from Anhui province vs. a rural worker from Qinghai province---therefore, given the same wage earned in urban areas, we would observe less migration from those rural areas located far away from big cities.

Proposition 2.3: Two different equilibrium scenarios may appear in rural areas after rural workers move to urban areas. Rural workers with human capital in excess of a_N move to the US sector. The workers with less human capital than a_N could enter RM or stay in RA. These two scenarios are depicted in Figure 2.3.

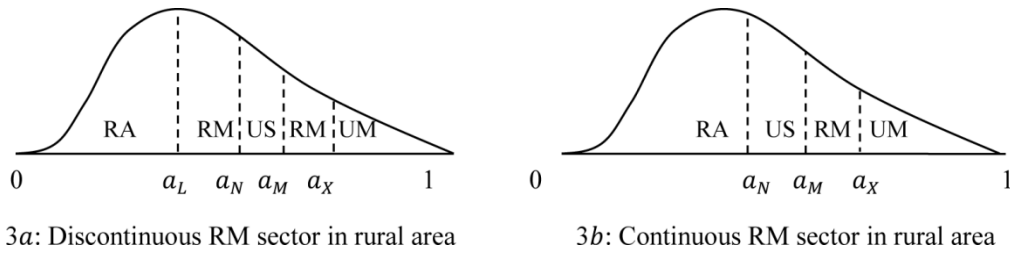


Figure 2.3. Career distribution in rural areas

The mathematical conditions for these two scenarios are showed in Appendices 2B and 2C. The intuition is as follows. Fewer rural workers move to the urban US sector when moving costs are high. This scenario is shown in Figure 2.3a. Figure 2.2c implies a_N in Figure 2.3a is greater than a_N in Figure 2.3b which has lower moving costs. It implies a higher wage if the one on the boundary works in RM. This provides room for rural workers with human capital slightly less than a_N to earn higher wages in RM than staying in RA after some rural workers move to US. The rural workers with human capital higher than a_L can enter RM after those with human capital between (a_N, a_M) , move to US. The departure of some RM workers increases the physical capital per capita for the remaining RM workers, which encourages more farmers to enter RM. Therefore we can observe two groups of human capital within which rural workers are in RM: (a_L, a_N) and (a_M, a_X) . The values of a_N , a_M and a_X identify the moving populations and their occupational choices. In rural areas, people with human capital between a_N and a_M move to US, while those with human capital greater than a_X go to the UM sector. Because people only move when they can obtain higher utility, the rural migrant workers and those former farmers who move to RM are better off. Because the supply of labor in US increases, it reduces wages in this sector, making the pre-existing urban poor worse off.

More rural workers can afford to move to the US sector when moving costs are low. This scenario is shown in Figure 2.3b. The marginal worker staying in rural areas possesses less human capital than when moving costs are high. Because of the low human capital endowments, of those who remain in rural areas, after those with human capital (a_N, a_M) move to cities, investment cannot support wages in RM higher than those obtained by farming. In rural areas, people with skills lower than a_N work in the

agricultural sector. People with human capital between a_N and a_M move to US. Those with human capital between (a_M, a_X) stay in RM and those with human capital greater than a_X will go to the UM sector. All rural workers with greater human capital than a_N are better off. But because the supply of labor in the US sector increases more than in the first case, it reduces incomes in this sector.

2.3 Minimum wage

Workers' moving decisions and the market outcomes with free labor mobility may be different with government intervention. To avoid a huge migration flow flushing into cities when the labor mobility constraint is removed, government can use minimum wage policies to smooth the transition, and to maintain subsistent living standards for low-income workers. Since it is effective to enforce minimum wage on formal sectors, I assume that minimum wage is imposed on the UM sector at w . It has significant effects on the labor market. To begin, we consider the UM workers.

Proposition 2.4: After labor becomes mobile, the minimum wage induces fewer urban workers to enter UM. The effects on migration to UM depend on the value of the minimum wage. When \underline{w} is low, it induces more migrant workers to move to UM, compared to the condition without a minimum wage. When \underline{w} is high, migrant workers are limited from moving to UM and less migrant workers move to UM.

Proof. We begin by considering the effects of \underline{w} on urban workers. Without any migrant workers, the UM employment is $N_{UM} = L_u \int_{a_u}^1 p^u da$. When labor is mobile, total employment in the UM sector includes urban workers and migrant workers. That is, $N_{UM} = L_u \int_{a_w}^1 p^u da + N_{MW}$ where a_w is the least human capital that an urban worker can have and still stay in UM, and $N_{MW} > 0$ is the number of migrant workers in UM. When

the minimum wage is enforced, it determines the least human capital with which the urban worker could stay in UM. We have:

$$\underline{w} = MPN^{um}(a_w, \frac{K_u}{L_u \int_{a_w}^1 p^u da + N_{MW}}) \quad (2.12)$$

For any given urban human capital level, the RHS of equation (2.12) is less than $MPN^{um}(a_w, \frac{K_u}{L_u \int_{a_w}^1 p^u da})$, which is the wage of urban UM workers when labor is immobile, since each worker will have less physical capital to work with. Figure 2.4 shows the effect of \underline{w} on urban workers.

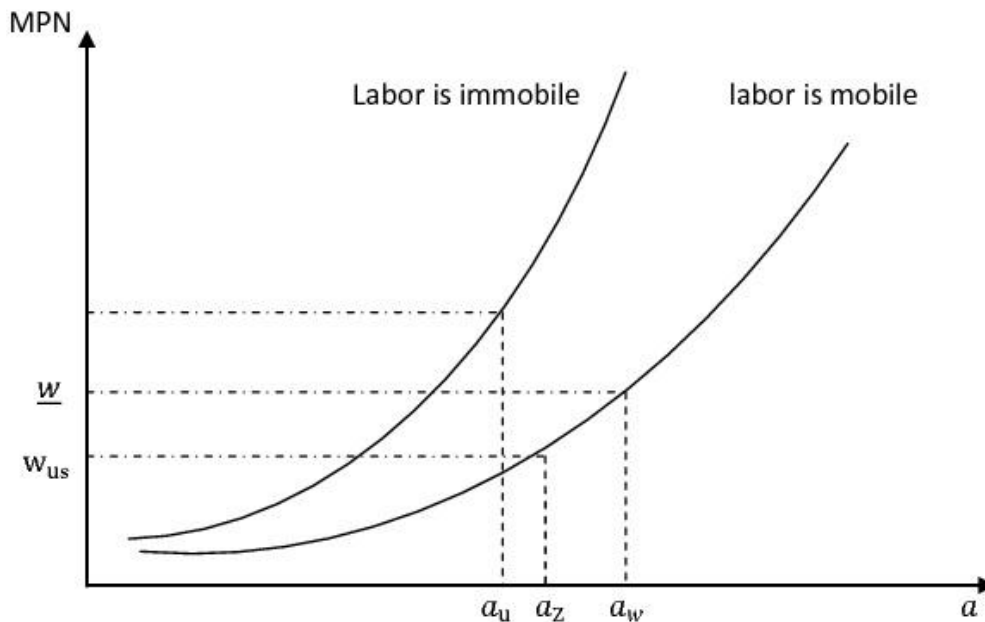


Figure 2.4. The effects of \underline{w} on urban workers

Because \underline{w} must be greater than w_{us} , a_w is greater than a_z . Figure 2.4 shows that when \underline{w} is enforced, the probability of fewer urban workers staying in UM after labor becomes mobile is higher than in the case without \underline{w} . If w_{us} drops quickly after labor becomes mobile, we may observe more urban workers in UM after the labor mobility constraints are removed.

With regard to the rural workers, we know that $a_x \geq a_z$. Because if not, then a_x would be the minimum requirement to enter UM in the urban area. Since everyone in UM has the same amount of capital to work with, the marginal migrant workers with a_x would earn less than the marginal urban workers with a_z . Because the marginal urban workers with a_z is indifferent between entering UM and US, their incomes are w_{us} . Therefore the marginal migrant workers to UM would earn less than w_{us} which is impossible since they would then move to US instead of UM.

There are two scenarios regarding rural workers. If the MPN of marginal movers when they work in UM is greater than w , their decision is based on:

$$MPN_{a_x}^{UM} - MPN_{a_x}^{RM} = C(a_x) \quad (2.13)$$

where $MPN_{a_x}^{UM}$ is the wage if the worker moves to UM and $MPN_{a_x}^{RM}$ is the wage if the same worker stays in RM. If we keep the same a_x as before, since we expect fewer urban workers in UM than in the case without \underline{w} , only $MPN_{a_x}^{UM}$ is affected, and will be higher than in the case without minimum wage. Therefore, the LHS of equation (2.13) must be reduced if it is to hold, which implies that more rural workers are moving to UM.

Nevertheless, if $MPN_{a_x}^{UM} < \underline{w}$, then rural workers whose MPN when working in UM is lower than w are not accepted by any UM firms, because of the enforcement of the minimum wage. In this case the MPN of the last worker moving to UM must be at least equal to \underline{w} . That is:

$$MPN_{a_x}^{UM} = \underline{w} \quad (2.14)$$

The higher the minimum wage, the less qualified rural workers need be to move to UM. Because \underline{w} also equals the MPN of the last urban workers who can stay in UM, the lowest human capital levels are the same for both urban and rural workers.

The effects of \underline{w} on the decision to move to US are not certain without making further assumptions about the properties of the functions. Generally speaking, it is ambiguous because: on the one hand, \underline{w} drives more urban workers to the US sector; and because w_{us} is negatively related to the US labor supply, we expect a lower value of w_{us} with a higher value of \underline{w} . On the other hand, since \underline{w} reduces the income in the

US sector, it provides less incentive for rural workers to migrate, which in turn has positive effects on the value of w_{us} . It is reasonable to expect that high \underline{w} induces a smaller migration flow to the US sector, since it lowers w_{us} . The effects of minimum wages will be examined using simulations.

Because the minimum wage policy limits workers from entering UM, it protects UM workers but hurts US workers, since the US wage is lower with a higher \underline{w} . The lower \underline{w} pushes some previous migrant workers in US back to rural areas, so that employment in RA increases. This obviously hurts the RA workers. The effects on the welfare of other workers are ambiguous. In the next section, by using data from China, I simulate a calibrated model to provide various results for different values of \underline{w} .

2.4 Numerical analysis

In this section, I first make assumptions on specific functional forms that are consistent with all the previous assumptions about pdfs of human capital, production functions, wage functions, etc. I use the 2006 data from China to calibrate my model, then use the calibrated model to simulate the effects of the minimum wage policy on the aggregate level and distribution of China's output. This is an extension of another calibration which is done by using data from 1986.⁵⁴ The cut-offs of labor allocations (a_N, a_M, a_X, a_Z) are the endogenous variables in my model. The values of free parameters are either based on real data $(L_u, L_r, K_u, K_r, \alpha_u, \alpha_r, \beta_u, \beta_r, A)$, standardized (c_r, z_{rm}, z_a) , or derived from theories which are consistent with the data (c_u, z_{um}, a, γ) . The outcomes are consistent with all theoretical assumptions.

⁵⁴ Please refer to chapter 1 in which the calibration is also done using 1986 data.

2.4.1 Calibration

I assume human capital in both urban and rural areas follows a triangular distribution on the domain $a \in (0,1)$. The rural distribution peaks at c_r and the urban distribution peaks at c_u .⁵⁵ c_r is assumed to be 0.3 and c_u is 0.6867 which is calibrated when using 1986 data.⁵⁶ The distribution of urban human capital thus has first-order stochastic dominance over which of rural human capital.

The manufacturing sector uses a Cobb-Douglas production function:

$$y_{im} = z_{im} \cdot a_i \cdot N^{\alpha_i} \cdot k_i^{\beta_i} \quad (2.15)$$

RM is more labor intensive and has less value-added than UM.⁵⁷ Moreover Jin and Du (1997) suggests that α_r is roughly equal to β_r .⁵⁸ Given a CRTS production function, they are both assumed to be 0.5. Sharma (2007) estimates a Cobb-Douglas production function along with a time trend to capture the effect of technological progress after the reforms in 1978 using a cointegration and Error-Correction modeling framework for the 1952-1998 period. He found that the output elasticity for labor was about 0.37 under the assumption of constant returns to scale for all of China. Since rural industry accounted for roughly 1/5 of total industry, $\alpha_u = 1/3$ and $\beta_u = 2/3$.⁵⁹ z_{rm} and z_{um} are free parameters in my model. Each worker's physical labor, N , is normalized to

⁵⁵ The pdf of a triangle distribution is triangle shaped. It is $2(x-A)/((B-A)(C-A))$ if $A \leq x \leq C$, and it is $2(B-x)/((B-A)(B-C))$ if $C \leq x \leq B$, where A is the lower limit, B is the upper limit and C is the mode.

⁵⁶ Please refer to chapter 1.4 for the details.

⁵⁷ Zen (2002) suggested that China's rural industry is more labor intensive, has a lower added-value and large bulk.

⁵⁸ Please refer to Table 3.3 in Jin and Du (1997).

⁵⁹ The urban capital share is $0.63 - (0.5 \cdot 1/5) = 0.53$ and the urban labor share is $0.37 - (0.5 \cdot 1/5) = 0.27$. The ratio is roughly 2.

1 in both sectors. The total investment in urban and rural areas was 2692.03 and 479.47 billion Yuan, respectively, in 1986 prices, which are used to approximate capital stock.⁶⁰

The relative price function is derived in Appendix 2.A:

$$P = \frac{y_{um} + y_{rm}}{A \cdot y_a} \quad (2.16)$$

The total outputs of the first and second industries were 2473.7 and 10316.2 billion. Considering the openness of China's economy in 2006, the ratio between the value of industrial goods and agricultural goods was about 1:3.6 in China; I assume $A=3.6$.⁶¹

The wage in US sector is assumed to be $\ln w_{us} = \gamma \ln y_{um} - \eta \ln N_{us}$. Using data from 1986 to 2008, I ran a regression of $\ln \Delta y_{um}$ on $\ln(\Delta N_{us})$ and $\ln(\Delta w_{us})$ and have $\eta = 1.23\gamma$.⁶² Accordingly, the wage function is assumed to be:

$$w_{us} = \frac{(y_{um})^\gamma}{(N_{us})^{1.23\gamma}} \quad (2.17)$$

The production function of RA is:

$$y_a = z_a \cdot N_A^a \quad (2.18)$$

where a is 0.6091.⁶³ From 1986 to 2006, agricultural output increased by 120%, while agricultural employment changed from 312.53 million to 325.61 million. By keeping a constant and normalizing z_a in 1986, z_a is approximated to be 2.0678 for 2006.

⁶⁰ Because there is no data on China's capital stock across periods, I use investment flow to approximate capital stock. We need very strong economic assumptions to do this approximation, such as assuming the depreciation rate, δ , is very high close to 1 as $K = I/\delta$ at steady state.

⁶¹ This ratio is trade-adjusted. In 2006 China's net exports totalled 1421.77 billion Yuan and most of it (97.5%) was produced by the industrial sector. (China Statistical Yearbook, 2007). Those numbers should be subtracted from total outputs to evaluate domestic preferences.

⁶² The coefficients of $\ln(\Delta N_{us})$ and $\ln(\Delta w_{us})$ are 1.23 and 0.71 with P-values 1.49E-08 and 8.90E-06. Adjusted R² is 0.9494.

Because workers are free to move between labor markets, all variables are pooled into one equation system. The moving cost function is assumed to be:

$$C(a) = c_F + \frac{1}{c_V \cdot a^2} \quad (2.19)$$

where c_F is the fixed moving cost.⁶⁴

In 2006, the urban labor force was 283.10 million and the rural labor force was 480.90 million. Of the 131.81 million rural migrant workers, 56.7% went to the industrial sector and 40.5% went to the service sector.

Based on the information above, the parameters in my current calibration are $L_u = 283$, $L_r = 481$, $K_u = 2692$, $K_r = 479$, $A = 3.6$, $z_a = 2.0678$, $c_r = 0.3$, $c_u = 0.6867$, $\alpha_r = 1/2$, $\beta_r = 1/2$, $\alpha_u = 2/3$, $\beta_u = 1/3$ and $a = 0.6091$. I have z_{rm} , z_{um} , c_F and c_V as the free parameters.

The facts which I have tried to replicate are as follows:

1. In 2006, China's rural labor force was 480.90 million, and employment in the rural industrial and private sectors was 194.59 million. I approximate the number of farmers by taking the difference between these two numbers, which is about 59.53% of the rural labor force.

2. China's employment in the third industry is 32.20% of the total labor force.

3. After cancelling the manual migration costs imposed by the government, the transportation cost becomes the major explicit moving cost. In China, long distance travel is mostly by rail. In 2006, the average rail fare was 57.93 RMB, and, generally,

⁶³ The value of a is calibrated using the 1986 data. Please refer to Chapter 1.4.1.

⁶⁴ The moving cost function has two parts. The second term is used to approximate non-money costs, though "it would be difficult to quantify these costs" (Sjaastad (1962)).

rural workers have to make at least one transfer to reach the big cities. Therefore, the round-trip fare would be 231.71 RMB, which is 6.45% of a farmer's income in 2006.

4. Because industrial goods are normalized in my model, the outputs are comparable. The industrial output in 2006 was 9.33 times that of 1986.

