ESSAYS ON TRADE AND FACTOR MARKETS

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A thesis submitted to the

Faculty of the Graduate School of the

University of Colorado in partial fulfillment

of the requirements for the degree of

Doctor of Philosophy

Department of Economics

2016

This thesis entitled:
Essays on Trade and Factor Markets
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The final copy of this thesis has been examined by the signatories, and we find that both the content and the form meet acceptable presentation standards of scholarly work in the above mentioned discipline.

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Essays on Trade and Factor Markets

Thesis directed by Professor James Markusen

This thesis consists of three chapters investigating different aspects of factor markets and their interaction with trade, with a particular interest in developing countries.

The first chapter discusses how globalization affects welfare by reallocating labor across firms, sectors and space when factor markets are distorted. It incorporates a traditional agriculture sector into the trade literature with heterogeneous firms, matching frictions and multiple asymmetric regions in terms of their geographical locations. The model predicts that a reduction in trade impediments reallocates market share towards more productive producers, encourages firms to post more vacancies, and induces workers to migrate towards the manufacturing sector and towards the coastal regions. In addition, by comparing the decentralized competitive equilibrium with the socially optimal solution, I show that falls in trade barriers exacerbate existing distortions caused by matching frictions but decrease misallocation of labor across sectors and space. This implies potential gains from trade through increase in labor market efficiency. The main mechanism in the model is supported by empirical evidence from China.

In the second chapter, I analyze how trade cost reductions raise skill premium and human capital investment in developing countries by building a dynamic general equilibrium model featured with endogenous human capital accumulation and production fragmentation. The simulation results show that within the Heckscher-Ohlin framework, trade liberalization leads to divergence of the world income distribution by inducing skill accumulation in skilled labor abundant countries and skill de-accumulation in skilled labor scarce countries. On the contrary, when the production fragmentation is allowed, trade cost reduction leads to a convergence in income and factor endowments across countries. In addition, the transition path following the trade cost reduction is non-monotonic. The trade-induced increases in skill premium raise human capital investment, which

increases labor supply and depresses returns to education over time. This indicates the equalizing effect of the endogenous adjustment in skills supply. I then examine the theoretical predictions in the context of China's trade reform in 1978. The estimated coefficients from the difference-in-difference regressions are consistent with the simulation results.

The last chapter is a joint work with Wolfgang Keller and Carol Shiue. In this chapter, my coauthors and I employ an asset-pricing model to estimate consistent interest rates and compare capital market development in Britain and China with the most comprehensive grain prices available. The estimated interest rates for Britain were at least 28% lower than those for China during 1770–1860. In addition, we analyze the integration of capital markets by examining the correlation of interest rates across regions with varying geographic distances. We find that the regional integration of capital markets in Britain was substantially higher than in China. Our results suggest that capital market performance may have been important to explain the divergence in incomes across countries in the 18th and 19th century.

Dedication

To my beloved family.

Acknowledgments

Thanks to:

My advisor, Prof. James Markusen, for his invaluable guidance on my work, his continuous confidence in my abilities, and his kind support in my academic development, for being always approachable and patient, and for letting me know how to conduct good economics research.

Prof. Wolfgang Keller, for his great support and offering me the invaluable learning opportunity to work closely with him both as a research assistant and as a co-author on the project that has led to Chapter 3 of this thesis.

The rest of my thesis committee: Prof. Keith Maskus, Prof. Carol Shiue, and Prof. Yacheng Sun, for all insightful discussions and continuous encouragement, and for inspiring me to analyze problem from different perspectives.

All my colleagues at the productive Trade Group, as well as the participants at various conferences, for their useful feedback and for providing a stimulating research environment.

The Department of Economics and Graduate School at CU Boulder, for the scholarship to support the completion of this dissertation.

My husband, for always being my support and sharing all my exciting and tough moments.

My parents, for their immense endless love and for making me who I am today.

Contents

Tables

Table

Figures

Figure

Chapter 1

International Trade and Internal Migration with Labor Market Distortions: Theory and Evidence from China

1.1 Introduction

Factor markets inefficiencies are prevalent and have been widely studied in the economic development literature. Numerous studies have shown that labor allocation plays a significant role in explaining cross-country variation in total factor productivity (TFP) and total income (Gollin et al., 2002; Hsieh and Klenow, 2009; Vollrath, 2009; Duarte and Restuccia, 2010)[1] . Yet, one feature shared by most models of trade-induced structural change is that they abstract from changes in distortions of factor markets and concentrate on the benefits through expansion of sectors with comparative advantages. The goal of this paper is to go beyond this channel of gains from trade and discuss the welfare enforcement effects of international trade through increasing factor markets efficiency.

In this paper I incorporate two different types of labor market distortions in a unified framework. First, I consider the inefficiency within the manufacturing sector caused by two central market failures in the matching model: congestion externalities and appropriability problems[2] . When the appropriability and congestion problems do not balance each other, the competitive equilibrium

[1] See Restuccia and Rogerson (2013) for a literature review.