After calibrating, the values of the free parameters are derived as: $z_{rm} = 0.2181$, $z_{um} = 0.4416$, $c_F = 0.0195$ and $c_V = 30.219$.

2.4.2 The second best outcome

The second best outcome occurs when utility is maximized aggregately with only one constraint: predetermined capital profile. Because the outputs of different sectors are involved in my model and they are not comparable, we must resort to the utility function to find the optimal outcome with which the total utility is maximized. The utility function is assumed to be a Cobb-Douglas, as shown in Appendix 2.A. Calibrated using the 2006 data, it is

$$U(x_A, x_M) = x_A x_M^{3.6} \quad (2.20)$$

where x_A is the consumption of agricultural goods and x_M is the consumption of industrial goods. I assume consumers have homogeneous preferences, thus every consumer spend the same proportions of her income on both goods. In the second best case, the marginal product of labor from UM and from RM must be equalized for the same workers. If a_E is the optimal solution to the second best, the workers in both regions with human capital higher than a_E work in either RM or UM sector, and those with lower human capital work in agricultural sector, based on the assumption that US doesn't produce real outputs. Therefore the optimization problem is to maximize equation 20 subject to

$$a_r \cdot z_{rm} \cdot k_r^{\beta_r} = a_u \cdot z_{um} \cdot k_u^{\beta_u} \quad (2.21)$$

which comes from $MPN_{rm} = MPN_{um}$ for the same worker. Physical labor is normalized to 1. Since $k_i = K_i/N_i$ where $i = rm$ or um , and N_i is the labor employed in each sector,

equation 2.21 determines the migration flow: high-skilled rural workers move to the UM sector while low-skilled urban workers move to the agriculture sector. Because β_r and β_u are different, the problem is to maximize utility subject to a non-linear constraint. Given a_E , the optimal allocation of labor can be found by equalizing MPNs; then k_r and k_u can be expressed as functions of a_E , as are the outputs, y_{um} , y_{rm} and y_a , since they can be solved as functions of k_r , k_u and a_E , and since k_r and k_u are functions of a_E , y_{um} , y_{rm} and y_a are functions of a_E . Therefore the utility function is also a function of a_E and we are able to find the optimal solution to maximize it.

Instead of solving this complicated non-linear optimization problem, I resort to simulations to find the optimal solution to it. The second best occurs when the boundary of human capital between the modern manufacturing sectors and the agricultural sector is 0.6112: those with human capital higher than 0.6112 enter either RM or UM, while those with lower human capital enter the agricultural sector. The total employment in the manufacturing sector is 232.92. But the distribution is very uneven: RM employs only 10.27, while UM employs 222.65, ensuring that a worker makes the same MPN in both sectors. The migration flow from RM to UM is 93.56 which is 19.45% of the rural population.

2.4.3 The market equilibrium outcome

2.4.3.1 Equations system

Due to the friction caused by the existence of moving costs as well as the predetermined capital investment profile, the optimal market outcome may not be the best. For the same reason, even though minimum wage is always binding for urban workers, it may or may not be binding for the migrant workers, since they require higher incomes (and thus have higher MPN) to compensate their moving costs.

The optimal market equilibrium outcome can be solved by maximizing agents' utilities (equation 20) under certain constraints. To calculate the values of outputs, we need to find the critical values of human capital had by the marginal workers. The systems of equations which determine the outcomes are different depending on whether

the minimum wage is binding for migrant workers. If it is not binding for migrant workers, i.e. $\underline{w} < MPN_{a_X}^{UM}$, the system contains equations 2.22, 2.23, 2.24 and 2.25.

$$w_{us} = p \cdot w_a + C(a_N) \quad (2.22)$$

$$w_{us} = MPN_{a_M}^{RM} + C(a_M) \quad (2.23)$$

$$\underline{w} = MPN_{a_Z}^{UM} \quad (2.24)$$

$$MPN_{a_X}^{UM} = MPN_{a_X}^{RM} + C(a_X) \quad (2.25)$$

Equation 2.22 implies that the rural workers with human capital a_N are indifferent between working in the RA sector and the US sector. Equation 2.23 implies that the rural workers with human capital a_M are indifferent between working in RM sector and US sector. Equation 2.24 implies that the urban workers with human capital a_Z are indifferent between working in the UM sector and the US sector. Equation 2.25 implies that the rural workers with human capital a_X are indifferent between working in the UM sector and the RM sector, while migrant workers in the UM sector receive higher wages than the minimum wage. Minimum wage is binding for urban UM workers only, and all migrants workers in UM earn higher wages than it.

If minimum wage is binding for migrant workers, i.e. $\underline{w} = MPN_{a_X}^{UM}$, the system is almost the same as before, only with Equation 2.25 replaced by Equation 2.26. Thus it contains equations 2.22, 2.23 2.24 and 2.26.

$$\underline{w} = MPN_{a_X}^{UM} \quad (2.26)$$

2.4.3.2 Simulations

Given the function forms and the calibrated values of parameters, I am able to solve for the optimal value of the minimum wage and use simulation to visualize its effects on the levels of utilities and outputs, provided it would yield a better outcome than the market-clearing wage $MPN_{a_Z}^{UM}$. It turns out that the optimal minimum wage is 0.4814, when minimum wage is just about to be binding for migrant workers. The optimal utility

level is 740.58, compared with the market-clearing UM wage of 0.4725 which yields the utility level 728.71.⁶⁵ The effects of minimum wage on the values of outputs and levels of utility are visualized in Figure 2.5.

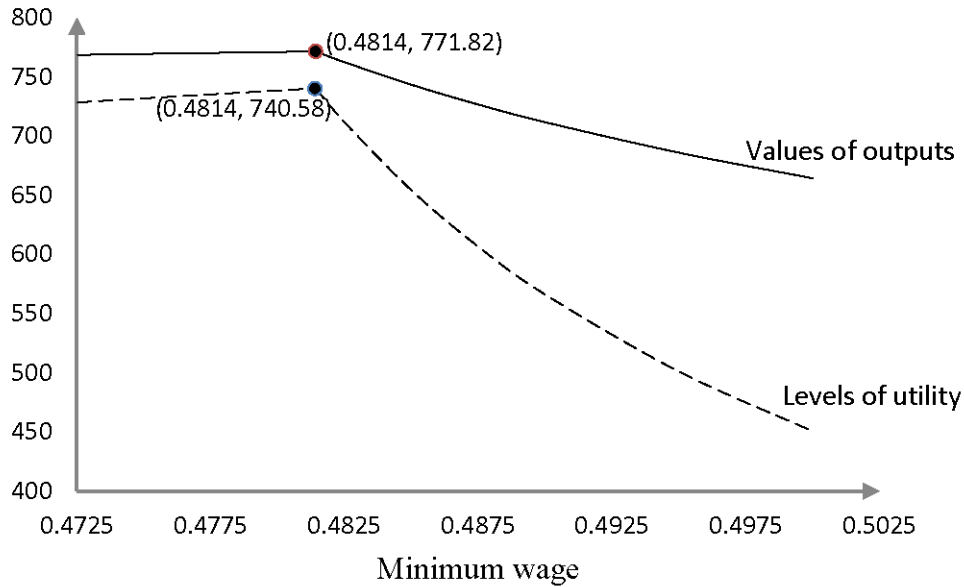


Figure 2.5. The effects of w on utility and outputs

Furthermore, I compare the market equilibrium outcomes for three different levels of minimum wage: a low level of 0.4750, the optimal level of 0.4814 and a high level of 0.4900, to show the detailed effects on outputs, inequalities and welfare changes from different values of minimum wages. When w is low, the minimum wage is not binding for rural migrant workers, though it is just binding when w is optimal, and it is strictly binding when w is high. The equilibrium outcomes are shown in Table 2.1.

⁶⁵ I have done a positive monotonic transformation on the initial form of the utility function so that the values of the utilities are close to the values of output, and so they can be shown in the same figure, as in Figure 2.5.

Table 2.1. Equilibrium outcomes when \underline{w} is enforced

\underline{w}	a_Z	a_N	a_M	a_X	Y_a	Y_m	Y_{us}
No \underline{w}	0.6214	0.4678	0.6039	0.6342	64.86	510.74	116.25
Low	0.6237	0.4681	0.6028	0.6329	64.90	511.33	116.35
Optimal	0.6295	0.4690	0.5998	0.6295	64.98	512.78	116.61
High	0.6332	0.4772	0.5971	0.6332	65.80	474.32	105.94
\underline{w}	w_a	p	MPN^{RA}	w_a	$MPN_{a_N}^{RM}$	$MPN_{a_M}^{RM}$	$MPN_{a_X}^{RM}$
No \underline{w}	0.4725	2.1873	0.1380	0.3018	0.2806	0.3623	0.3805
Low	0.4724	2.1887	0.1379	0.3019	0.2810	0.3619	0.3799
Optimal	0.4720	2.1919	0.1378	0.3020	0.2820	0.3606	0.3785
High	0.4386	2.0024	0.1367	0.2738	0.2607	0.3263	0.3460
\underline{w}	$MPN_{a_X}^{UM}$	$MPN_{a_Z}^{UM}$	N_{RA}	N_{RM}	N_{UM}	M_{UM}	M_{US}
No \underline{w}	0.4822	0.4725	286.34	15.83	215.82	91.97	86.87
Low	0.4820	0.4750	286.58	15.81	215.32	92.60	86.01
Optimal	0.4814	0.4814	287.22	15.76	213.99	94.31	83.71
High	0.49	0.49	293.15	19.08	210.23	92.46	76.32

As \underline{w} increases, the size of the UM employment becomes smaller, and it decreases by 0.23%, 0.85% and 2.59%, when compared to the case without \underline{w} . In the US sector, wage decreases by 0.03%, 70.12% and 7.18%. The income of farmers changes by 0.03%, 0.09% and -9.29%. Regarding migration flows to UM, M_{UM} , when \underline{w} is low, the migration flow is 92.60. It increases to 94.31 when \underline{w} is the optimal, and decreases to 92.46 when \underline{w} is high. When \underline{w} is low, the migration flow to US, M_{US} , is 86.01. When \underline{w} is optimal or high, M_{US} is 83.71 and 76.32, respectively.

Imposing a minimum wage has significant effects on the values of outputs. Table 2.2 summarizes the changes with different minimum wages.

Table 2.2. The effects of \underline{w} on output values

Output value	y_a	y_m	y_{us}	Total value	% change
No \underline{w}	141.88	510.74	116.25	768.87	
Low \underline{w}	142.03	511.44	116.35	769.72	0.11%
Optimal \underline{w}	142.44	512.78	116.61	771.82	0.38%
High \underline{w}	131.75	474.32	105.94	712.02	-7.39%

An interesting result is seen when the minimum wage is a little higher than the market-clearing wage, as it helps economic growth. Because of the existence of moving costs, the marginal migrant workers in UM require higher income when they work in UM than when they work in RM, given there is no minimum wage. Since only the relatively low-skilled workers in the RM sector would consider moving to US to earn w_{us} , which is the same as the lowest wage for urban UM workers, the marginal migrant workers (who are relatively high-skilled) in UM must earn a higher wage than the lowest wage earned by urban UM workers. This difference provides room for the minimum wage to be set between these two wages. At the time that \underline{w} greater than the lowest wage earned by urban UM workers is enforced on urban formal sector, if it is lower than the wage earned by marginal the migrant workers when there is no minimum wage, it is only binding for urban workers but not for migrant workers. Thus it drives some urban, low-ability workers at the margin out of the UM sector, and they are replaced by comparatively high-ability, rural migrant workers. Thus the output of the UM sector increases. More output from the UM sector, in turn, benefits the workers in the US and RA sectors. When the minimum wage is high enough to restrain the more efficient rural workers from moving, however, it hurts economic growth. We would expect that the higher the minimum wage, the lower the value of the total output.

With regards to the changes of inequality, I compare the income of workers with human capital equal to 0.8 with that of the majority in rural areas. Because the gap between capital income and labor income is the main source of inequality in urban areas, I mean to show the changes of the ratio between capital income and that of US workers. They illustrate the intra-area inequality change. I also calculate the Gini coefficients, derived from labor income only, since I lack data about the number of

capital owners and the distribution of capital incomes. The inequality changes are shown in Table 2.3.⁶⁶

Table 2.3. The effects of \underline{w} on inequalities

Income	Rural inequality change			Urban inequality change			Gini
	$a_r=0.8$	farmer	ratio	capital	US worker	ratio	
No \underline{w}	0.6083	0.3018	2.0158	332.66	0.4725	q	0.1470
Low \underline{w}	0.6093	0.3019	2.0183	333.07	0.4724	1.0015q	0.1473
Optimal \underline{w}	0.6118	0.3921	2.0254	334.09	0.4720	1.0054q	0.1483
High \underline{w}	0.6191	0.2738	2.2614	307.67	0.4386	0.9964q	0.1737

In rural areas the workers with human capital of 0.8 work in UM sector. When \underline{w} is low, their incomes are 0.6093, which is 2.02 times that of a farmer's income. When \underline{w} is set at optimal, in rural areas those with human capital of 0.8 earn 0.6118, which is 2.03 times that of a farmer's income. When \underline{w} is high, in rural areas those with human capital of 0.8 earn 0.6191, which is 2.26 times that of a farmer's income. Table 2.6 indicates that inequality becomes worse in rural areas when w increases.

In urban areas the effect of w_{us} is very small when \underline{w} is low or optimal, and it decreases by 2.35% when \underline{w} is high. The income of capital owners changes by 0.36%, 0.43% and -7.51% respectively. The minimum wage increases the income ratio between capital owners and US workers when it is not binding for migrant workers, while it decreases this ratio when it is binding for migrant workers. The Gini coefficient, which is based on labor income only, keeps increasing from 0.1470 to 0.1737, suggesting that labor-income inequality is worsened with higher minimum wage for the whole country.

⁶⁶ Because I lack data about the number of capital owners, I assume the ratio between the incomes of capital owners and US workers is q when no minimum wage is present, given that the income is equally distributed among capital owners.

2.4.3.3 Welfare change

Because a minimum wage can restrict labor from entering the industrial sector, it benefits the workers who stay in UM. The effects on other workers depend on the value of the minimum wage. If the minimum wage is low and very close to the market equilibrium price, it may slightly benefit most workers, though the effects would be limited. If the minimum wage is slightly above the market equilibrium price, no rural workers will benefit from it. Table 2.4 and Table 2.5 compare the welfare changes for both rural and urban workers when the minimum wages are set at optimal (0.4814) and high (0.49), respectively. Figure 2.6 and Figure 2.7 indicate the changes of career allocations when the minimum wages are optimal (0.4814) and high (0.49), respectively. These tables indicate that a low minimum wage slightly benefits most workers. However, a high minimum wage benefits the migrant workers in UM at a high cost to all other workers.

Table 2.4. Welfare change after $w = 0.4814$ is enforced

	Rural workers human capital (# of workers, % in local labor force)				
	[0, 0.4678) (286.34, 59.53%)	[0.4678, 0.4690) (0.88, 0.18%)	[0.4690, 0.5998) (83.71, 2.28%)	[0.5998, 0.6039) (2.28, 0.47%)	[0.6039, 0.6295) (13.48, 2.80%)
Before	0.3018	0.3018-0.3026	0.3026-0.3610	0.3610-0.3623	0.3623-0.3777
After	0.3021	0.3021	0.3021-0.3606	0.3606-0.3631	0.3625-0.3784
% Δ	0.09	(-0.16)-0.09	(-0.16)-(-0.14)	(-0.14)-0.21	0.21
	Rural workers human capital (# of workers, % in local labor force)		Urban workers human capital (# of workers, % in local labor force)		
	[0.6295, 0.6342) (2.35, 0.49%)	[0.6342, 1] (91.97, 19.12%)	[0, 0.6214) (159.15, 56.24%)	[0.6214, 0.6295) (4.18, 1.48%)	[0.6295, 1] (119.68, 42.29%)
Before	0.3777-0.3805	0.3805-0.7079	0.4275	0.4275-0.4287	0.4287-0.7604
After	0.3779-0.3832	0.3807-0.7122	0.4270	0.4270	0.4814-0.7648
% Δ	0.21-0.72	0.60-0.72	-0.11	(-1.39)-(-0.11)	0.57

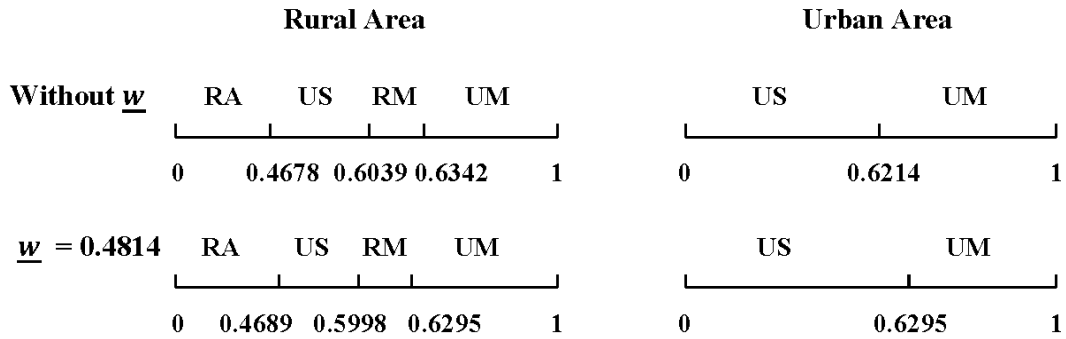


Figure 2.6. Career distributions after after $\underline{w} = 0.4814$ is enforced

Table 2.5. Welfare change after $\underline{w} = 0.4900$ is enforced

	Rural workers human capital (# of workers, % in local labor force)				
	[0, 0.4678) (286.34, 59.53%)	[0.4678, 0.4772) (6.82, 1.42%)	[0.4772, 0.5971) (76.31, 15.87%)	[0.5971, 0.6039) (3.74, 0.78%)	[0.6039, 0.6332) (15.34, 3.19%)
Before	0.3018	0.3018-0.3080	0.3080-0.3605	0.3605-0.3623	0.3623-0.3799
After	0.2738	0.2738	0.2738-0.3263	0.3263-0.3300	0.3300-0.3460
% Δ	-9.29	(-11.13)-(-9.29)	(-11.13)-(-9.48)	(-9.48)-(-8.91)	-8.91
	Rural workers human capital (# of workers, % in local labor force)		Urban workers human capital (# of workers, % in local labor force)		
	[0.6332, 0.6342) (0.49, 0.10%)	[0.6342, 1] (91.97, 19.12%)	[0, 0.6214) (159.15, 56.24%)	[0.6214, 0.6295) (4.18, 1.48%)	[0.6295, 1] (119.68, 42.29%)
Before	0.3799-0.3805	0.3805-0.7079	0.4275	0.4275-0.4815	0.4815-0.7604
After	0.3460-0.3465	0.3884-0.7214	0.4386	0.4386	0.49-0.7739
% Δ	-8.91	1.90-2.09	-7.18	(-8.91)-(-7.18)	1.77

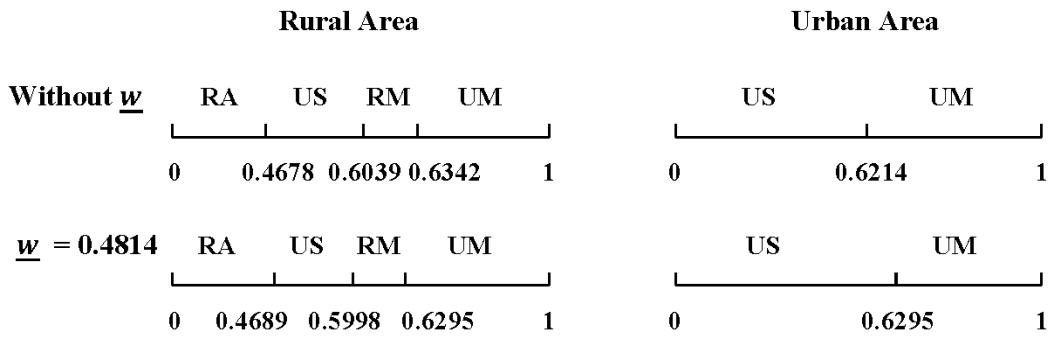


Figure 2.7. Career distributions after after $\underline{w} = 0.4900$ is enforced

2.5 Policy implication

China adopted a minimum wage policy in the 1990s when its physical labor mobility constraints were virtually removed. Table 2.4 shows the effects of enforcing a minimum wage. First, it protects the insiders in the UM sector by inducing fewer workers to join UM; thus k_u is greater, and every insider would earn a high wage. Nevertheless, the benefits enjoyed by the UM insiders come at a cost to the majority of other workers in the economy when the minimum wage is slightly higher than w_{us} , in particular, US and RA workers receive lower incomes. The effects on RM workers are uncertain: a low minimum wage benefits them as more high-ability rural workers leave RM for UM, while the median and high values of a minimum wage may hurt them because many high-ability rural workers may have to stay in RM. Second, enforcing minimum wage would have significant effects on migration flows, depending on its value. When \underline{w} is low, the MPN of the marginal migrant worker to UM is higher. Since fewer urban workers would stay in UM, the low \underline{w} would attract more migrant workers to work in UM. The migration flow to UM would thus be greater than before. In contrast, when \underline{w} is high, the market equilibrium MPN of the marginal migrant worker in UM is smaller, and the enforcement of a minimum wage would restrain rural workers from moving to UM, causing the migration flow to UM to drop. The effect on the migration flow to US, M_{us} , depends on two factors: w_{us} and the payoff from the rural sectors. When \underline{w} increases, fewer rural workers would be willing to move to US.

An important consideration is the effect of \underline{w} on the development of the economy as a whole, as well as on adjustments to social inequality. When the minimum wage is not high enough to constrain the qualified rural workers from moving to the UM sector, the economic grows, since the low-skilled urban workers are replaced by relatively high-skilled migrant workers; on the other hand, a insufficiently high minimum wage hurts economic growth since skilled workers are constrained from entering UM which would reduce aggregate outputs. In rural areas, a minimum wage enhances inequality: the higher the minimum wage, the worse the inequality in rural areas. In urban areas, imposing a minimum wage has the opposite effect, inducing a quicker drop in the capital owners' incomes relative to the incomes of US workers. Thus a high minimum wage enhances inequality in rural areas, but improves it in urban areas. The combination of imposing a minimum wage and controlling moving costs may yield a better balance between economic development and reducing inequality.

Keeping the assumption of surplus labor in the agriculture sector, and focusing on manufacturing sectors only, when compared with the second best outcome in which the workers with human capital higher than 0.6112 work in the manufacturing sectors, we notice that the RM sector has some lower skilled workers while the UM sector has higher skilled workers at the market equilibrium. To achieve the second best outcome, the minimum requirements on human capital must be the same for the RM and UM sectors, implying that a_M equals a_Z . Since rural workers with a_M are indifferent between entering either the US or the RM sectors, and since urban workers with a_Z are indifferent between entering the US or UM sectors, a_M is smaller than a_Z provided moving costs exist. Thus, to make them equal, the moving costs must be fully compensated for those migrant workers moving from RM to US. Such compensation could be provided to encourage the RM workers at the margin to move to urban areas. Furthermore, since minimum wage policy can be used to adjust the minimum human capital with which workers stay in the manufacturing sectors, it need not be binding for migrant workers in UM. Otherwise, since a_X equals a_Z , a_M must be smaller than a_Z .

Although China has increased the level of its minimum wages several times recently, many export-oriented enterprises in eastern coastal areas (even in the central region of China) cannot recruit enough rural migrants to fill their orders.⁶⁷ This fact does not imply that my model fails but model parameters or functional forms change, especially the moving costs (in which the portion of non-money psychic cost has been increasing dramatically, due to extreme long working hours, wage arrears, etc.). In the meantime, rural workers have less incentive to move because of the improved working conditions in rural areas. Those changes bring about transitions back and forth off equilibrium. Even though increasing wages and/or decreasing moving costs may attract more migrant workers, the enforcement costs would also increase dramatically. Instead, allocating physical capital by considering the labor force allocation may be more effective in increasing the output of the manufacturing sectors. This would require a change in government strategy. When urban areas have significant advantages over rural areas, labor follows capital. Nowadays, since transportation, medical and education systems have been much improved in rural areas, capital may start to follow labor.

2.6 Conclusion

In this paper, I present a theoretical model with heterogeneous agents, endogenous internal migration, and endogenous labor markets, and calibrate this model to analyze the effects of China's minimum wage policy on its economic development and inequality issues within the country's urban and rural areas. Because China's government adopted an urban-biased investment strategy since it was founded, the investment decisions are exogenous in the model as the source of inequality between urban and rural areas. Nevertheless, as heterogeneous workers are looking for jobs in two regions (urban and rural areas) and across four sectors (urban modern industry

⁶⁷ Please refer to a report, The Investigation on the Shortage of Migrant Workers, which was published by South Weekend (Nanfang Zhoumo) on March 3rd, 2011.

sector (UM), urban subsistence sector (US), rural modern industry sector (RM), and rural traditional agricultural sector (RA)), at equilibrium, high-ability rural workers go to the UM sector, while workers who stay in the RM sector may come from two discontinuous groups. All workers who are between the two groups have an incentive to move to the US sector. An enforced minimum wage may have different effects on the economy, depending on whether or not it is binding for migrant workers in the urban industrial sector. If not, the minimum wage policy replaces low-skilled urban UM workers with relatively high-skilled migrant workers, benefiting the whole economy. Otherwise it negatively affects the whole economy, while helping to slow down the inequality enhancement in cities. To achieve the second best outcome, full compensation of moving costs should be given to the marginal migrant workers from the RM to the US sector, and the minimum wage should not be binding for migrant workers in the UM sector.

Although most stylized facts related to China's internal migration can be explained from my model, it has several weaknesses that point to possible extensions in future research, besides potential improvement in specific function forms. First, the economy in my model is assumed to fully follow market principles. In the real world, however, China is still transitioning from a planned economy to a market economy, though it has already changed from a closed economy to a large open economy during the process of marketization.⁶⁸ My model does not capture the price distortion occurring at the beginning of China's economic reform or some features of an open economy.⁶⁹ Second, my model is a static model and no dynamics are included in the agent's utility function, while in reality people think not only about their current benefits but also about their future welfare. This static model also fails to explain the urban-rural inequality change. Third, though I mention that human capital can be influenced by education and

⁶⁸ China began its economic reform in 1979 and declared its market economy in 1992. As of February 2008, China's market economy status has not yet been recognized by the US or the EU, though it has been recognized by 77 other countries.

⁶⁹ The price scissors between industrial goods and agricultural goods existed in China until 1992 when the country declared itself as a market economy. See Lin and Yu(2009).

job training, I do not assume options for agents to accumulate human capital. Because urban areas have better education resources, another incentive is present for the rural workers to move. Such issues are explicitly clear in Lucas (2004). Fourth, since no unemployment is present, no uncertainty exists in my model, which is not consistent with the actual economy. 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 by using a search model. These authors all provide good hints on how to incorporate unemployment into the present model.

2.7 References

- Andolfatto, D., 2008. Search Models of Unemployment. The New Palgrave Dictionary of Economics, 2nd edition.
- Ashenfelter, O., Farber, H., Ransom, M., 2010. Labor Market Monopsony. *Journal of Labor Economics*. 28(2), 203--210.
- Boal, W., Ransom, M., 1997. Monopsony in the Labor Market. *Journal of Economic Literature*. 35(1), 86--112.
- Borjas, G., 1987. Self-Selection and the Earnings of Immigrants. *The American Economic Review*. 77, 531--553.
- Broadway, R., Cuff, K. 2001. A minimum wage can be welfare-improving and employment-enhancing. *European Economic Review*. 45, 553--576.

- Cheng, Y., 2007. The Evolution of China's Gini Coefficient and Its Decomposition Between Urban and Rural Areas After Economic Reform (in Chinese: Gaige Yilai Chengxiang Zhongti Gini Xishu de Yanbian Jiqi Chengxiang Fenjie). *China's Social Science (Zhongguo Shehui Kexue)*. 4.
- Cole, W., Sanders, R., 1985. Internal Migration and Urban Employment in the Third World. *The American Economic Review*, 75(3), 481--494.
- Cooper, R., 1985. Worker Asymmetric Information and Involuntary Unemployment. *Journal of Labor Economics*. 3(2), 188--208.
- Drazen, A., 1986. Optimal Minimum Wage Legislation. *The Economic Journal*. 96, 774--784.
- Guo, X., 2004. A New Estimation of the Income Gap Between Rural and Urban Areas (in Chinese: Chenxiang Shouru Chaju de Xinguji). *Shanghai Economic Study (Shanghai Jinji Yanjiu)*. 12.
- Harris, J., Todaro, M., 1970. Migration, Unemployment and Development: A Two-sector Analysis. *The American Economic Review*. 60(1), 126--142.
- Lin, J., Yu, M., 2009. The Political Economic Analysis of China's Price Scissors: Theory Model and Empirical Evidence (in Chinese: Wogou Jiage Jiandaocha de Zhengzhi Jingjixue Fenxi: Lilun Moxin Yu Jiliang Shizheng). *Economic Study (Jingji Yanjiu)*, 1, 422--456.
- Lu, Y., 2002. China's Hukou System After 1949: Structure and Evolution (in Chinese: 1949 Nian Hou De Zhonggou Huji Zhidu: Jiegou Yu Bianqian). *Journal of Peking University (Beijing Daxue Xuebao)*. 2.
- Lucas, R., 2004. Life Earnings and Rural-Urban Migration. *Journal of Political Economy*. 112(1), S29--S59.
- Naughton, B., 2007. *The Chinese Economy: Transitions and Growth*. MIT Press. Cambridge.
- Pan, X., Sun, G., 2008. A Survey and Analysis on the Education of the Children of Migrant Workers (in Chinese: Jincheng Mingong Zinu Jiating Jiaoyu De Diaocha Yu Fenxi). *Journal of the Party School of CPC Hangzhou (Zhonggong Hangzhou Shiwei Dangxiao Xuebao)*. 4.
- Ravallion, M., and Chen, S., 2007. China's (uneven) progress against poverty. *Journal of Development Economics*. 82, 1--42.
- Roy, A.D., 1951. Some Thoughts on the Distribution of Earnings. *Oxford Economic Papers*. 3, 1352--146.
- Sharma, H., 2007. Sources of Economic Growth in China, 1952-1998. *Issues in Political Economy*, 17.

- Shoven, J., and Whalley, J. 1992. *Applying General Equilibrium*. Cambridge University Press.
- Sjaastad, L., 1962. The Costs and Returns of Human Migration. *The Journal of Political Economy*. 70(5), 80--93.
- Strobl E., Walsh F., 2007. Dealing with monopsony power: Employment subsidies vs. minimum wages. *Economics Letters*. 94, 83--89.
- Wang, F., Zuo, X., 1999. Inside China's Cities: Institutional Barriers and Opportunities for Urban Migrants. *The American Economic Review*. 89, 276--280.
- Watanabe, S. 1976. Minimum wages in developing countries: myth and reality. *International Labour Review*. 113, 345--58.
- Whalley, J., Zhang, S., 2007. A Numerical Simulation Analysis of (Hukou) Labour Mobility Restrictions in China. *Journal of Development Economics*. 83, 392--410.
- Yang, D., 1999. Urban-Biased Policies and Rising Income Inequality in China. *The American Economic Review*. 89(2), 306--310
- Yao, S., 1994. *Agricultural Reforms and Grain Production in Rural China*. Palgrave Macmillan.
- Zen, F., 2002. On the Interaction of Urbanization and Industry Structure (in Chinese: Lun Chengshihua Yu Chanye Jiegou De Hudong Guanxi). *Economic Review (Jingji Zhongheng)*, 10.
- Zhao, Y., 1999. Labor Migration and Earnings Differences: The Case of Rural China. *Economic Development and Cultural Change*. 47(4), 767--782.
- Zhang, W., Lei, K., 2008. The Analysis of the Structure, Status Quo and Determinants of a New Urban Migrant's Social Integration (in Chinese: Chengshi Xinyimin Shehui Ronghe). *Sociology Study (Shehuixue Yanjiu)*. 5.

2.8 Appendices

Appendix 2.A: relative price forming

Assume the homogeneous utility function over agricultural and industrial goods is:

$$U(x_A, x_M) = x_A^a x_M^b \quad (2.A1)$$

With different income levels m_i and a normalized price of industrial goods, the optimal consumption of each person is:

$$x_A^* = \frac{q}{a+b} \frac{m_i}{P} \quad (2.A2)$$

$$x_M^* = \frac{b}{a+b} m_i \quad (2.A3)$$

We have:

$$\frac{x_A^*}{x_M^*} = \frac{a}{b \cdot P} \quad (2.A4)$$

To clear the market, x_A^*/x_M^* must equal y_a/y_M which gives us:

$$P = \frac{a}{b} \left(\frac{y_a}{y_M} \right)^{-1} \quad (2.A5)$$

Generalizing it I assume the relative price forming function as equation 2.4.