[2] The discussion of these two problems goes back to Hosios (1990). The appropriability problem arises when firms only internalize a part of the value of the match created by its vacancy, while the social planner considers the whole social value of a job. It leads to too few vacancies. The congestion externality exists because firms only cares about the average probability at which a vacancy is filled, while the social planner makes its decision according to the marginal effects of an additional vacancy. This leads to too many vacancies. Since this paper takes a dynamic setting, the conditions that generate the optimality of the equilibrium is not exactly the same as in Hosios (1990).

involves either too many or too few vacancies. Second, the model includes misallocation of labor between the agriculture sector and the manufacturing sector due to the sharing rule of wages within family farms. I assume that the supply price of migrants is the value of the average product in the agriculture sector, rather than the marginal product. This mechanism of determining wages is common in developing countries where factor markets are absent, resulting in too many workers in the agriculture sector. An important contribution of this paper is to investigate these two mechanisms above within the standard international trade framework of monopolistic competition heterogeneous firms, so that I can separate out the impact of changes in labor market distortions from the total gains from trade. Decrease in trade costs exacerbates the first type of distortion as it has larger impact on the number of vacancies in the planner's problem than in the decentralized problem. Meanwhile, the second type of distortion is mitigated when trade induces some members in family farms to leave and makes the rest receive their full marginal product.

The paper also contributes to the literature by discussing the interaction among different types of labor reallocation induced by international trade. It is motivated by several stylized facts in developing countries, including increasing integration with the world market, reallocation of labor toward exporting firms, dramatic economic structural change, and huge migration flows across space. These phenomena are quite common in developing countries and usually happen simultaneously, indicating a potential linkage among them. Discussion without considering this linkage may lead to incorrect policy implications and underestimation of the actual impacts of trade cost reduction. However, most research in the trade literature investigates the impacts of international trade on reallocation of labor across firms, sectors, and space separately. My work fills this gap by incorporating different trade-induced labor reallocations within a unified framework and shows how the Melitz (2003) type of labor reallocation within the manufacturing sector induces labor movement across sectors and space.

A general-equilibrium model is developed to bring together the dual economy structure, trade between and within countries, structural change across sectors, and factor mobility across space. In particular, this paper considers multiple regions partitioned into two countries. Regions are distinguished from each other by differences in shipping costs. There are two sectors within each region: the agriculture sector and the manufacturing sector. Goods are assumed to be mobile between sectors, regions, and countries, but factors move only between sectors and regions within the same country. Labor is fully employed in the agriculture sector and gets average product as their income, while unemployment generated by the search frictions exists in the manufacturing sector and acts as the equilibrating mechanism between labor markets across sectors. Firms in the manufacturing sector are similar as in Melitz (2003) with monopolistic competition and heterogeneous productivity. They post optimal number of vacancies to maximize their profit.

The model is first analyzed for a special case with symmetric regions. No labor migrates across space under this assumption so that we focus on the trade-induced labor reallocation across firms and sectors. The analytical solution shows that within each region, a reduction in trade impediments raises the average productivity as in Melitz (2003). Firms post more vacancies, which makes it much easier for workers to be hired in the manufacturing sector and it's more valuable for workers to search jobs. As a consequence, workers migrate from the agriculture sector to the manufacturing sector, with an increase in wages in both urban and rural sectors. The assumption is then relaxed to account for the gains from trade through labor reallocation across space. I calibrate the model to match main economic statistics in China, a country featured with large reforms in openness policy, serious factor misallocation across sector and space (Brandt et al., 2013; Tombe and Zhu, 2015), and large domestic trade cost (Poncet, 2005). The simulation results predict larger impacts of trade cost reduction on the labor market at locations with geographical advantages. The heterogeneity in trade effects induces spatial movements of labor from the interior regions to regions closer to the global market.

With the calibrated model, I decompose the welfare gains from trade with counterfactual analysis into four channels: increase in market share of the more efficient firms in the manufacturing sector, increase in vacancy-unemployment ratio in the manufacturing sector, reallocation of labor from rural to urban, and migration flows towards the ports. The results show that although the change within the manufacturing sector plays an important role in explaining the welfare gain from trade, the reallocation of labor across sectors and space contributes around 40% of the total welfare increase. I then separate out the impact of changes in labor market efficiency from the total gains from trade. By comparing the decentralized competitive equilibrium with the first-best labor market conditions, I show that decreasing trade barriers exacerbates within sector inefficiency but raises across-sector allocative efficiency. The overall effect is still positive in the calibrated model. The difference between the actual total welfare in the competitive equilibrium and the social optimal solution decreases from 7.7% to 5.5%, indicating an efficiency gain of 30%. The total revenue in the calibrated economy converges to its first-best value as trade cost falls. This suggests that opening to trade can impact welfare through changes in the labor market efficiency.

The main theoretical implications are examined with China's census data in 1990, 2000, and 2010. My empirical analysis follows studies using micro level data to evaluate local effects of trade (Edmonds et al. 2006, Kovak 2013, Autor, 2013) and exploits the fact that cities in China vary in their composition of employment across industries and tariff changes vary across industries. The empirical evidence supports the main predictions of the theoretical model that increases in the export exposure reduce size of labor force in the agricultural sector and induces inter-regional labor migration. In particular, in the district that experience the average rising export exposure, the increase in export explains more than 50 percent of the decline in the employment share in agriculture during 2000-2010. Additionally, compared with prefectures at the 25th percentile of export exposure growth, the migrants share in prefectures at the 75th percentile increased by 11.66 percentage points more during this period. Moreover, the effects of export exposure decrease over distance to the coastline. Using firm level data from the Annual Survey of Industrial Production, I also provide empirical support of the differentiation in trade effects on regional average productivity, which is the central mechanism of the model.