Appendix 2.B: mathematical equilibrium in figure 2.3a

Mathematically, employment levels in the urban sectors, N_{US} and N_{UM} are defined as:

$$N_{us} = L_r \int_{a_N}^{a_M} p^r(a_r) da_r + L_u \int_0^{a_Z} p^u(a_u) da_u \quad (2.B1)$$

$$N_{um} = L_r \int_{a_X}^1 p^r(a_r) da_r + L_u \int_{a_Z}^1 p^u(a_u) da_u \quad (2.B2)$$

Because some previous farmers would move to RM, the employment levels in rural areas now change. Now a farmer with human capital a_L is indifferent between working in RA or RM, and the employment levels in RA and RM are:

$$N_{RA} = L_r \int_0^{a_L} p^r(a_r) da_r \quad (2.B3)$$

$$N_{RM} = L_r \int_{a_L}^{a_N} p^r(a_r) da_r + L_r \int_{a_M}^{a_X} p^r(a_r) da_r \quad (2.B4)$$

The relative price, P , is defined as:

$$P = \rho\left(\frac{y_a}{y_{um} + y_{rm}}\right) \quad (2.B5)$$

where y_a , y_{rm} and y_{um} are defined as:

$$\bar{y}_a = g(N_{RA}) \quad (2.B6)$$

$$y_{rm} = L_r \int_{a_L}^{a_N} h\left(a_r, \frac{K_u}{N_{RM}}\right) p^r da_r + L_r \int_{a_M}^{a_X} h\left(a_r, \frac{K_u}{N_{RM}}\right) p^r da_r \quad (2.B7)$$

$$y_{um} = L_r \int_{a_X}^1 f\left(a_r, \frac{K_u}{N_{UM}}\right) p^r da_r + L_u \int_{a_Z}^1 f\left(a_u, \frac{K_u}{N_{UM}}\right) p^u(a_u) da_u \quad (2.B8)$$

At equilibrium, the rural worker with a_L must be indifferent between farming and working in RM; that is:

$$h'_N\left(a_L, \frac{K_r}{N_{RM}}\right) = P \cdot g'(N_{RA}) \quad (2.B9)$$

For the rural worker with a_N who is indifferent between working in RM and US:

$$h'_N\left(a_N, \frac{K_r}{N_{RM}}\right) = w_{us}(y_{um}, N_{US}) - C(a_N) \quad (2.B10)$$

For the rural worker with a_M who is indifferent between working in RM and US:

$$h'_N\left(a_M, \frac{K_r}{N_{RM}}\right) = w_{us}(y_{um}, N_{US}) - C(a_M) \quad (2.B11)$$

For the rural worker with a_X who is indifferent between working in RM and UM:

$$h'_N\left(a_X, \frac{K_r}{N_{RM}}\right) = f'_N\left(a_X, \frac{K_u}{N_{UM}}\right) - C(a_X) \quad (2.B12)$$

For the urban worker with a_Z who is indifferent between working in US and UM:

$$w_{us}(y_{um}, N_{US}) = f'_N \left(a_Z, \frac{K_u}{N_{UM}} \right) \quad (2.B13)$$

With the expression of P which is shown in equation 2.B5, the equation system with equation 2.B9, 2.B10, 2.B11, 2.B12 and 2.B13 determines the values of a_L , a_N , a_M , a_X , a_Z . To make extra labor enter RM, at equilibrium the solutions must satisfy:

$$h'_N \left(a_N, \frac{K_r}{N_{RM}} \right) \geq P \cdot g'(N_{RA}) \quad (2.B14)$$

Appendix 2.C: mathematical equilibrium in figure 2.3b

N_{RM} is the employment in RM:

$$N_{RM} = L_r \int_{a_M}^{a_X} p^r(a_r) da_r \quad (2.C1)$$

The wage of farmers is:

$$w = P \cdot g'(N_{RA}) \quad (2.C2)$$

where P is the relative price which is determined by:

$$P = \rho \left(\frac{y_a}{y_{um} + y_{rm}} \right) \quad (2.C3)$$

where y_a , y_{rm} , and y_{um} are the equilibrium outputs of RA, RM and UM sectors, which are defined in equation 2.C7, 2.C8, and 2.C9.

The employment levels of RA, US and UM are:

$$N_{RA} = L_r \int_0^{a_N} p^r(a_r) da_r \quad (2.C4)$$

$$N_{US} = L_r \int_{a_N}^{a_M} p^r(a_r) da_r + L_u \int_0^{a_Z} p^u(a_u) da_u \quad (2.C5)$$

$$N_{UM} = L_r \int_{a_X}^1 p^r(a_r) da_r + L_u \int_{a_Z}^1 p^u(a_u) da_u \quad (2.C6)$$

The outputs of RA, RM and UM are:

$$y_a = g(N_{RA}) \quad (2.C7)$$

$$y_{rm} = L_r \int_{a_M}^{a_X} h\left(a_r, \frac{K_u}{N_{RM}}\right) p^r da_r \quad (2.C8)$$

$$y_{um} = L_r \int_{a_X}^1 f\left(a_r, \frac{K_u}{N_{UM}}\right) p^r da_r + L_u \int_{a_Z}^1 f\left(a_u, \frac{K_u}{N_{UM}}\right) p^u(a_u) da_u \quad (2.C9)$$

The rural worker with a_N must be indifferent between working in agricultural and US; that is:

$$P \cdot g'(N_{RA}) = w_{us}(y_{um}, N_{US}) - C(a_N) \quad (2.C10)$$

The rural worker with a_M must be indifferent between working in RM and US; that is:

$$h'_N\left(a_M, \frac{K_r}{N_{RM}}\right) = w_{us}(y_{um}, N_{US}) - C(a_M) \quad (2.C11)$$

The rural worker with a_X must be indifferent between working in RM and UM; that is:

$$h'_N\left(a_X, \frac{K_r}{N_{RM}}\right) = f'_N\left(a_X, \frac{K_u}{N_{UM}}\right) - C(a_X) \quad (2.C12)$$

The urban worker with a_Z must be indifferent between working in US and UM; that is:

$$w_{us}(y_{um}, N_{US}) = f'_N\left(a_Z, \frac{K_u}{N_{UM}}\right) \quad (2.C13)$$

Because my employment functions and output functions are all of a_N , a_M , a_X and a_Z , the equilibrium values are determined by solving the equation system containing 2.C10, 2.C11, 2.C12, and 2.C13. To make no extra labor enter RM, at equilibrium the solutions must satisfy:

$$h'_N\left(a_N, \frac{K_r}{N_{RM}}\right) \leq P \cdot g'(N_{RA}) \quad (2.C14)$$

Chapter 3. Population growth and the Environmental Kuznets Curve

3.1 Introduction

The side effects of economic growth on environmental quality were brought to the attention of economists after worldwide environmental degradation was observed in the 1960s. Many economists claimed that the pollution emissions evidenced in some local environmental health indicators, such as water and air pollutants, displayed an inverted-U shape with respect to economic growth, which is summarized as the Environmental Kuznets Curve: pollution is rising at the stage of low income per capita, while the trend is reversed after a threshold is reached. If the EKC hypothesis is plausible, most developing countries which are at low income levels must suffer from rising pollution. Since developing countries often have fast population growth, this raises the question: what effect does population growth have on environmental quality? In this paper, I first build a theoretical model to induce the EKC to analyze those effects of positive population growth which are shown by simulations. By using an overlapping generations (OLG) model, I focus on technological effects, where the properties of the existing pollution abatement technologies could generate the inverted U-shaped EKC and other growth-pollution paths for the less advanced economies. If the EKC exists, positive population growth does not change its overall pattern despite its significant effects on the slope of the EKC. I then apply a fixed-effect model by using the panel data from China to examine the effects of population growth on the pollution paths for several pollutants which have only local effects, such as SO_2 , waste water, and industrial waste gas. Empirical evidence from China partially supports these results.

Extensive literature is available regarding the theory and empirical evidence for the EKC, the former of which were developed in the early 1970s. One plausible explanation is based on the perspective of a natural progression of economic development: the economy starts from a clean agrarian economy, develops into a polluting, industrial economy, and then develops into a clean, service-based economy (Arrow et al., 1995). Other theories are focused on scale, technological, and composition effects, as advocated by Grossman and Krueger (1991). Some follow the endogenous growth theory, and extend the basic dynamic growth model of Ramsey, Cass, and Koopmans to include the environment and the disutility of pollution (Selden and Song, 1995; Dinda, 2005).

An important factor for the EKC is technological change, including both production technology and abatement technology. Production technologies differ in their pollution intensity. According to Stokey (1998), at a low level of per capita income the pollution-intensive production process is implemented; after income per capita becomes high enough, so clean production technology becomes available. Andreoni and Levinson (2001) focused on the characteristics of abatement technology and showed that the EKC can be explained with increasing returns to scale in abatement technology. The EKC can also be derived from an overlapping generations (OLG) model, as in John and Pecchenino (1994), and Cao et al. (2011). We also consider other explanations based on the change in consumer preferences over environmental quality, as in Barbier (1997) and Carson et al. (1997). Vita (2007) indicated the crucial role played by the discount factor in inducing the EKC.

Pioneering empirical work was done by Grossman and Krueger (1991), who used SO₂ and "dark matter" as pollution variables and found the EKC peaks under \$5000 (1985 U.S. dollars) for both. Panayotou (1993), Seldon and Song (1994), and Shafik (1994) also suggested the existence of the EKC. Nevertheless, other studies have cast doubt on it. Holtz-Eakin and Selden (1995) showed the absence of an EKC for CO₂; and Grossman and Krueger (1995) found an N-shaped relation between emissions of SO₂ and output. Later, empirical studies were improved (either "statistically" or "methodologically"), but some findings still favored the existence of the EKC, such as Panayotou (1997), Hilton and Levinson (1998), Song et al. (2007), Wagner (2008), Jiang, Lin and Zhang (2008) and Martinez-Zarzoso and Maruotti (2011). Others, such as

Carson et al. (1997), Koop and Tole (1999), Roy and Van Kooten (2004), Caviglia-Harris et al. (2009), Du, Wei and Cai (2012) did not. Many economists have claimed that population growth plays an important role in shaping the EKC. Panayotou (1993) found that the turning point is delayed by a higher population density, and Panayotou (1997) proved that population density raises the height of the EKC for SO₂ at every level of income. Some findings indicate that the effect of fast population growth on the environment quality is negative (i.e., Cropper and Griffiths, 1994; Nguyen, 2003), while others conclude that it is positive (i.e., Vincent, 1998).⁷⁰

My theoretical analysis takes place in two steps. The first step is to develop a model inducing the EKC. I focus on technological effects and follow many economists by assuming that pollution is an unavoidable by-product of production. In the OLG model, I assume that only parents make all the decisions for their household while children have no decisive influences, to simplify inter-generation effects. Environmental quality is assumed to only affect children, but adults must consider it. When adults maximize their current utility, the inverted-U-shaped EKC may be induced. The properties of both production and abatement technologies are the joint deterministic factors that shape the growth-pollution path. It can be an inverted-U-shape or an N-shape, depending on the evolution of both technologies. The second step is to use another benefit of the OLG model to examine the effects of population growth on the EKC. On one side, the positive population growth puts pressure on consumption and, consequently, production, which generates more pollution. On the other side, parents are more concerned about the environmental quality if they have more children. The results from the model indicate that the consumption effect dominates the environmental effect when agents are poor, but the environmental effect takes over after agents become rich. Simulations are provided to graphically present the model's results, clearly indicating the negative effect

⁷⁰ Cropper and Griffith (1994) found an inverted U-relationship between deforestation and income and a positive relationship between deforestation and population growth by using panel data for Asia, Africa and Latin America over 1961-1988; Nguyen(2003) suggested population pressure exerts a positive effect of the rate of deforestation; Vincent (1998) found the net impact of population density on total suspended particulates concentration was positive in Malaysia.

of population growth on environmental quality. By using the panel data from China, I examine the pollution paths of SO₂, waste water, and industrial waste gas in six regions of China. The findings partially support my model since negative effects of population growth on the EKC are observed when it is rising in some regions for certain pollutants (for waste water in the East, and for waste gas in the North).

The rest of this paper is organized as follows. Section 3.2 contains the model set-up and analysis. Section 3.3 analyzes the effects of positive population growth on pollution and environmental quality. Section 3.4 presents numerical simulations for my model. Section 3.5 provides empirical evidence from China. Section 6 concludes the paper.

3.2 Model

3.2.1 Assumptions

I consider an overlapping generations model (OLG) in which agents live for two periods and then die. Agents are children in the first period and adults in the second period. The initial population is normalized to 1. The gross population growth rate is η . Every adult has η children at the beginning of period two, and lives with her children in this period. Every child is a net receiver. As a child, every agent is in the custody of her parents and is endowed with nothing. Every child's consumption comes from her parent's consumption decisions. A child makes no economic decisions, neither for her own consumption, nor for the method of production. As an adult, every agent makes decisions for herself and for her children. Adults determine their consumption levels and environmental abatement investments. Every adult is endowed with human capital, H_t , at period t . Because knowledge can be passed along from parent to child, human capital is assumed to accumulate over time, and to increase at an exogenous growth rate, h . Every child is ready to work at the beginning of period two. At the beginning of period 2, workers have to determine how to allocate their human capital between production and the development of green production technology.

I assume that every adult owns a firm, and that the market is competitive. In equilibrium, no firm makes positive profits. For simplicity, labor is the only variable input in the production process. The production function is $y_t = f(L_t)$, with $f'(\cdot) > 0 > f''(\cdot)$, and L_t is the actual human capital input used. Following many environmental economists, I assume that pollution is a side-effect of production: pollution is increasing in output. Firms have options from a variety of different production technologies which differ only in terms of their pollutive intensity. A greener, more environmentally-friendly technology is less pollution-intensive but requires more fixed input in terms of human capital, z , to cover the research cost and/or training cost, since it may be more complicated to manipulate. $z = 0$ means that firms make no effort to reduce pollution, which represents the most pollution-intensive technology. At each period, human capital is used either as the input for the production process or as the fixed cost required by the specific production technology. Pollution emission is determined by the function

$$p_t = \eta^t \cdot g(z_t) \cdot f(H_t - z_t) \quad (3.1)$$

z_t is the fixed cost required by production technology at period t , and η^t acts as an index of the number of firms. $g(z_t)$ measures the degree of the pollution-intensive technology. Because greener production technology implies less pollution emission, $g(z_t) > 0$, $g'(z_t) < 0$ and $g''(z_t) > 0$. Moreover, I assume that $g(z_t)$ is bounded between $[\underline{g}, \bar{g}]$ because of technological constraints. I assume that $g(0) = \bar{g}$. This function implies the substitution between greener production technology and higher output level.

Environmental quality evolves over time according to

$$E_{t+1} - E^* = (1 - b)(E_t - E^*) - \max(0, p_t - \bar{p}) \quad (3.2)$$

where b is between 0 and 1, measuring the self-adjustment ability of nature.⁷¹ Without human activity, environment quality eventually converges to E^* , which is an equilibrium.

⁷¹ The self-adjustment ability has also been considered by other economists, such as John and Pecchenini (1994), etc

Because the research literature shows that the earth can absorb and purify minor quantities of pollutants, especially because of the chemical properties of some vegetation, I assume that environmental quality would not be affected by small amounts of pollution. That is, the harm to the environment is not irreversible.⁷² Yet the amount of pollution that can be absorbed by the ecosystem is limited. For simplicity, I assume the limit is \bar{p} . Therefore, when production begins, environmental quality degrades by the amount of $\max[0, p_t - \bar{p}]$ at time t .

3.2.2 Model analysis

Because agents own the firms, they earn all the profit and make decisions about human capital allocations to maximize their utility with consideration to that of their households. As adults, the agents are physically stronger than their children, thus environmental quality doesn't affect them directly, but rather only through the utilities of their children whose health is directly affected by environmental quality. Because parents care about their children, their total utility function embodies the happiness of both. Adults place more weight on their children's utilities if they have more children. At period t , the utility function of an adult is assumed to be:

$$U(c_{at}, c_{ct}, E_t) = c_{at} \cdot (c_{ct} \cdot E_t)^\eta \quad (3.3)$$

where η is the gross population growth rate, c_{at} is the consumption of the adult, c_{ct} is the total consumption of the children in the household and E_t is the environment quality, which is determined by the level of z_t .

Every adult divides her human capital into either an input in production, H_{pt} , or as the fixed cost of adopting a certain production technology, z_t . I normalize the first-period human capital to 1 and assume that the exogenous growth rate of human capital is h . At each period, we have:

⁷² Some of these papers are on the biological purification of sewage from chemical plants, and document research on the ability of 21 ornamental plants to absorb and purify environmental pollutants, such as Koren'kov (1991) and Wang et al. (2006).

$$H_{pt} + z_t = (1 + h)^t \quad (3.4)$$

Total consumption comes from the adult's income, w_t . Because the agent owns the firm and takes all the output, $w_t = f(H_{pt})$.

By combining the information about production technology and environment evolution, the agent's problem is:

$$\begin{aligned} \max_{c_{at}, c_{ct}, E_t} \quad & U(c_{at}, c_{ct}, E_t) = c_{at} \cdot (c_{ct} \cdot E_t)^\eta \\ \text{s. t.} \quad & c_{at} + c_{ct} = f(H_{pt}) \\ & H_{pt} + z_t = (1 + h)^t \\ & E_{t+1} - E^* = (1 - b)(E_t - E^*) - \max(0, p_t - \bar{p}) \\ & p_t = \eta^t \cdot g(z_t) \cdot f(H_t - z_t) \end{aligned}$$

To consider the effect of population growth on environment quality, I start with the agent's problem under the assumption of zero population growth. The pollution emission function and utility function are then:

$$p_t = g(z_t) \cdot f(H_t - z_t) \quad (3.1')$$

$$U(c_{at}, c_{ct}, E_t) = c_{at} \cdot c_{ct} \cdot E_t \quad (3.3')$$

To solve this problem, I decompose it into the following three stages: At first, because the agent has very little human capital and the output is thus low, I assume that $g(0) \cdot f(H_t) \leq \bar{p}$. In the second stage, after human capital accumulates to a certain level, the firms can generate more pollution than \bar{p} . The environmental quality degrades, and agents need to think of ways to balance consumption with environmental quality. The third stage begins after agents adopt a very green technology such that the pollution level can decrease back below \bar{p} .

Stage 1: $H_t < \bar{H}$ where $g(0) \cdot f(\bar{H}) = \bar{p}$.

At this stage, the outcome is trivial. Although agents adopt the most pollution-intensive technology, the pollution emissions are still less than the limit that can be absorbed by the ecosystem, and environmental quality does not change. Thus agents have no incentive to sacrifice any of their household consumption, and they spend nothing on adopting greener technology ($z_t = 0$). If environmental quality starts from its natural equilibrium, $E = E^*$ for the duration of the stage.

Stage 2: $\bar{H} < H_t < \tilde{H}$ where $g(z(\tilde{H})) \cdot f(\tilde{H} - z(\tilde{H})) = \bar{p}$ for $z(\tilde{H}) > 0$.⁷³

Pollution becomes more severe as H_t grows. If firms ignore the negative impact on the environment but only focus on their production, the pollution they produce begins to exceed the level that the earth can absorb ($g(0)f(H_t) > \bar{p}$). Adopting the most pollution-intensive technology may not be optimal, since the environmental quality starts to degrade; thus agents consider adopting greener technology to balance consumption with environmental quality. To find the optimal solution, I use the Lagrangian function:

$$L = c_{at} \cdot c_{ct} \cdot E_t + \lambda_t [(1 - b)E_{t-1} + bE^* - g(z_t) \cdot f(H_t - z_t) + \bar{p} - E_t] + \mu_t [f(H_t - z_t) - c_{at} - c_{ct}] \quad (3.6)$$

FOCs are

$$c_{at}: \quad c_{ct} \cdot E_t = \mu_t \quad (3.7)$$

$$c_{ct}: \quad c_{at} \cdot E_t = \mu_t \quad (3.8)$$

$$E_t: \quad c_{at} \cdot c_{ct} = \lambda_t \quad (3.9)$$

$$z_t: \quad -\lambda_t [g'(z_t) \cdot f(H_t - z_t) - g(z_t) \cdot f'(H_t - z_t)] = \mu_t f'(H_t - z_t) \quad (3.10)$$

$$\lambda_t: \quad E_t - E^* = (1 - b)(E_{t-1} - E^*) - g(z_t) \cdot f(H_t - z_t) + \bar{p} \quad (3.11)$$

⁷³ $z(H)$ is implicitly defined by equation system (3.11) and (3.15)

$$\mu_t: c_{at} + c_{ct} = f(H_t - z_t) \quad (3.12)$$

To solve this equation system, I start from (3.7), (3.8), (3.9) and (3.12). The Lagrangian multipliers are expressed as

$$\lambda_t = \left[\frac{f(H_t - z_t)}{2} \right]^2 \quad (3.13)$$

$$\mu_t = \left[\frac{f(H_t - z_t)}{2} \right] E_t \quad (3.14)$$

Then, substituting equations (3.13) and (3.14) into equation (3.10), we have:

$$- [f(H_t - z_t)]^2 g(z_t) + f(H_t - z_t) g(z_t) \cdot f'(H_t - z_t) - 2E_t f'(H_t - z_t) = 0 \quad (3.15)$$

Equation (3.15) suggests that corner solutions to this problem, if E_t is very big and $f(\cdot)$ is very small, may cause the equation to not hold. There are only two corners: one is $z_t = H_t$, which implies that no output is produced. If this were the case, the economy would collapse, making our analysis meaningless. The other corner is $z_t = 0$, which means that agents spend all of their human capitals in production use, and opt to use the most pollution-intensive technology. Also, if $f(\cdot)$ is a very big number, equation (3.15) would hold only when choosing a positive z_t . Thus, when environmental quality is very good and the output level is low, we run into corner solutions with $z_t = 0$ and equation (3.15) does not hold. Within these periods agents exert all efforts to maximize their outputs and the pollution emission dramatically increases. After the economy becomes richer, equation (3.15) starts to hold with a large $f(\cdot)$. The problem then has interior solutions. Suppose that the corner solution ends at period T , when the human capital of an agent is H_T . I assume that $H_T > \bar{H}$. The following studies the case after period T .

Proposition 3.1: *An agent invests more in green technology when her human capital accumulates, i.e., $dz_t/dH_t > 0$, if $f''(\cdot) < 0 < f'(\cdot)$ and $g'(\cdot) < 0$.*

Proof. Totally differentiate equation (11) and (15) and solve the two new differentiation equations for (dz_t/dH_t) . Under the condition that $f''(\cdot) < 0 < f'(\cdot)$ and $g'(\cdot) < 0$, we have $dz_t/dH_t > 0$ and $dz_t/dH_t < 1$. The detailed proof is shown in the appendix.⁷⁴

Proposition 3.1 suggests that an agent prefers a greener technology when the economy becomes richer and her human capital accumulates. When human capital accumulates, agents are capable of producing more output, which makes it possible for households to enjoy more consumption than before. Since pollution is the by-product of the production process, the higher output level leads to more serious environmental problems. If the damage from environmental degradation to the household is more than the benefits from more consumption, adults must try to achieve a balance. When agents are richer, they are less able to tolerate environmental degradation. Therefore, as human capital accumulates, agents always prefer greener technology, and allocate part of their extra human capital as the fixed cost to adopt it. The rest of their extra human capital is put into the production process and households can still achieve higher consumption levels.

Is it still possible to observe the inverted-U-shaped relationship between pollution emission and economic growth, given a different path of pollution emission?

Proposition 3.2: The pollution emission shows an inverted-U shape with economic growth over time, in the range where the degree of "relative curvature" of $g(\cdot)$ to $f(\cdot)$ is very high initially and then decreases.⁷⁵

Proof: Because $dz_t/dH_t < 1$, with the exogenous growth of human capital, the input in the production process, the outputs are both increasing over time. Because z_t is

⁷⁴ See the appendix 3.A, proof of proposition 3.1.

⁷⁵ The "relative curvature" of $g(\cdot)$ to $f(\cdot)$ is defined as $\frac{d(g(\cdot)/g'(\cdot))}{dz_t} + \frac{d(f(H_t-z_t)/f'(H_t-z_t))}{d(H_t-z_t)}$

increasing overtime as well, if I can calculate that dp_t/dH_t is positive when H_t is small, and negative when H_t is large, then the inverted-U shaped relationship between pollution emission and economic growth can be derived.

$$\begin{aligned}
\frac{dp_t}{dH_t} &= \frac{d[g(z_t) \cdot f(H_t - z_t)]}{dH_t} \\
&= g'(z_t) \cdot f(H_t - z_t) \frac{dz_t}{dH_t} + g(z_t) \cdot f'(H_t - z_t) \left(1 - \frac{dz_t}{dH_t}\right) \\
&= g'(z_t) \cdot f(\cdot) \frac{-2f(\cdot)f'(\cdot)g(z_t) + 3[f'(\cdot)]^2 g'(z_t) - \frac{[f(\cdot)]^2 f''(\cdot)g'(z_t)}{f'(\cdot)}}{D} + g(z_t)f'(\cdot) \frac{-3f(\cdot)f'(\cdot)g'(z_t) + [f(\cdot)]^2 g''(z_t)}{D} \\
&= \frac{-2[f(\cdot)]^2 f'(\cdot)[g'(z_t)]^2 + [f(\cdot)]^2 f'(\cdot)g(z_t)g''(z_t) - [f(\cdot)]^3 f''(\cdot)[g'(z_t)]^2 / f'(\cdot)}{D} \\
&= \frac{[f(\cdot)]^2}{f'(\cdot)D} ([g'(z_t)]^2 f(\cdot)f'(\cdot) - 2[f'(\cdot)]^2 [g'(z_t)]^2 + [f'(\cdot)]^2 g(z_t)g''(z_t)) \\
&= \frac{[f(\cdot)]^2}{[g'(z_t)]^2 [f'(H_t - z_t)]^3 D} \left(\frac{g(z_t)g''(z_t) - [g'(z_t)]^2}{[g'(z_t)]^2} + \frac{f(\cdot)f''(H_t - z_t) - [f'(H_t - z_t)]^2}{[f'(H_t - z_t)]^2} \right) \tag{3.16}
\end{aligned}$$

where $D = -\frac{\partial F(H_t, z_t, E_t)}{\partial z_t} + 2[f'(H_t - z_t)]^2 g(z_t) - 2f'(H_t - z_t)g'(z_t) \cdot f(H_t - z_t) > 0$.⁷⁶

Because $\frac{[f(\cdot)]^2}{[g'(z_t)]^2 [f'(\cdot)]^3 D} > 0$, $\frac{dp_t}{dH_t}$ has the same sign as

$$\frac{g(z_t)g''(z_t) - [g'(z_t)]^2}{[g'(z_t)]^2} + \frac{f(\cdot)f''(\cdot) - [f'(\cdot)]^2}{[f'(\cdot)]^2} \tag{3.17}$$

The first term of (3.17) is actually $-\frac{d(g(z_t)/g'(z_t))}{dz_t}$ and the second term is $-\frac{d(f(H_t - z_t)/f'(H_t - z_t))}{d(H_t - z_t)}$, thus (3.17) can be written as

⁷⁶ $F(H_t, z_t, E_t)$ is the LHS of equation (3.15).

$$-\left(\frac{d(g(z_t)/g'(z_t))}{dz_t} + \frac{d(f(H_t-z_t)/f'(H_t-z_t))}{d(H_t-z_t)}\right) \quad (3.18)$$

Because $d[f(\cdot)/f'(\cdot)]/d(\cdot)$ can be interpreted as an indirect measure of the curvature of a function f , the sign of dp_t/dH_t is decided by the "relative curvature" of $g(\cdot)$ and $f(\cdot)$ at time t . $d[f(H_t - z_t)/f'(H_t - z_t)]/d(H_t - z_t) > 0$ for all t . Based on my assumptions, $f(\cdot)$ is not bounded while $g(\cdot)$ is. Therefore it would be logical to observe that $f(H_t - z_t)/f'(H_t - z_t)$ is increasing at a decreasing rate, while $g(z_t)/g'(z_t)$ is decreasing fast at first and then increasing. The derivative of $g(z_t)$ is concave, and after $H_t > H_T$, some periods may exist where $g(z_t)$ is much more curved than $f(\cdot)$, so that $g(z_t)/g'(z_t)$ drops faster than the increasing rate of $f(H_t - z_t)/f'(H_t - z_t)$, and we would then have $dp_t/dH_t > 0$. Otherwise $dp_t/dH_t < 0$, which is more likely to be observed when H_t is a little higher and $g(z_t)$ is getting flatter. One possible example to induce the inverted-U shaped EKC is as follows. $f(x) = x^\theta$, with $0 < \theta < 1$ and $g(z) = (1/(z^\gamma + K))$, with $K > 0$. We have $(f(x))/(f'(x)) = (x/\theta)$, and thus $(d(f(H_t - z_t)/f'(H_t - z_t)))/(d(H_t - z_t)) = (1/\theta)$, which is constant. $g(z_t)/g'(z_t) = -(z^\gamma + K)/(\gamma z^{\gamma-1})$ and $d[g(z_t)/g'(z_t)]/dz_t = Kz^{-\gamma}((\gamma - 1)/\gamma) - (1/\gamma)$. Therefore equation (3.18) is $-Kz^{-\gamma}((\gamma - 1)/\gamma) + (1/\gamma) - (1/\theta)$. If $\theta < \gamma < 1$, the result may be $-Kz^{-\gamma} \left(\frac{\gamma-1}{\gamma}\right) + \left(\frac{1}{\gamma}\right) - \left(\frac{1}{\theta}\right) > 0$ when z is small, and $-Kz^{-\gamma} \left(\frac{\gamma-1}{\gamma}\right) + \left(\frac{1}{\gamma}\right) - \left(\frac{1}{\theta}\right) < 0$ when z is big. For example, when $K = 1$, $\theta = (1/3)$ and $\gamma = 1/2$, expression (3.18) is positive when $z < 1$, and negative when $z > 1$.

The economic interpretation is that when agents realize it is not worth investing all of their human capital in production, as their production activity hurts the environment and thus reduces their utility, they start adopting more environmentally-friendly technology. The result of proposition 3.1 shows that agents always invest a proportion of their increased human capital toward adopting greener technology. From equation (3.15), the use of human capital is balanced when the marginal benefit from production equals the marginal benefit from less environmental degradation. In the first periods, once the corner solution ends $g(z_t)$ begins to decrease from a very large value $g(0)$, i.e. \bar{g} . Due to the shape of $g(\cdot)$ function, agents initially invest less in adopting greener technology because it is efficient to take advantage of the high marginal product of labor. Therefore, in the first periods after stage 2 begins, production increases rapidly.

Nevertheless, the technology effect is not large enough to offset the production effect, which causes pollution levels to increase. With the degradation of environmental quality, rich agents have more difficulty tolerating the pollution. Thus they act to adopt a greener technology which is sufficiently strong to offset the negative effect from the increasing production, and pollution emissions start to decrease.

From the above analysis, EKC is a possible result, but not the only one. If the properties of $g(\cdot)$ change, the pollution emission path may exhibit a different shape, accordingly. For example, if improvements occur in abatement technology in the future, $g(\cdot)$ becomes strongly convex again in some periods; i.e., $g(z_t) / g'(z_t)$ drops very fast. dp_t/dH_t would change sign again, and we may observe N-shaped pollution path.

Proposition 3.3: *The value of the parameter of the self-adjustment ability of nature, b , determines the path of environmental quality in stage 2. If b equals 0, the environmental quality degrades in stage 2; if b is between 0 and 1, the environmental quality is U-shape in stage 2.*

From the evolution equation of environmental quality (3.11), I derive the function of E_t , which equals $E^* + \bar{p} - p_T$ if $b = 1$; $E^* - \sum_{t=1}^{T-1} (1-b)^{T-t} p_t + \frac{1-(1-b)^T}{b} \bar{p} - p_t$ if $0 < b < 1$; or $E^* - \sum_{t=1}^T p_t + T p_t$ if $b = 0$. E_t reaches its minimum point either when p_t goes to its maximum, at the end of stage 2, or sometime in between. Because $b=1$ is unrealistic, I focus on the cases where $0 < b < 1$ or $b = 0$, which imply that environmental quality either degrades or starts to show a U-shape in stage 2. The calculation is shown in the appendix 3.B, proof of proposition 3.3.

Stage 3: $H_t > \tilde{H}$.

From proposition 3.2, pollution emission is decreasing after the economy passes a threshold. Because the FOC of dp_t/dH_t is more negative when H_t is growing, pollution emission will be reduced back down to \bar{p} . Consider the period right after p goes back to \bar{p} . Agents would keep adopting the greener technology, measured by z_t , which

would reduce pollution emission to $p_t < \bar{p}$. But since the effects on environmental quality are no different from $p = \bar{p}$ and $p < \bar{p}$, agents have an incentive to increase their household consumption by simply maintaining the pollution emission level $p = \bar{p}$ by investing more in the production process. So z_t still increases; if this were was not the case, then p_t would increase due to the increasing output. Because $p = \bar{p}$, pollution has no effects on environmental quality, and E_t starts to converge back to E^* .

The above analysis implies that the inverted-U-shaped pollution-emission-over-time is seen in stage 1 and stage 2, while the U-shaped environmental-quality-over-time is observed in stage 2 and stage 3. Intuitively, when the economy starts at a situation with low consumption but good environmental quality, people care more about consumption than environmental quality, and thus have less incentive to invest in green technology; so pollution increases. When the economy is getting richer and environmental quality has deteriorated, people become increasingly affected by the degraded environment and begin investing in greener technology. In the long-run, pollution levels are reduced and environmental quality converges to its natural equilibrium, provided the deteriorated environmental quality is reversible.

3.3 Positive population growth

When the population growth rate is positive, $\eta > 1$, we may still observe an inverted-U shaped EKC, but there is a minor difference from the above results. The setup of the problem is the same as above, but the objective function now is (3.3), rather than (3.3'), and pollution emission is (3.1), rather than (3.1'). The Lagrangian function is:

$$L = \ln c_{at} + \eta \ln c_{ct} + \ln E_t + \lambda_t [(1 - b)E_{t-1} + bE^* - \eta^t g(z_t) \cdot f(H_t - z_t) + \bar{p} - E_t] + \mu_t [f(H_t - z_t) - c_{at} - c_{ct}] \quad (3.19)$$

The four different FOCs are

$$c_{at}: \quad \frac{1}{c_{at}} = \mu_t \quad (3.20)$$

$$c_{ct}: \quad \frac{\eta}{c_{ct}} = \mu_t \quad (3.21)$$

$$E_t: \quad \frac{1}{E_t} = \lambda_t \quad (3.22)$$

$$z_t: \quad -\eta^t \lambda_t [g'(z_t) \cdot f(H_t - z_t) - g(z_t) \cdot f'(H_t - z_t)] = \mu_t f'(H_t - z_t) \quad (3.21)$$

The other two FOCs are the same as in (3.11) and (3.12). By solving this problem, proposition 3.4 is obtained.