The work in this paper builds on several strands of existing literature. It relates closely to the literature on trade and structural change. Reduction in trade cost induces expansion in sectors with comparative advantage due to differences in technology, relative factor endowments, or institution quality[3] . A more recent strand of theoretical literature examines how institutional frictions affect the implications of trade for labor market reallocation (Cuñat and Melitz, 2012; Kambourov, 2009; Helpman and Itskhoki, 2010; Davis and Harrigan, 2011). This work, however, has largely focused on the composition of economy and stays silent on the efficiency of the division of labor markets between sectors. In contrast with the existing literature, the model in this paper is built in the dual economy framework which is characterized with between-sector distortions. Individuals earn their average product in the agriculture sector and make migration decisions according to the expected values of searching jobs in the manufacturing sector, following the influential work in Harris and Todaro (1970). This set up is used to capture the welfare enhancement effects of trade through alleviating labor markets distortion across sectors. In addition, my work relate the labor reallocation across sector with the intra-sector labor reallocation and highlights a new mechanism by which trade cost reduction induces structural change.

This paper also connects with models investigating the impact of international trade on internal geographical labor mobility. A commonly used theoretical framework in this strand of literature is the new economic geography model, which explains the importance of region's access to markets and the agglomeration of economic activity. However, only a small number of papers have explicitly incorporating regional heterogeneity within a country, such as Allen and Arkolakis (2013), Cosar and Fajgelbaum (2013), Redding (2012), and Tombe and Zhu (2015). However, since most of these papers consider complete specialization in each region, trade-induced labor reallocation across space in these theoretical framework is essentially the same as reallocation of labor across sectors. My main departure from these papers is that it allows for incomplete specialization at each location and examines the structural transformation within each region. It is the heterogeneity in the impacts of international trade on structural change across space that generates the migration among different regions.

My work also contributes to the literature on the welfare gains of trade with the presence of

[3] There is also a large strand of literature empirically investigating labor reallocation induced by trade opening. See, for example, Wacziarg and Wallack (2004), Uy et al. (2012), and McCaig and Pavcnik (2013).

distortions. This literature has focused distortions in the goods market and discussed gains from trade through changes in markup dispersions[4] . Davidson et al. (1999) show the importance of the introduction of Diamond–Mortensen–Pissarides-type search and matching frictions into competitive models of international trade. Its extensions include, but are not limited to, Helpman and Itskhoki (2010), Helpman et al., (2010) and Felbermayr et al. (2011). None of these papers, however, has discussed the importance of this type of factor markets distortion in explaining gains from trade, which is one of the main concerns of this paper.

Lastly, my paper is most closely related to several papers. Using a two-country two-sector model of trade, Helpman and Itskhoki (2010) investigate how reductions in trade impediments generates welfare gains by changing the distribution of labor across sectors. In this paper, I extend it to a richer spatial setting by borrowing the idea of regional heterogeneity from Fajgelbaum and Redding (2014), as well as assumptions of agriculture wage determination and equilibrating mechanism across sector from Harris and Todaro(1970). There are two important differences between my work and Helpman and Itskhoki (2010). First, in contrast with Helpman and Itskhoki (2010) in which labor market tightness depends only on the labor market parameters and is fixed, I model labor market tightness as endogenous and make it dependent on trade barriers, following the key assumption in Felbermayr et. al. (2011)[5] . This assumption is used to captures additional channel through which opening to trade affects welfare. Second, the the focus of the analysis is different. Helpman and Itskhoki (2010) do not explicitly discusses the impacts of trade on the efficiency of the economy, while my main interest lies in separating the impact of changes in labor market distortions out from the total welfare gains from trade.

The rest of the paper is structured as follows. Section 2 describes two stylized facts that motivate my analysis. Section 3 develops the model and characterizes its steady state equilibrium.

[4] See for instance Epifani and Gancia (2011), Edmond et al. (2014) and Holmes et al. (2014). Epifani and Gancia (2011) discuss the conditions under which trade may reduce welfare by changing the distribution of markups and exacerbating the market distortions. Edmond et al. (2014), on the contrary, identify the conditions for trade to reduce markup distortions.

[5] Felbermayr et. al. (2011) consider a economy with only one sector whereas my model considers two sectors and investigates both changes within sector and between sectors. In addition, my main interest lies in how welfare gains from trade are affected by labor market distortions, while Felbermayr et. al. (2011) concentrate on how trade openness affects unemployment rate.

I also compare different mechanisms of welfare gains from trade with counterfactual analysis. In Section 4 I discuss the empirical strategy to test the main prediction of the model and present the main evidence. Section 5 concludes. The Appendix provides the proof of the theoretical implications and details of main measurements used in the empirical analysis.

1.2 Motivating Stylized Facts

As shown in Figure 1.1, since the opening policy in 1978, China has experienced a sharp increase in the export of GDP ratio, from 4.6% in 1978 to 24.11% in 2013, with the agriculture employment share dropped from 70% in 1978 to 34.36% in 2012. Data from the National Rural Fixed-point Survey shows that the average share of migrants out of total rural labor force rose from 15.45% in 2000 to 30.12% in 2009. In additional, the number of inter-provincial migrants increased from 42.6 million to 85.8 million during 2000-2010 according to the population census in 2000 and 2010. Meanwhile, these changes are not equally distributed across all regions in China. There are two main stylized facts manifested in the population census of the spatial pattern of these changes that motivate the analysis in this paper.