Proposition 3.4: *If the population growth rate η is greater than 1, agents invest more in green technology, compared to the situation where $\eta=1$. That is, $z_t(\eta > 1|H_t) > z_t(\eta = 1|H_t)$.*

Proof. From equations (3.20), (3.21), and (3.12), I have:

$$\mu_t = \frac{1+\eta}{f(H_t - z_t)} \quad (3.24)$$

And with equation (3.22) and (3.23), I have:

$$\frac{-g'(z_t)[f(H_t - z_t)]^2 / f'(H_t - z_t) + g(z_t)f(H_t - z_t)}{E_t} = \frac{1+\eta}{\eta^{t+1}} \quad (3.25)$$

with positive population growth $\eta > 1$. When $t > 0$, the derivative of the RHS of equation (3.25) is:

$$\frac{d((1+\eta)/\eta^{t+1})}{d\eta} = -\frac{t+1+t\eta}{\eta^{t+2}} < 0 \quad (3.26)$$

This implies that the higher the rate of population growth, the lower the ratio of the LHS of equation (3.25).

Keeping the assumptions of $g(\cdot)$ and $f(\cdot)$, when z_t increases $-g'(z_t)$ becomes less positive, as do $[f(H_t - z_t)]^2 / f'(H_t - z_t)$ and $g(z_t) f(H_t - z_t)$. Thus the numerator of the LHS of (3.25) is negatively related to z_t .

The environmental quality evolution equation is:

$$E_t - E^* = (1 - b)(E_{t-1} - E^*) - \eta^t \cdot g(z_t) \cdot f(H_t - z_t) + \bar{p} \quad (3.27)$$

From it, I have:

$$\frac{dE_t}{dz_t} = -\eta^t \cdot [g'(z_t) \cdot f(H_t - z_t) - g(z_t) \cdot f'(H_t - z_t)] > 0 \quad (3.28)$$

Therefore, the derivative of the LHS of equation (3.25) with respect to z_t is negative. To achieve it as a lower ratio with positive population growth, z_t must increase.

Proposition 3.4 compares two possible scenarios of the same economy (with and without population growth). Next, proposition 3.5 compares two different economies that make similar investments in pollution abatements initially, with and without population growth.

Proposition 3.5: When the population growth rate is positive, $(dz_t)/(dH_t)$ is smaller than without population growth before pollution emission reaches its maximum. After the economy becomes rich and pollution emission starts to decrease, $(dz_t)/(dH_t)$ will be greater with positive population growth than without.

The mathematical proof is shown in the appendix 3.C, proof of proposition 3.5. Proposition 3.5 compares the cases of different countries. Because each developing country is at its own stage of economic development, the proposition 3.5 suggests that a less developed country with a higher population growth rate may make similar abatement investments to a more developed country with a lower population growth rate. In this circumstance, the country with higher population growth would always adopt slightly more green technology until its EKC peaks. This implies that agents in countries with positive population growth tend to adopt less green technology than do those in countries with zero population growth, for every level of z , when the economy is poor. After the economy becomes rich, agents adopt greener technology, at every level of H_t , than do those in countries without population growth.

The positive population growth rate has two effects. The first is that adults must produce more to feed themselves and their children. This increase in output leads to higher level of pollution. Secondly, because environmental quality is important to children and the parents who care for them, they must take care to avoid activities that might harm the environment. This effect gives adults an incentive to adopt greener technology and to avoid causing serious pollution. Proposition 3.5 says that when agents are poor they care more about consumption, and the first effect dominates the second at certain levels of z_t . When the wealth of agents passes a benchmark, environmental quality becomes the first concern and the second effect dominates the first. This result seems to be consistent with the trend of the EKC. The EKC is derived more formally in proposition 3.6.

Proposition 3.6. *With a positive population growth rate, we may still observe the inverted-U-shaped EKC under the same assumptions as in proposition 3.2, with the additional assumption that the population grows more slowly than human capital accumulates. This EKC has a steeper slope when it rises than the one with zero population growth.*

Proof.
$$\frac{dp_t}{dH_t} = \frac{d\eta^t}{dH_t} g(z_t) \cdot f(H_t - z_t) + \eta^t \frac{d[g(z_t) \cdot f(H_t - z_t)]}{dH_t}$$

where $X_t = \frac{d\eta^t}{dH_t} g(z_t) \cdot f(H_t - z_t)$ is defined as the population growth effect and $Y_t = \eta^t \frac{d[g(z_t) \cdot f(H_t - z_t)]}{dH_t}$ is defined as the production effect. It is easy to show that:

$$\begin{aligned} Y_t &= \eta^t \frac{d[g(z_t) \cdot f(H_t - z_t)]}{dH_t} \\ &= \eta^t [g'(z_t) \cdot f(H_t - z_t) \frac{dz_t}{dH_t} + g(z_t) \cdot f'(H_t - z_t) \left(1 - \frac{dz_t}{dH_t}\right)] \\ &= \eta^t [g'(z_t) \cdot f(H_t - z_t) \frac{\eta \cdot A_t + (1-\eta) \cdot B_t}{\eta \cdot C_t + (1-\eta) \cdot D_t} + g(z_t) \cdot f'(H_t - z_t) \left(1 - \frac{\eta \cdot A_t + (1-\eta) \cdot B_t}{\eta \cdot C_t + (1-\eta) \cdot D_t}\right)] \\ &= \frac{\eta^{t+1} [g'(z_t) \cdot f(H_t - z_t) A_t + g(z_t) \cdot f'(H_t - z_t) \cdot (C_t - A_t)]}{\eta \cdot C_t + (1-\eta) \cdot D_t} \end{aligned}$$

$$= \frac{\eta^{t+1}}{\eta \cdot C_t + (1-\eta) \cdot D_t} M_t \quad (3.29)$$

where $M_t = g'(z_t) \cdot f(H_t - z_t) A_t + g(z_t) \cdot f'(H_t - z_t) \cdot (C_t - A_t)$ and A_t, B_t, C_t, D_t are defined as in appendix 3.C, the proof of proposition 3.5. From the proof of proposition 3.2 we know that $\frac{dp_t}{dH_t} |_{\eta=1} = \frac{1}{c_t} M_t$ and $\frac{\eta^{t+1}}{\eta \cdot C_t + (1-\eta) \cdot D_t} > \frac{1}{c_t}$, which indicates that the production effect itself induces an EKC curve that has a steeper slope than that without population growth. Nevertheless, the turning point condition is the same as in case without population growth: $\frac{g(z_t)g''(z_t) - [g'(z_t)]^2}{[g'(z_t)]^2} + \frac{f(\cdot)f''(\cdot) - [f'(\cdot)]^2}{[f'(\cdot)]^2} = 0$.

The population growth effect, $X_t = \frac{d\eta^t}{dH_t} g(z_t) \cdot f(H_t - z_t)$, is always positive. Because $\frac{d[\eta^t]}{dH_t} = \frac{d[\eta^t]}{dt} \frac{dt}{dH_t}$, and in combination with equation 3.4, I have:

$$\frac{d[\eta^t]}{dH_t} = \frac{\ln(\eta)}{\ln(1+h)} \left(\frac{\eta}{1+h}\right)^t \quad (3.30)$$

$d[\eta^t]/dH_t$ is positive because $\eta > 1$ and $h > 0$. From the previous proof, $g(z_t) \cdot f(H_t - z_t)$ increases at first and then decreases. If $\eta < 1 + h$, the population growth effect will be dominated by the production effect with t increases, and the smaller the ratio of $\eta/(1+h)$, the earlier a decreasing path of pollution emission is observed. Therefore, the overall effects of X_t and Y_t suggest an inverted-U-shaped EKC with a steeper slope before it reaches its summit. Immediately after passing its summit, the change in slope is ambiguous, since X_t and Y_t work in opposite directions.

3.4 Simulation

In this section, I replace the general forms of functions in my model with specific forms, whose properties are consistent with all previous assumptions, to analyze the pollution-growth pattern. The production function is assumed to be:

$$F(H_t - z_t) = (H_t - z_t)^\theta \quad (3.31)$$

With $0 < \theta < 1$.

The abatement technology function is assumed to be:

$$g(z) = \frac{1}{(s+z)^\gamma + K} \quad (3.32)$$

with $\gamma < 1$. A small s is included to prevent the nonexistence of a real solution to $g'(z)$ when $z = 0$ because $g'(z)$ would be $\frac{\gamma z^{\gamma-1}}{(z^\gamma + K)^2}$ without s .

Total human capital is growing at:

$$H_t = (1 + h)^t \quad (3.33)$$

The parameters are assumed as follows: $\theta = 1/3, s = 0.01, \gamma = 1/2, K = 1$ and $h = 0.05$. The environmental quality is initially at an equilibrium level $E^* = 20$. The self-adjustment parameter $b = 0.02$. The self-absorbing parameter $\bar{p} = 1$.

I use Matlab to find the solutions to the dynamic system with equations (3.11) and (3.15). I start with the case that assumes away population growth. The first stage ends at period 5 and the third stage begins at period 180. z_t is 0 for all $t \leq 5$. z_t does not immediately have a positive value at the beginning of stage 2 because pollution is not a serious problem to the agents in those periods. A positive z_t appears from period 17. Figure 3.1 presents the path of z_t , which proves proposition 3.1 that agents intend to use more human capital on greener technology as their human capital accumulates. Figure 3.2, the time path for output, indicates a steady increase; i.e., in total consumption. As I normalize the total population to 1, it also shows output per capita.

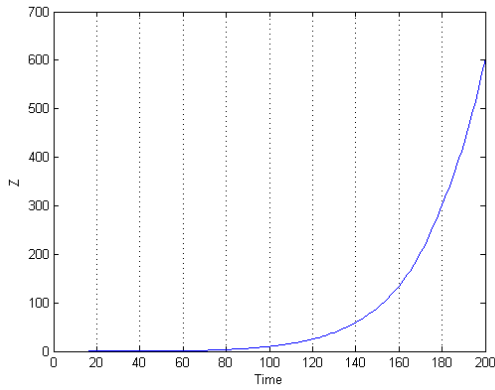


Figure 3.1. The time path of z

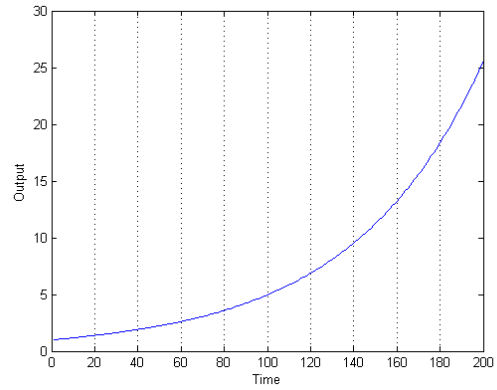


Figure 3.2 The time path of output

The changes in pollution and environmental quality are the main issues of concern. Figures 3.3 and 3.4 show the time paths for pollution and environmental quality. Figures 3.5 and 3.6 show the changes in pollution and environmental quality against the output level.

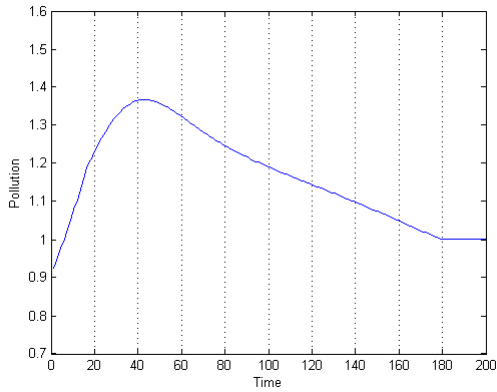


Figure 3.3. The time path of pollution

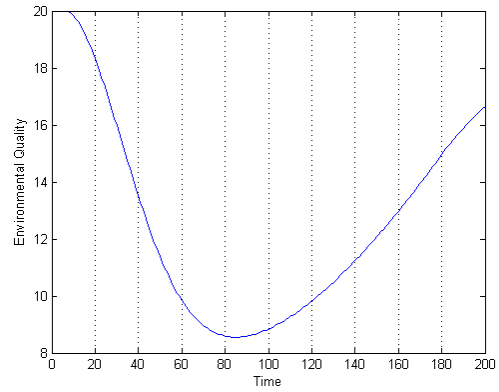


Figure 3.4. The time path of E

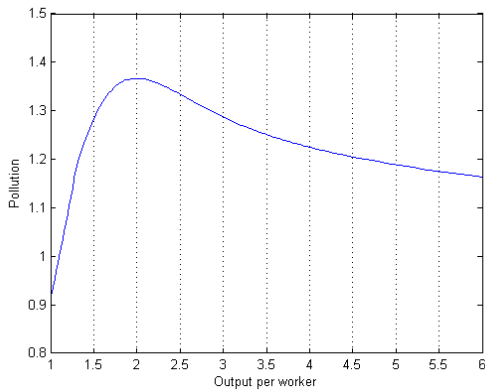


Figure 3.5. The EKC

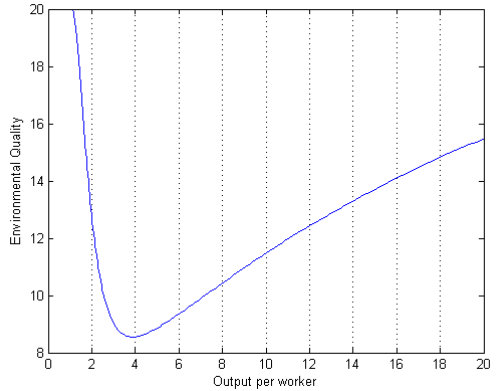


Figure 3.6. The E-output trace

Apparently, the inverted-U-shaped EKC is induced from this model (figure 3.5). It peaks in period 43, but is not symmetric. Pollution increases very fast at a lower output level and decreases slowly, after reaching its maxima, as output grows. Accordingly, environmental quality degrades sharply when the economy is poor and takes much longer to recover. Both pairs of figures indicate that agents care more about output, and thus consumption, at a low output level, while being more concerned about environmental quality only after their basic consumption needs are satisfied.

The effects of positive population growth on EKC are shown by solving the dynamic system with equations (3.25) and (3.27). The population growth rates are assumed to be 0.2% (low) and 0.4% (high) per period. Keeping the same values for

parameters as before, figure 3.7 compares the abatement investments under different conditions. Figure 3.8 shows the time paths for pollution. Figure 3.9 shows the paths of environmental qualities with and without population growth. Figure 3.10 depicts the EKC, the relation between pollution and output per worker.

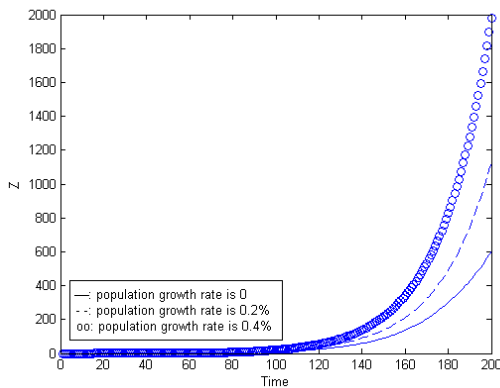


Figure 3.7. The time paths of z

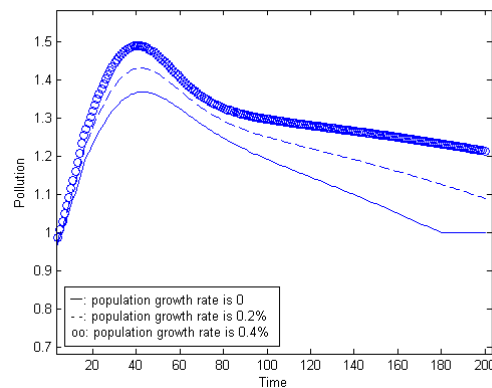


Figure 3.8. The time paths of pollution

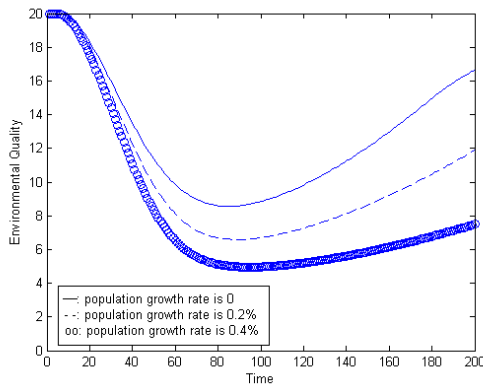


Figure 3.9. The time paths of E

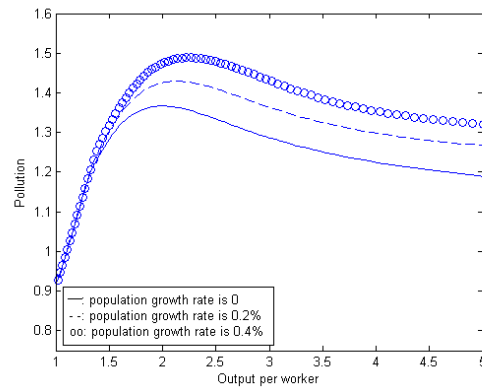


Figure 3.10. The EKCs

When η is 0.2%, stage 1 ends at period 5, and stage 3 starts at period 246. When η is 0.4%, stage 1 ends at period 4 and stage 3 starts at period 373. Both of the first stages are no later than in the situation without population growth; i.e., period 5. In either case, stage 2 takes more periods than in the case without population growth. When η is 0.2%, a positive z_t appears at period 17. When η is 0.4%, it becomes positive

at period 16. Figure 3.7 illustrates proposition 3.4, that agents intend to invest more on abatements with higher population growth rates. Higher population growth encourages agents to spend more human capital on greener technology to restrain the environmental quality from degrading rapidly. Figure 3.8 shows more severe pollution emission with faster population growth at all times. Figure 3.9 indicates the negative effects of positive population growth on the environment. With a higher population growth rate, environmental quality is worse everywhere, compared to a slower population growth situation, and it takes much longer to recover. Figure 3.10 shows that positive population growth raises the height of the EKC at every level of output per worker. Therefore, positive population growth does not affect the existence of the EKC, but it is nonetheless a burden on environment quality.