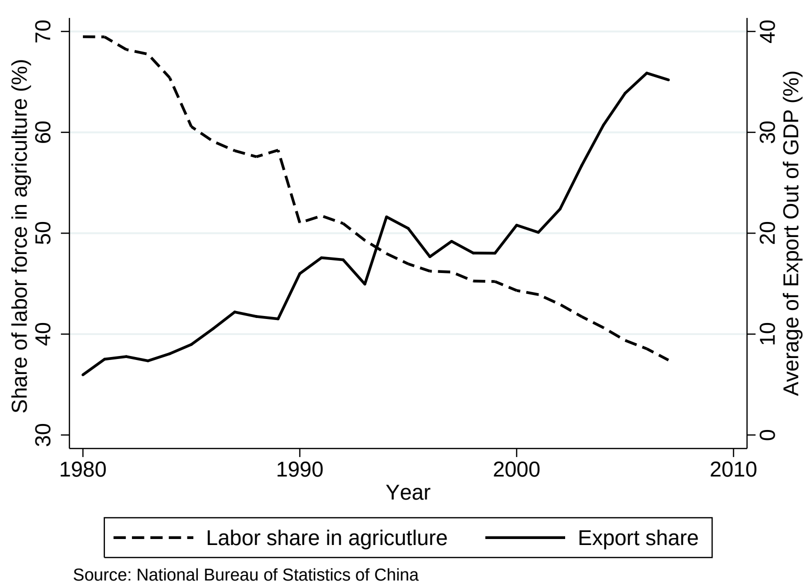


Figure 1.1: Agriculture employment share and export share during 1978-2008

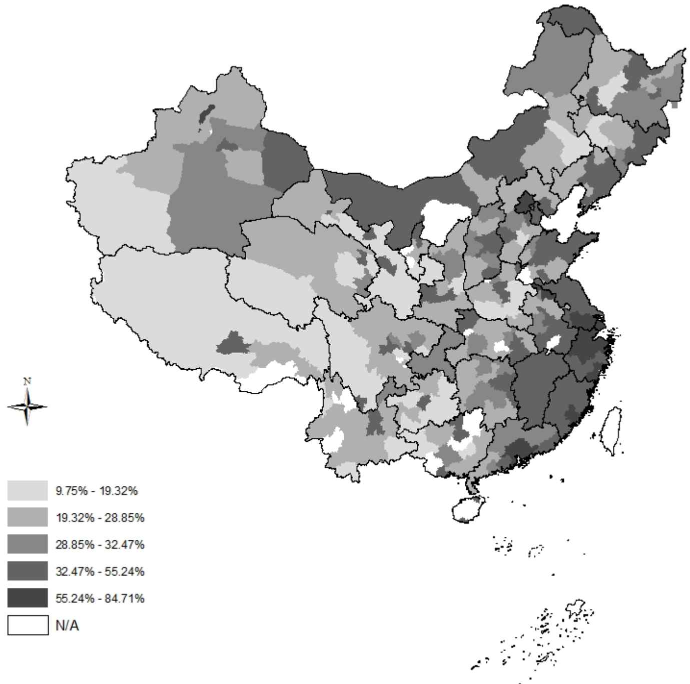
First, the employment share in non-agriculture sector is higher in coastal cities than that in most interior regions (Figure 1.2 Panel A). Prefectures with more than 60% population above the age of 16 employed in the non-agriculture sector are all located in the two major coastal megacity regions, the Pearl River Delta and the Yangtze River Delta. Moreover, given the initial employment share, the coastal area experienced a sharper decrease in the agriculture employment share during 2000-2010 (Figure 1.2 Panel B). Prefectures in Jiangsu and Zhejiang province particularly involved the most significant structural transformation. We can also see larger changes in the central region than the western region, which might be caused by the shorter geographical distance between the central region and eastern coastal cities than that between the western and eastern regions.

Second, there is a clear geographic pattern of the inter-regional migration flows in China. Based on population census in 2010, Panel A in Figure 1.3 shows the largest 20 inter-provincial migration flows. All flows are directed primarily towards coastal provinces such as Guangdong and the Yangtze Delta. Additionally, major flows between provinces are largely unidirectional. The major players in inter-provincial flows were basically either export provinces (such as Sichuan) or import provinces (such as Guangdong). In 2010, the migrants in the top 20 prefectures that had the largest inter-province migration population account for 47.65% of the total inter-province migrants in China. 18 out of these 20 cities were located in the three major coastal megacity regions (Figure 1.3 Panel B).