3.5 Empirical Evidence

In this section, I use a ten-year panel data from China to examine the EKC hypothesis and the effects population growth has on it, if it exists.⁷⁷ I examine pollutants that are supposed to have local effects (i.e., SO₂, waste water, and industrial waste gas), to check for evidence of the EKC in China's economic development.⁷⁸ I examine the possible effects from population growth on the EKC, if it is indeed present. The ten-year panel data for these three pollutants are compiled with other critical variables for China's 30 provinces and metropolises, from 2000 to 2009. The data is based on

⁷⁷ I understand that it may not be persuasive to use a 10-year data series to test the hypothesis from an OLG model. The main purpose of this section is to test the results derived from the model, rather than testing the validity of the OLG.

⁷⁸ The pollutants that I have studied include SO₂, waste residuals, industrial soot, industrial dust, waste water, COD in water and waste gas. I choose to report SO₂, waste water and waste gas because the evidence of the EKC is strong, with significant effects from population growth.

China's statistical yearbooks, from 2001 to 2010.⁷⁹ The yearly averages of the key variables are presented in Table 3.A1, shown in the appendix 3.D.

In the traditional model, where pollution is assumed to be a by-product of the production process, simple polynomial forms are widely used. EKC models usually use a simple reduced-form quadratic function, sometimes with polynomial terms for the income variable, and sometimes including the cubic level is also included in the reduced form. To examine the effects of local population growth, dummy variables are used for six different regions. Let X_{it} be the yearly emission of the pollutant in province i , at time t . The following equation specifies a possible form of the EKC model with population growth.

$$X_{it} = \alpha_i + \beta_1 \cdot Y_{it} + \beta_2 \cdot Y_{it}^2 + \beta_3 \cdot EM_{it} + \beta_4 \cdot IN_{it} + \beta_5 \cdot AB_{it} + \beta_6 \cdot POP_{it} + \sum_{k=7}^{12} \beta_k \cdot DBY_{kit} + \sum_{k=7}^{12} \beta_{k+6} \cdot DBY2_{kit} + \mu_{it} \quad (3.34)$$

where Y_{it} is GDP per capita, EM_{it} is aggregate employment, IN_{it} is aggregate physical capital investment, AB_{it} is aggregate abatement investment, and POP_{it} is population density. $DBY_{kit} = D_{kit} \cdot BIR_{it} \cdot Y_{it}$ and $DBY2_{kit} = D_{kit} \cdot BIR_{it} \cdot Y_{it}^2$, where BIR_{it} is the birth rate, D_{kit} is the dummy variable, and k represents different regions: 7 represents the North; 8 represents the Northeast, 9 represents the East, 10 represents the South, 11 represents the West and 12 represents the Center. $i = 1, \dots, 30$ indexes provinces and metropolises, and $t = 1999, \dots, 2009$ indexes time periods. Therefore the coefficients of DBY and $DBY2$ captures regional specific effects. The intercept is allowed to change across regions to capture the effects of other regional factors on local pollution over time. The EKC hypothesis would be supported if $\beta_1 > 0$ and $\beta_2 < 0$. The impacts of local population growth can be examined by looking at the values of the coefficients for DBY_{kit} and $DBY2_{kit}$, which, when combined, change the curvature of EKC. I use fixed effects

⁷⁹ China has 31 provinces and metropolises, and my data excludes Tibet because much of the data is missing. Appendix 3.D provides the basic statistics of the data. The consolidated data can also be found at: www.sfu.ca/~yuf/research/datafile.xlsx

transformation to eliminate the unobserved effect from the constant terms, α_i . Define $\ddot{X}_{it} = X_{it} - \bar{X}_i$, $\ddot{Y}_{it} = Y_{it} - \bar{Y}_i$, and so on. The general time-demeaned equation for each i , which is estimated by pooled OLS, is:

$$\begin{aligned} \ddot{X}_{it} = & \beta_1 \cdot \ddot{Y}_{it} + \beta_2 \cdot \ddot{Y}_{it}^2 + \beta_3 \cdot \ddot{EM}_{it} + \beta_4 \cdot \ddot{IN}_{it} + \beta_5 \cdot \ddot{AB}_{it} + \beta_6 \cdot \ddot{POP}_{it} \\ & + \sum_{k=7}^{12} \beta_k \cdot \ddot{DBY}_{kit} + \sum_{k=7}^{12} \beta_{k+6} \cdot \ddot{DBY2}_{kit} + \ddot{\mu}_{it} \end{aligned} \quad (3.35)$$

The output of the pooled OLS regression is shown in Table 3.1.

Table 3.1. The output of the fixed-effect model for three pollutants

Variables	SO2	Waste water	Waste gas
GDP per capita	334386.3*	40810.44*	3227.080***
GDP per capita squared	-67771.78**	-15105.13*	-1750.144**
Investment	-21.92183*	-0.228890	1.796716*
Employment	67.13806	23.85891*	0.177938
Abatement	0.558983*	0.064789*	0.010573*
Population density	311.0073**	20.74583	7.390717**
DBY _{North}	11392.13	-4153.669*	1466.668*
DBY _{Northeast}	-7552.770	1285.971	-1118.467*
DBY _{East}	-3906.875	-1369.698	-317.1589**
DBY _{South}	6846.002	-2101.157**	-180.4714
DBY _{West}	27723.72***	-558.2777	16.62992
DBY _{Center}	1464.856	-296.3571	-94.74063
DBY2 _{North}	-1680.540	1529.952*	-162.7307**
DBY2 _{Northeast}	9747.094	-609.4036	506.8265*
DBY2 _{East}	2406.026	1054.567*	155.7716**
DBY2 _{South}	-2562.942	1091.695**	84.63152
DBY2 _{West}	-19666.30**	-1683.638	124.2670
DBY2 _{Center}	2868.93	-279.6192	141.2488
R ²	0.414303	0.419493	0.809511
F value	11.25908*	11.50349*	67.93607*
Turning point (1000RMB)	20.71 – 24.67	13.50 – 14.52	8.48 – 12.27

Note. The coefficient with *, ** and *** is significant at 1%, 5% and 10% respectively.

The P-values for all F-tests are approximately 0.0000, which suggests overall significance for all three estimations. Furthermore, the significant positive β_1 and negative β_2 from all three estimations indicate very strong evidence of EKC's for SO₂, waste water, and industrial waste gas in China. Nevertheless, the effects of population growth are not significant for all regions.⁸⁰ For SO₂, only the coefficients of the dummy variables for the West are significant. For waste water, the coefficients of the dummy variables for the North, the South, and the East are significant. For industrial waste gas, the coefficients of the dummy variables for the North, the Northeast, and the East are significant. The turning points vary from 20,706 to 24,670 RMB for SO₂; from 13,501 to 14,523 RMB for waste water; and from 8,480 to 12,269 RMB for industrial waste gas.⁸¹ Furthermore, I notice that most coefficients of abatement investment and population density are significantly positive. The latter is not a surprise since pollution is produced by people, thus higher population density implies more intensive pollution. But the former may not be consistent with the expectation that more abatement investment should reduce pollution. A reasonable explanation is that the abatement investment is passively increased because of worse pollution. Therefore abatement investment increases along with the emission of pollution.

The effects of population growth are not significant for all regions. Figures 3.11, 3.12, and 3.13 show the effects of population growth for regions with significant coefficients.

⁸⁰ To be consistent in my model, I used birth rate to approximate population growth.

⁸¹ The real GDP per capita in China varies among different regions. In 2000 the range was from 3,127 to 33,863 RMB, and the national GDP per capita was 8,846 RMB. In 2009 the range was from 6,681 to 61,251 RMB and the national GDP per capita was 20,757 RMB. The base year is 1997.

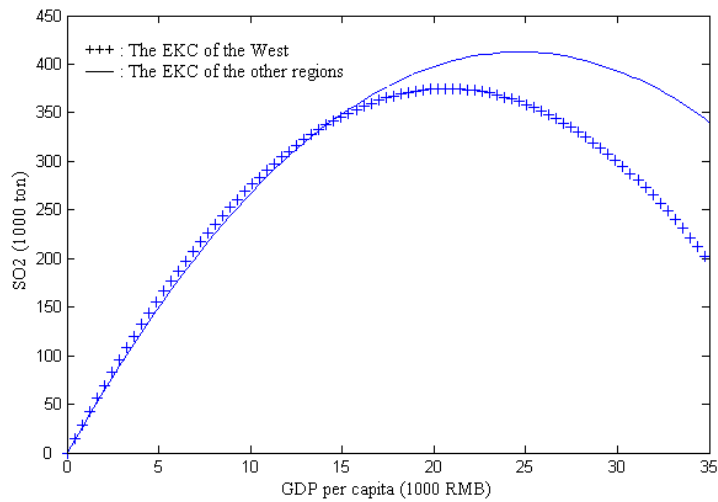


Figure 3.11. The EKCs of SO2

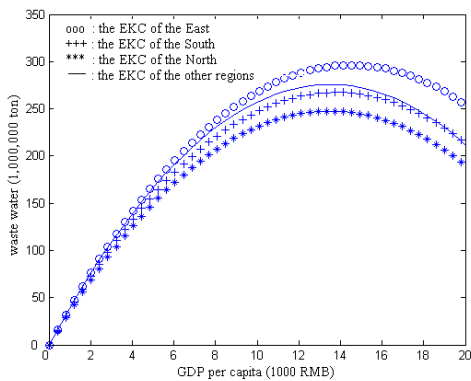


Figure 3.12. The EKCs of waste water

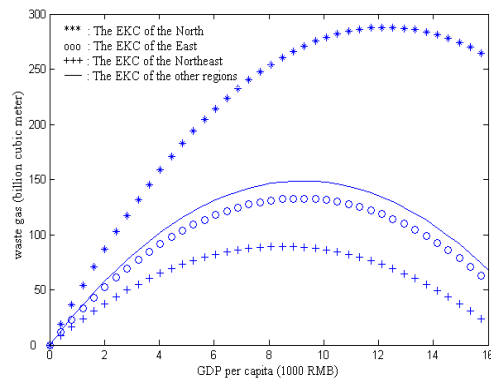


Figure 3.13. The EKCs of waste gas

From these three figures we can still observe EKCs with positive population growth while the effects of population growth in the EKCs are different. The solid curves are the benchmarks which ignore the regional difference. I then compared the EKCs of each region to the benchmark. We can see that when income level is low, the EKC grows faster with positive population growth for SO2 in the west, which is consistent to proposition 3.6. For the other two pollutants, waste water and waste gas, the evidence indicates the different effects of positive population growth on the EKCs. Some evidence shows faster rising EKCs at low income levels in some regions (the East for waste water

and the North for waste gas), which is consistent with proposition 3.6. Nevertheless, we also observe some slower rising EKC's at low income levels in the other regions (the South and the North for waste water, the East and Northeast for waste gas), where positive population growth rates are also significant. Not surprisingly, the shape of the EKC is determined by industry-specialized production technology, abatement technology, the relative growth rate of population to human-capital accumulation, and so on. Those factors are much different across regions which may induce different shapes of EKC's, but the rate of growth in population has an effect on the EKC.

3.6 Concluding remarks

In this paper, I use an overlapping generations (OLG) model to study the EKC, which has been empirically observed in many countries where pollution is measured with health indicators. This OLG model is a simplified version in the sense that inter-generational action is not present, since the parents decide everything for both their children and themselves, and the children are just net receivers. The parents must balance their household consumption with investments in pollution abatement technology. The investment increases monotonically as the economy becomes rich. The relative improvement of the abatement technology to the production technology is mathematically expressed as the degree of "relative curvature" of $g(\cdot)$ to $f(\cdot)$, and it determines the shape of the curve for the relationship between pollution and economic growth. When the "relative curvature" of $g(\cdot)$ to $f(\cdot)$ is initially very high, and then decreases, the inverted-U-shaped EKC is observed. If sudden improvement occurs in the abatement technology, we may even observe an N-shaped path. Population growth is not neutral and has two-sided effects on the EKC. On one side, more children in the household means more consumption, and thus production, which induces more pollution. On the other side, agents have an incentive to reduce pollution levels, since pollution affects their children. These two effects have impacts on the pollution path, though the inverted-U-shaped EKC can still be observed. The assumption about the self-adjustment ability of the environment is critical for obtaining the result that the environmental quality path will be U-shaped and then return to its original stable level.

This has been shown in the works of many past authors. In addition, this theoretic model matches well with developing countries, in contrast with developed ones. I assume that the developing countries are free to choose from existing production technologies, which differ only in terms of their pollution-making. The properties of the technology options, which are implied in the abatement technology, lead us to a similar EKC result. Simulations confirm the propositions and clearly indicate that the EKC is induced under the given assumptions of my model. Moreover, simulations display the effects of positive population growth on the EKC and environmental quality: the height of the EKC is raised at every level of output per worker and environmental quality is made worse everywhere. Empirical evidence from China partially supports these propositions, since faster rising EKC's can be observed at low income levels in some regions. The EKC theory implies that "in the end, the best -- and probably the only -- way to attain a decent environment in most countries is to become rich" (Beckerman 1992).

3.7 References

- Anderoni, J., and Levinson, A., 2001. The simple analytics of the environmental Kuznets curve. *Journal of Public Economics*. 80, 269-286.
- Arrow, K., Bolin, B., Costanza, R., Dasgupta, P., Folke, C., Holling, C. S., Jansson, B-O., Levin, S., Maler, K-G., Perrings, C., and D. Pimentel, 1995. Economic growth, carrying capacity, and the environment. *Science*. 268: 520-521.
- Barbier, E B. 1997. Introduction to the environmental Kuznets curve special issue. *Environment and Development Economics*. 2: 369-381.
- Beckerman, W. 1992. Economic Growth and the Environment: Whose Growth? Whose Environment?, *World Development* 20 (4), p. 481-496

- Cao, D., Wang, L. and Wang Y., 2011. Endogenous fluctuations induced by nonlinear pollution accumulation in an OLG economy and the bifurcation control. *Economic Modelling*, 28, 2528-2531.
- Carson, R, and McCubbin R., 1997. The relationship between air pollution emissions and income: US data. *Environment and Development Economics*. 2, 433-450.
- Caviglia-Harris J., Chambers D. and Kahn J. 2009. Taking the "U" out of Kuznets: A comprehensive analysis of the EKC and environmental degradation. *Ecological Economics*. 68, 1145-1155.
- Cropper, M., and Griffiths, C., 1994. The interaction of population growth and environmental quality. *American Economic Review*, 84(2), 250-254.
- Dinda, S., 2005. A theoretical basis for the environmental Kuznets curve. *Ecological Economics*, 53, 403-413.
- Du, L., Wei, C., and Cai, S., 2012. Economic development and carbon dioxide emissions in China: Provincial panel date analysis. *China's Economic Review*, 23(2), 371-384.
- Grossman, G.M, and Krueger, A.B., 1991. Environmental impacts of a North American Free Trade Agreement. NBER, working paper 3914, Cambridge, MA.
- Grossman, G.M, and Krueger, A.B., 1995. Economic growth and the environment. *Quarterly Journal of Economics*, 110(2), 353-377.
- Hilton, F.G.H., and Levinson, A., 1998. Factoring the environmental Kuznets curve: evidence from automotive lead emissions. *Journal of Environmental Economics and Management*. 35, 126-141.
- Holtz-Eakin, D., and Seldon, T.M., 1995. Stoking the fires? CO₂ emissions and economic growth. *Journal of Public Economics*. 57, 85-101.
- Jiang, Y., Lin, T., and Zhuang, J., 2008. Environmental Kuznets Curves in the People's Republic of China: Turning Points and Regional Differences. ADB Economic Working Paper Series from Asian Development Bank, No. 141.
- John, A., Pecchenino, R., 1994. An overlapping generations model of growth and the development. *The Economic Journal*. 104, 1393-1410.
- Koop, T., and Tole, T., 1999. Is there an environmental Kuznets curve for deforestation? *Journal of Development Economics*. 58, 231-244.
- Koren'kov, VN., 1991. Biological purification of sewage from chemical plants. *Russian Chemical Reviews*. 60, 273.
- Lopez, R., 1994. The environment as a factor of production: the effects of economic growth and trade liberalization. *Journal of Environmental Economics And Management*. 27, 163-184.