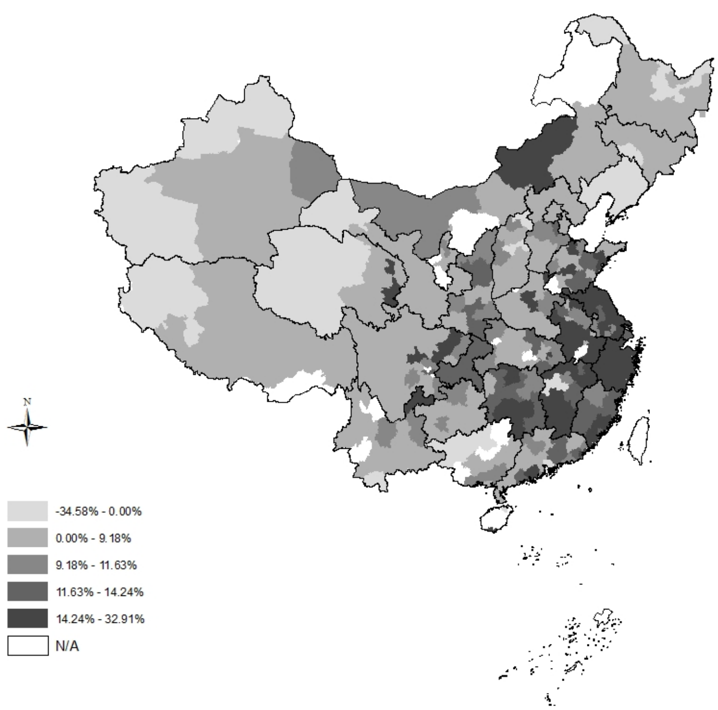
The model in the next section is developed to capture these two stylized facts.

1.3 Theoretical Framework

The model is built upon the work of Helpman and Itskhoki (2010) and Felbermayr et. al. (2011). Essentially, I extend the model in Melitz (2003) with the incorporation of a traditional agriculture sector and labor market frictions in the modern manufacturing sector, and adapt the original model to a setting with multiple asymmetric regions with respect to their geographical locations. Wages are determined in different manners across sectors, following the standard practice in the dual-economy literature. Within each location, individuals make their migration decision



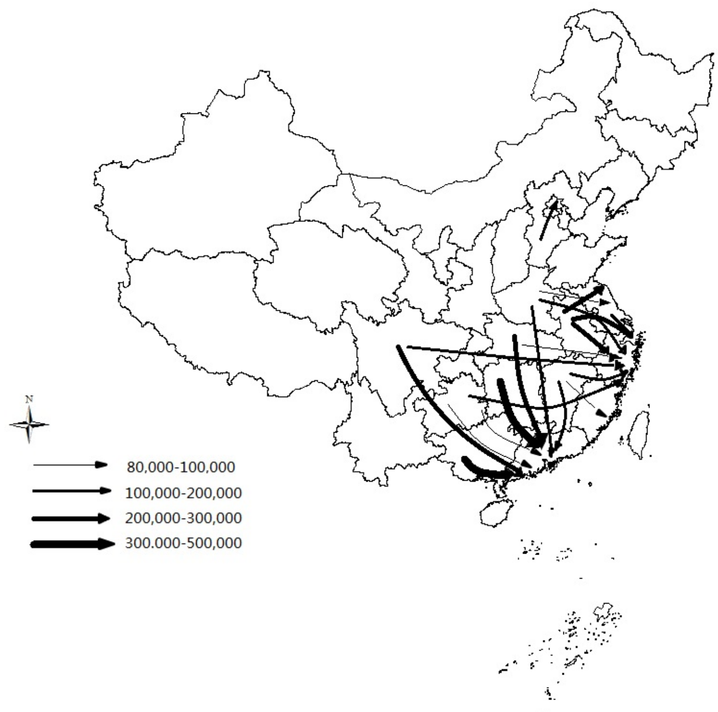
(a) Share of non-agriculture sector employment



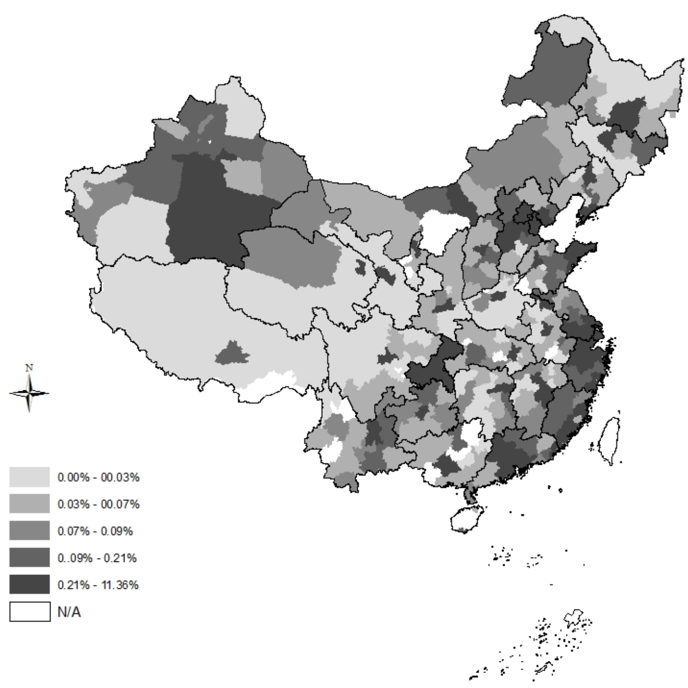
(b) Change in non-agriculture employment share during 2000-2010

Source: See main text; N/A=data is not available

Figure 1.2: Share of non-agriculture employment in 2010



(a) 20 largest inter-province migration flows



(b) Share of inter-province migration

Source: See main text; N/A=data is not available

Figure 1.3: Share of Inflow and outflow population in 2010

based on the wage they can earn in the agriculture sector and the value of searching jobs in the manufacturing sector. Additionally, workers move across regions in search for high welfare until no one has incentives to change his/her location.

In particular, the economy consists of K locations arbitrarily arranged in two countries. There are two sectors at each location, the rural or agricultural sector (A) and the urban or manufacturing sector (M). Labor is the only factor used in production. It is perfect intersectorally and interregionally mobile within countries, but immobile across countries. I devise my model in discrete time. All payments are paid at the end of each period. To simplify notations, henceforce I denote the current period variable x_t as x and the next period variable x_{t+1} as x'. $\hat{x}$ refers to the percentage change of variable x.

1.3.1 The setup of model

1.3.1.1 Demand

Each location i ($i = 1, ...K$) has a representative consumer with preferences given by the quasi-linear utility function[6]

$$U_i = X_i + \frac{1}{\alpha} Y_i^{\alpha} + \frac{\bar{H}_i}{N_i^{\zeta}}$$

in which X_i is the consumption of a homogeneous product in the rural agriculture sector in region i. Y_i is consumption of a composite of urban manufacturing varieties ω, defined as:

$$Y_i = [\int_{\omega} y_i(\omega)^{\rho} d\omega]^{\frac{1}{\rho}} \qquad 0 < \alpha < \rho < 1$$

where $y_i(\omega)$ is the consumption of ω. N_i is the total population at location i. $\bar{H}_i$ is the given value of local amenity shared by all workers at i. Note that I expect that the congestion acts as a spreading force that increases as the population grows. X_i is freely tradable between regions and it is considered as the numeraire. Its price p_{Xi} equals 1. The lifetime utility of the representative consumer is $\mathbb{U}_i = \sum_t \frac{1}{(1+r)^t} U_{it}$, where r is the discount rate shared by all locations. By solving the

[6] All conclusions in this paper also hold for a model with CES preferences.

consumer's problem, the demand of each manufacturing variety ω is given by

$$y_i(\omega) = p_i(\omega)^{-\frac{1}{1-\rho}} Y_i^{-\frac{\rho-\alpha}{1-\rho}} \tag{1.1}$$

where $p_i(\omega)$ is the price of ω at location i. Additionally, $Y_i = P_i^{-\frac{1}{1-\alpha}}$, with $P_i = [\int_\omega p_i(\omega)^{\frac{\rho}{\rho-1}} d\omega]^{\frac{\rho-1}{\rho}}$ as the price index of Y_i. Hence, the total expenditure on the differentiated good equals Y_i^α at location i. The indirect utility of the representative consumer is

$$V_i = E_i + \frac{1-\alpha}{\alpha} P_i^{-\frac{\alpha}{1-\alpha}} + \frac{\bar{H}_i}{N_i^\zeta} \tag{1.2}$$

where E_i refers to the total income. Falls in trade barriers can increase welfare at location i either by raising total income or reducing the price index.

1.3.1.2 Labor markets

At each location, the labor market is segmented into two sectors, labeled agricultural (A) and manufacturing (M). w_{si} and N_{si} are the wage rate and total population searching for jobs in sector s, respectively, where $s = A, M$. L_{Mi} is the total employment in sector M at location i. The total population at location i is N_i. The total population in the economy is given as $\bar{N}$.

Rural labor markets

All labor in the agricultural sector work on a big farm with full employment and share the same pot of income, i.e. $w_{Ai} = \frac{X_i}{N_{Ai}}$, where X is produced with the technology

$$X_i = F(N_{Ai}), \quad F' > 0,\ F'' < 0$$

Then the wage rate in the agricultural sector is given by:

$$w_{Ai} = \frac{F(N_{Ai})}{N_{Ai}} \tag{1.3}$$

where $N_{Ai} = N_l(1 - \frac{N_{Mli}}{N_i})$. This wage function implies that wage in the agriculture sector decreases with the total labor at each location and increases with the share of labor searching job in the manufacturing sector. I denote W_i as the value function of rural employment and U_i as the value of an urban unemployed worker searching for urban jobs. Assume that, to find an urban job, rural workers must move to the urban area[7] . Then the following relationship between U_i and W_i holds

$$(1+r)W_i = w_{A_i} + B_i' \tag{1.4}$$

where r is the discount factor and $B' = \max\{W_i', U_i'\}$. Equation (4) implies that $(1+r)W_i$ is equal to the flow of agriculture wage plus the value of the choices in the next period.

Urban labor markets

There are search-and-matching frictions in the manufacturing sector. Firms post v vacancies to attract workers, while workers have no knowledge about whether a particular firm is hiring. Workers are hired by firms with a matching technology. As commonly assumed in the search and matching literature, the probability that a vacancy is filled can be expressed as $q(\varphi_i)$, where φ_i is the vacancy-unemployment rate and represents the labor market tightness in the manufacturing sector. $q(\varphi_i)$ is decreasing in φ_i. Unemployed workers are hired at the rate $x(\varphi_i) = \varphi_i q(\varphi_i)$, which is an increasing function of φ_i. Before the beginning of the next period, each pair of match is destroyed with probability η due to match-specific shocks.