- Martinez-Zarzoso, I., and Maruotti, A., 2011. The impact of urbanization on CO2 emissions: Evidence from developing countries. *Ecological Economics*. 70(7), 1344-1353.
- Nguyen, V., 2002. Endogenous population and environmental quality. Working papers of BETA.
- Panayotou, T., 1993. Empirical tests and policy analysis of environmental degradation at different stages of economic development. International Labor Organization working paper 238, Geneva, Switzerland.
- Panayotou, T., 1997. Demystifying the environmental Kuznets curve: Turing a black box into a policy tool. *Environment and Development Economics*. 2, 465-484.
- Roy N., and Van Kooten C., 2004. Another look at the income elasticity of non-point source pollutants: a semi parametric approach, *Economic letters*. 85(1), 17-22.
- Seldon, T.M., and Song, D., 1994. Environmental air quality and development: is there a Kuznets curve for air pollution emissions. *Journal of Environmental Economics and Management*. 27, 147-162.
- Seldon, T.M., and Song, D., 1995. Neoclassical growth, the J curve for abatement, and the inverted-U curve for pollution. *Journal of Environmental Economics and Management*. 29, 162-168.
- Shafik, N., 1994. Economic development and environmental quality: An econometric analysis. *Oxford Economic Papers*.
- Song, T., Zheng, T., and Tong, L., 2008. An empirical test of the environmental Kuznets curve in China: A panel cointegration approach. *China Economic Review*. 19, 381-392.
- Stern, D., 2004. The rise and fall of the environmental Kuznets curve. *World Development* 32, 1419-1439.
- Stokey, N., 1998. Are there limits to Growth? *International Economic Review*. 39(1), 1-31.
- Vincent, J., 1998. Environment and Development In a Resource-Rich Economy: Malaysia Under the New Economic Policy. Har ch on the ability of twenty- one ornamental plants to absorb and purify environmental pollutants. *Journal of Shandong Forestry Science and Technology*. 06, 005.vard University Press.
- Vita, G., 2007. Is the discount rate relevant in explaining the environmental Kuznets curve? *Journal of Policy Modelling*. 30, 191-207.
- Wagner, M., 2008. The carbon Kuznets curve: A cloudy picture emitted by bad econometrics? *Resource and Energy Economics*. 30, 388-408.
- Wang, C., Fang, Y., Wu, X., and Hu, D., 2006. Resear

3.8 Appendices

Appendix 3.A: proof of proposition 3.1

From equation (3.7) and (3.8), $c_{at} = c_{ct}$. Combining with equation (3.12), I have

$$c_{at} = c_{ct} = \frac{f(H_t - z_t)}{2} \quad (3.A1)$$

From equation (3.7) or (3.8) and (3.9), equations (3.13), (3.14) and (3.15) are derived. Totally differentiating equation (3.15) I have:

$$\frac{\partial F(H_t, z_t, E_t)}{\partial H_t} dH_t + \frac{\partial F(H_t, z_t, E_t)}{\partial z_t} dz_t - 2f'(H_t - z_t) dE_t = 0 \quad (3.A2)$$

where

$$\begin{aligned} \frac{\partial F(H_t, z_t, E_t)}{\partial H_t} &= -2f(H_t - z_t) g'(z_t) \cdot f'(H_t - z_t) + [f'(H_t - z_t)]^2 g(z_t) - 2E_t f''(H_t - z_t) \\ &\quad + f(H_t - z_t) g(z_t) \cdot f''(H_t - z_t) \\ \frac{\partial F(H_t, z_t, E_t)}{\partial z_t} &= -\frac{\partial F(H_t, z_t, E_t)}{\partial H_t} - [f(H_t - z_t)]^2 g''(z_t) + f(H_t - z_t) g'(z_t) \cdot f'(H_t - z_t) \end{aligned}$$

All the terms in $\partial F(H_t, z_t, E_t)/\partial H_t$ are positive except $-2E_t f''(H_t - z_t) + f(H_t - z_t) g(z_t) \cdot f''(H_t - z_t)$. From (3.15) I know that:

$$-2E_t + f(H_t - z_t) g(z_t) = \frac{[f(H_t - z_t)]^2 g'(z_t)}{f'(H_t - z_t)} < 0$$

Thus $-2E_t f''(H_t - z_t) + f(H_t - z_t) g(z_t) \cdot f''(H_t - z_t)$ is non-negative if $f''(\cdot) \leq 0$. Therefore in combination with the assumption that $g''(\cdot)$ is non-negative, I have $\partial F(H_t, z_t, E_t)/\partial H_t < -\partial F(H_t, z_t, E_t)/\partial z_t$.

Totally differentiating (3.11) I have:

$$-[g(z_t) \cdot f'(H_t - z_t)]dH_t - [g'(z_t) \cdot f(H_t - z_t) - g(z_t) \cdot f'(H_t - z_t)]dz_t - dE_t = 0 \quad (3.A3)$$

Solve the equation system containing (3.A2) and (3.A3), I have:

$$\frac{dz_t}{dH_t} = \frac{(\partial F(H_t, z_t, E_t) / \partial H_t) + 2[f'(H_t - z_t)]^2 g(z_t)}{-(\partial F(H_t, z_t, E_t) / \partial z_t) + 2[f'(H_t - z_t)]^2 g(z_t) - 2f'(H_t - z_t) g'(z_t) f(H_t - z_t)} \quad (3.A4)$$

Since both the numerator and the denominator of (3.A4) are positive provided $f''(\cdot) \leq 0$ and $g''(\cdot) \geq 0$, $dz_t/dH_t > 0$. Furthermore, because the numerator is always smaller than the denominator, I then have $dz_t/dH_t < 1$.

Appendix 3.B: Proof of proposition 3.3

If the economy starts from its natural equilibrium $E_0 = E^*$, based on equation (3.11) the environmental quality at time T is:

$$\begin{aligned} E_T - E^* &= (1 - b)(E_{T-1} - E^*) - p_T + \bar{p} \\ &= (1 - b)[(1 - b)(E_{T-2} - E^*) - p_{T-1} + \bar{p}] - p_T + \bar{p} \\ &= \dots \dots \\ &= (1 - b)^T (E_0 - E^*) - \sum_{t=1}^{T-1} (1 - b)^{T-t} \cdot p_t + \frac{1 - (1 - b)^T}{b} \bar{p} - p_T \text{ if } b \neq 1 \end{aligned}$$

i.e.,

$$\text{if } b = 1: \quad E_T = E^* + \bar{p} - p_T \quad (3.B1)$$

$$\text{if } 0 < b < 1: \quad E_T = -\sum_{t=1}^{T-1} (1 - b)^{T-t} \cdot p_t + \frac{1 - (1 - b)^T}{b} \bar{p} - p_T \quad (3.B2)$$

$$\text{if } b = 0: \quad E_T = E^* - \sum_{t=1}^T p_t + T\bar{p} \quad (3.B3)$$

When $b = 1$, we also have:

$$E_T - E_{T-1} = -(p_T - p_{T-1}) \quad (3.B4)$$

This implies that the trace of E_T is totally opposite to that of p_T . Since p_T is inverted-U-shaped, E_T is then be U-shaped and reaches its minimum point when p_T goes to the maximum.

If $b = 0$:

$$E_T - E_{T-1} = -(p_T - \bar{p}) \quad (3.B5)$$

Because in stage two $p_T > \bar{p}$, the environmental quality will then degrade at all times in this stage. At the end of this period $p_T = \bar{p}$ which means E_T reaches its minimum at this time because it will start to improve in stage three.

If $0 < b < 1$:

$$E_T - E_{T-1} = b \sum_{t=1}^{T-1} (1-b)^{T-t-1} \cdot p_t + (1-b)^{T-1} \bar{p} - p_T \quad (3.B6)$$

Because in stage two I have:

$$b \sum_{t=1}^{T-1} (1-b)^{T-t-1} \cdot p_t + (1-b)^{T-1} \bar{p} > [1 - (1-b)^{T-1}] \bar{p} + (1-b)^{T-1} \bar{p} > \bar{p}$$

Also, if $p_M = \max(p_t)$ when $t \leq T$ in stage two:

$$b \sum_{t=1}^{T-1} (1-b)^{T-t-1} \cdot p_t + (1-b)^{T-1} \bar{p} < [1 - (1-b)^{T-1}] p_M + (1-b)^{T-1} p_M < p_M$$

Therefore $b \sum_{t=1}^{T-1} (1-b)^{T-t-1} \cdot p_t + (1-b)^{T-1} \bar{p}$ is bounded between (\bar{p}, p_M) . When p_t is increasing, which implies $\bar{p} = p_M$ then E_t is decreasing over time, even after p_T reaches its maximum. But at the end of stage two, $p_T = \bar{p}$ and $E_T - E_{T-1} > 0$. This indicates E_T is already increasing. Because p_t is monotonically decreasing after reaching its maximum point, the minimum of E_T must appear sometime between the time when p_t reaches its maximum and the end of stage 2.

Appendix 3.C: Proof of proposition 3.5

From equation (20) and (21), I have $\mu_t = \eta/c_{ct} = 1/c_{at}$. In combination with (3.12), (3.22), and (3.23), I have:

$$\eta^{t+1} (-g'(z_t) [f(H_t - z_t)]^2 + f(H_t - z_t) g(z_t) \cdot f'(H_t - z_t)) - (1 + \eta) E_t f'(H_t - z_t) = 0 \quad (3.C1)$$

Totally differentiating (3.C1), I have:

$$\frac{\partial G(H_t, z_t, E_t)}{\partial H_t} dH_t + \frac{\partial G(H_t, z_t, E_t)}{\partial z_t} dz_t - (1 + \eta) f'(H_t - z_t) dE_t = 0 \quad (3.C2)$$

where

$$\begin{aligned} \frac{\partial G(H_t, z_t, E_t)}{\partial H_t} &= -2\eta^{t+1} f(H_t - z_t) g'(z_t) \cdot f'(H_t - z_t) + \eta^{t+1} [f'(H_t - z_t)]^2 g(z_t) - \\ &\quad (1 + \eta) E_t f''(H_t - z_t) + \eta^{t+1} f(H_t - z_t) g(z_t) \cdot f''(H_t - z_t) \\ &= \eta^{t+1} \{-2f(H_t - z_t) g'(z_t) \cdot f'(H_t - z_t) + [f'(H_t - z_t)]^2 g(z_t) \\ &\quad + [f(H_t - z_t)]^2 g'(z_t) f''(H_t - z_t) / f'(H_t - z_t)\} \\ &= \eta^{t+1} \frac{\partial F(H_t, z_t, E_t)}{\partial H_t} \end{aligned}$$

$$\frac{\partial G(H_t, z_t, E_t)}{\partial z_t} = -\frac{\partial G(H_t, z_t, E_t)}{\partial H_t} - \eta^{t+1} \{[f(H_t - z_t)]^2 g''(z_t) + f(H_t - z_t) g'(z_t) \cdot f'(H_t - z_t)\}$$

Solving the equation system containing (3.C2) and (3.A3), I have:

$$\frac{dz_t}{dH_t} = \frac{\eta A_t + (1 - \eta) B_t}{\eta C_t + (1 - \eta) D_t} \quad (3.C3)$$

where

$$A_t = \frac{\partial F(H_t, z_t, E_t)}{\partial H_t} + 2 [f'(H_t - z_t)]^2 g(z_t)$$

$$B_t = [f'(H_t - z_t)]^2 g(z_t)$$

$$C_t = -\frac{\partial F(H_t, z_t, E_t)}{\partial H_t} + 2 [f'(H_t - z_t)]^2 g(z_t) - f(H_t - z_t) g'(z_t) \cdot f'(H_t - z_t)$$

$$D_t = [f'(H_t - z_t)]^2 g(z_t) - f(H_t - z_t) g'(z_t) \cdot f'(H_t - z_t)$$

Because both the denominator and numerator of (3.C3) are positive, and the numerator is smaller than the denominator, I have $0 < dz_t/dH_t < 1$.

Equation (3.C3) shows that $dz_t/dH_t = A_t/C_t$ if there is no population growth. Because $1 - \eta < 0$, I know that:

$$\frac{\eta A_t + (1 - \eta) B_t}{\eta C_t + (1 - \eta) D_t} < \frac{A_t}{C_t} \quad \text{if} \quad \frac{A_t}{C_t} < \frac{B_t}{D_t}$$

$$\frac{\eta A_t + (1 - \eta) B_t}{\eta C_t + (1 - \eta) D_t} > \frac{A_t}{C_t} \quad \text{if} \quad \frac{A_t}{C_t} > \frac{B_t}{D_t}$$

Therefore the relationship between A_t/C_t and B_t/D_t decides which dz_t/dH_t is bigger, either that in (A4) or that in (3.C3). I know that:

$$\frac{A_t}{C_t} > \frac{B_t}{D_t} = \frac{[f(\cdot)]^2 [g'(z_t)]^2 \cdot f'(\cdot)}{d} \left(\frac{g(z_t)g''(z_t) - [g'(z_t)]^2}{[g'(z_t)]^2} + \frac{f(\cdot)f''(\cdot) - [f'(\cdot)]^2}{[f'(\cdot)]^2} \right) \quad (3.C4)$$

where d is the product of the two denominators, C_t and D_t , and it is positive. Therefore $A_t/C_t - B_t/D_t$ is positive, as in equation (3.17). Because $A_t/C_t < B_t/D_t$ before pollution emission reaches its maximum, this implies dz_t/dH_t with positive population growth is smaller than without population growth. After the economy becomes rich and pollution emission starts to decrease, dz_t/dH_t with positive population growth will be greater than without population growth.

Appendix 3.D: The basic statistics of the data

The basic statistics of the data is presented in table 3.D1

Table 3.D1. The yearly averages of the panel data

Province	SO2 (ton)	Waste water (10000 ton)	Gas (100 million m ³)	GDP Per capita (10000 RMB)	Real Investm ent (100 million RMB)	Employ ment (10000)	Real abatement (10000 RMB)	Population density (per km ²)	Pop growth rate (‰)
Beijing	115087	16607	3711	2.5406	2258.5	865	65612	891.3821	1.58
Tianjin	209474	21078	3986	2.6852	1453.9	445	96314	881.2472	1.92
Hebei	1188256	112227	25406	1.1906	3888.7	3499	119814	359.7127	5.64
Shanxi	1047918	36474	14094	0.8786	1454.8	1486	173371	210.2571	6.23
Inner Mongolia	970855	24189	12223	1.1389	1865	1051	64963	20.00311	4.42
Liaoning	823598	96849	18235	1.6546	3610	1948	174795	284.469	1.6
Jilin	255672	36568	4529	1.0801	1690.5	1116	47682	143.5528	2.79
Heilongjiang	329913	46556	5743	1.3672	1609.5	1664	74099	83.44418	2.76
Shanghai	331362	60637	7928	4.1033	2896.8	790	64901	2657.896	0.62
Jiangsu	1139960	250812	17443	2.0199	6348.4	3896	210428	720.6637	2.43

Province	SO2 (ton)	Waste water (10000 ton)	Gas (100 million m ³)	GDP Per capita (10000 RMB)	Real Investm ent (100 million RMB)	Employ ment (10000)	Real abatement (10000 RMB)	Population density (per km ²)	Pop growth rate (‰)
Zhejiang	696351	167948	11758	2.1349	5009.6	3098	147119	466.3847	4.17
Anhui	438846	65720	7937	0.8297	2414.8	3481	56306	443.422	6.24
Fujian	313492	100127	5602	1.8119	2362.9	1828	125670	284.3904	5.53
Jiangxi	415291	53672	4238	0.7965	1741	2072	32119	254.5905	7.78
Shandong	1543785	134086	21083	1.6322	6426.7	5031	375634	580.3073	4.85
Henan	1070006	117298	13540	0.8806	3858.3	5573	127124	563.1387	5.46
Hubei	555634	99408	8417	1.1839	2473.1	2720	100779	312.6937	3.09
Hunan	673323	111594	5989	0.9085	2103.1	3621	70732	304.9056	4.79
Guangdong	1010679	168215	12915	1.877	5587.2	4508	218847	462.315	7.79
Guangxi	812124	125282	8252	0.8153	1587.4	2645	66175	199.9296	7.4
Hainan	21706.3	6954.9	759.4	0.9688	332.27	368	4117.7	226.8859	9.04
Chongqing	627432	75315	4645	0.9118	1569.8	1697	33978	359.9889	3.37
Sichuan	957149	112388	9252	0.7944	3095.3	4596	105907	172.5918	3.57
Guizhou	718105	17565	5413	0.4065	857.34	2148	40691	212.1471	8.68
Yunnan	377304	35048	5214	0.6691	1390.8	2437	50192	109.9928	8.31
Shaanxi	693357	37854	5088	0.7228	1588.5	1878	57730	178.0309	4.26
Gansu	393161	20490	4143	0.5852	733.4	1294	62259	56.42585	6.53
Qinghai	73777	5142.7	1581	0.7798	285.13	260	5722.1	7.361878	9.9
Ningxia	255691	14345	2549	0.7217	336.87	292	26829	86.63381	10.3
Xinjiang	325396	18305	3921	0.9764	1024.5	741	37889	11.592	10.5

All provinces of China are divided into six regions. The North includes Beijing, Tianjin, Hebei, Shanxi and Inner Mongolia; the Northeast includes Liaoning, Jilin and Heilongjiang; The East includes Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiang xi and Shandong; The South includes Henan, Hubei, Hunan, Guangdong, Guangxi and Hainan; The West includes Chongqing, Sichuan, Guizhou and Yunnan; The center includes Gansu, Qinghai, Ningxia and Xinjiang.

All numbers are yearly averages, from 2001 to 2010.

GDP per capita, investment and abatement spending are in real terms. The base year is 1997.

Data source: China's statistical yearbooks, 2001 to 2010.