Once the matching technology brings together firms and workers successfully, wage w_{Mi} is decided through Nash-bargaining. The surplus from successful matches is split between workers and the firm to solve:

$$\max_{w_{Mi}} (E_i(\theta) - U_i)^{\beta} (\frac{\partial J_i(l;\theta)}{\partial l})^{1-\beta}, \quad 0 \leq \beta \leq 1 \tag{1.5}$$

where $J_i(l;\theta)$ is the asset value of a firm with productivity θ and l workers, to be defined below. $\partial J_i(l;\theta)/\partial l$ measures the firm's surplus by hiring an additional worker. β shows the bargaining power of the worker. $E_i(\theta)$ is the present value of being employed by a firm with productivity θ, and it satisfies the following Bellman equations:

$$(1+r)E_i(\theta) = w_{Mi} + [(1-\psi)\max\{E_i'(\theta), B_i'\} + \psi B_i'] \tag{1.6}$$

$$1+r)U_i = (1 - x(\varphi)')B_i' + (1 - x(\varphi_i))\max\{E_i'(\theta), X_i'\}$$

[7] The main results in this paper do not change when I assume workers can search for jobs in the manufacturing sector while staying in the agriculture sector.

where ψ is the actual separation rate of each firm-work match[8] . The above equations imply that $(1+r)E_i(\theta)$ depends the wage rate in each period and the probability at which the current employment status continues.The same holds for $(1+r)U_i$[9] .

1.3.1.3 Manufacturing sector producers

The production in the manufacturing sector is modeled in a similar fashion as in Melitz (2003). Manufacturing firms produce heterogeneity varieties under monopolistic competition, incurring melting-iceberg type variable cost $\tau_{ij} \geqslant 1$ when shipped between location i and j. A firm with productivity θ produces θl units of output if it employs l units of labor, with θ drawn from a common distribution $G(\theta)$, which is same across locations. Before entry, firms only know the distribution of their productivity. In order to enter the market, a firm needs to pay an entry cost f_e. After entry, firms decide the optimal number of vacancies to be posted according to their productivity level and consider wage as given. Henceforce I use θ to index firms. Before the beginning of the next period, firms are forced to leave the market with the probability δ. Firms at location i bear fixed cost f_{ij} for sales to location j.

Assume the cost of posing a vacancy is c. The producer maximizes its market value by solving

$$J_i(l:\theta) = \max_{v_i} \tfrac{1}{1+r}\left[R_i(h:\theta) - w_{Mi}(l;\theta)l - cv_i - f_{ii} - \textstyle\sum_{j\neq i} I_{ij}(\theta) f_{ij} + (1-\delta)J_i(l':\theta)\right] \quad (1.7)$$
$$\text{s.t.} \quad l'_i = (1-\eta)l_i + q(\varphi_i)v_i$$

where $I_{ij}(\theta)$ is an indicator function and takes one if a firm chooses to sell to location j. $R_i(l:\theta)$ is the total revenues of a firm with productivity θ and l workers at location i.

Let $\pi_{ij}(\theta)$ denote the profits earned in market j in each period. An entering firm with productivity θ will continue to produce when $\pi_{ii}(\theta) \geq 0$ and will sell to market j if $\pi_{ij}(\theta) \geq 0$. Or in other words, define θ^*_{ij} as the cutoff productivity such that $\pi_{ij}(\theta^*_{ij}) = 0$, then firms with productivity

[8] In this paper, I consider two reasons that may lead to a job separation in each period. First, firms are hit by a idiosyncratic shock at the rate of δ that forces firms to leave the market. Second, each match of workers and firms may be destroyed by a match-specific shock with probability η. Therefore, the actual rate of job separations is $\psi = \eta + \delta - \eta\delta$.

[9] For simplicity, I set unemployment benefit to 0. This assumption does not have any impacts on all main results in this paper.

lower than θ^*_{ii} cannot make profits. For firms with productivity at least as high as θ^*_{ii}, they do not sell to market j unless their productivity is higher than θ^*_{ij}.

Additionally, a prospective firm enters the market only if the expected profits from entry are at least as high as the entry cost. Therefore, we have the free-entry condition as

$$\frac{1+r}{r+\delta}\sum_{j=1}^{K}\int_{\theta^*_{ij}}^{\infty}\pi_{ij}(\theta_{ij})dG(\theta) = f_e,\, i = 1, 2\cdots K$$

1.3.2 Steady state equilibrium

In this section I characterize the structure of the general equilibrium conditions in the steady state. First let's define the equilibrium of the economy.

Definition 1

An equilibrium of the economy consists of labor density N_i, factor distribution $\{N_{Ai}, N_{Mi}\}$, factor prices $\{w_{Ai}, w_{Mi}\}$, goods prices P_i, productivity threshold $\{\theta^*_{ij}\}_{j=1,2...K}$, labor market tightness φ_i, and number of firms M_{ei} at each location i such that : 1) consumers maximize utility; 2) firms maximize profits; 3) labor markets clean; 4) trade is balanced.

Condition 1 implies that workers equalize value of W_i and U_i within each location i and the utility of the representative consume is equal across all locations, which determines the labor distribution across sectors and locations. Condition 2 gives us the optimal vacancy post strategy of firms and productivity cutoffs, while condition 3 and 4 pin down the price series.

1.3.2.1 Optimal vacancy post and wage bargaining result

As proved in the Appendix A, the first order condition of the firm's problem in (1.7) yields the optimal hiring rule of a firm in the steady state as

$$\frac{\partial R_i(l;\theta)}{\partial l} = w_{Mi}(l:\theta) + \frac{c}{q(\varphi_i)}\frac{r+\psi}{1-\delta} + \frac{\partial w_{Mi}(l;\theta)}{\partial l}l \qquad (1.8)$$

This equation differs from the solution in a friction-free market with the consideration of the expected cost to hire extra workers. Additionally, reinserting the first order condition for vacancy posting into the bargaining rule and plugging in the relations in equation (1.6) , we obtain the relationship between φ_l and w_{Ml} as

$$w_{Mi} = rU_i + \frac{\beta}{1-\beta}\frac{r+\psi}{1-\delta}\frac{c}{q(\varphi_i)} \tag{1.9}$$

with $rU_i = \frac{\beta}{1-\beta}\frac{1}{1-\delta}\varphi_i c$[10] . From equation (9), we can see that the manufacturing wage is a function of labor market tightness φ_i and it's independent of firms' productivity levels. This is due to the assumption that the posting cost are the same across firms. Additionally, wage is increasing in the market tightness. Larger φ means lower probability of successful match, which indicates higher expected costs of hiring new workers. This implies that increases in φ raise marginal costs and reduce firm's profits. This is the same as the conclusion in Felbermayr et al. (2011).

1.3.2.2 Equilibrium in goods markets

Substituting the expression of wage (1.9) into equation (1.8), firm's optimal hiring rule can be rewritten as

$$\frac{\partial R_i(l;\theta)}{\partial l} = \frac{\beta}{1-\beta}\frac{1}{1-\delta}\frac{\sigma-\beta}{\sigma}[\varphi_i c + \frac{r+\psi}{\beta}\frac{c}{q(\varphi_i)}] \tag{1.10}$$

where $\sigma = \frac{1}{1-\rho}$. Define $a(\varphi) \equiv \frac{\partial R(l;\theta)}{\partial l}$. Since $q(\varphi_i)$ is decreasing in φ, $a(\varphi)$ is an increasing function in φ. Substituting the expression of $a(\varphi)$ into the zero cutoff condition, the productivity thresholds are given by

$$(\theta^*_{ii})^{\frac{\rho}{1-\rho}} = Bf_{ii}a(\varphi_i)^{\frac{\rho}{1-\rho}}Y_i^{\frac{\rho-\alpha}{1-\rho}} \tag{1.11}$$
$$(\theta^*_{ij})^{\frac{\rho}{1-\rho}} = Bf_{ij}\tau_{ij}^{\frac{\rho}{1-\rho}}a(\varphi_i)^{\frac{\rho}{1-\rho}}Y_j^{\frac{\rho-\alpha}{1-\rho}}$$

where $B = (\frac{1+r}{1-\delta}\frac{\sigma-\beta}{1-\beta})\rho^{-\frac{1}{1-\rho}}$. Therefore, for any pair of locations i and j the productivity cutoffs satisfy

$$\frac{\theta^*_{ii}}{\theta^*_{ji}} = (\frac{f_{ii}}{f_{ji}})^{\frac{\rho}{1-\rho}}\tau_{ji}^{-1}(\frac{a_i(\varphi)}{a_j(\varphi)}) \tag{1.12}$$

Equation (1.12) implies that the cutoffs depend on the relative size of marginal revenues at the equilibrium, which are influenced by the labor market conditions. In addition, as proved in Appendix

[10] See Appendix A for more details.

A, the free entry condition can be simplified as

$$\sum_j \int_{\theta^*_{ij}}^{\infty} f_{ij}[(\frac{\theta}{\theta^*_{ij}})^{\frac{\rho}{1-\rho}} - 1]dG(\theta) = \frac{r+\delta}{1+r} f_e,\ i = 1, 2 \cdots K \tag{1.13}$$

Relation (1.12) and (1.13) derive $K * K$ functions, which can be used to pin down θ^*_{ij} as functions of φ_i and φ_j ($j = 1, 2...K$). Once the productivity thresholds are determined, we can get the consumption level of Y_i with equation (1.11). Additionally, total expenditure in the differentiated sector equals total revenues of all firms serving demand in this sector, which determines the entry rate of new firms as[11]

$$Y_i^{\alpha} = \frac{1+r}{1-\delta}\frac{\sigma-\beta}{1-\beta}\{\sum_j \frac{M_{ej}}{\delta}\int_{\theta^*_{ji}}^{\infty} f_{ji}(\frac{\theta}{\theta^*_{ji}})^{\frac{\rho}{1-\rho}} dG(\theta)\},\ i = 1, 2 \cdots K \tag{1.14}$$

With these K functions we can write M_{ei} as function of φ_i and φ_j ($j = 1, 2...K$) as well[12] .

1.3.2.3 Equilibrium in labor markets

Analogous to the Harris and Todaro (1970) model, the mobility equilibrium condition requires that staying in the rural sector has the equal value as migrating to the urban sector and searching for urban job as an unemployment worker, i.e. $W_l = U_l$. Therefore, the wage and labor market tightness satisfy

$$w_{Ai} = \frac{\beta}{1-\beta}\frac{1}{1-\delta}\varphi_i c \tag{1.15}$$

Equation (1.15) implies that the labor in the agriculture sector depends on the labor market tightness in the manufacturing sector. Quite intuitively, increases in φ raise the probability at which the unemployed workers meet firms. Therefore, the value of urban unemployment goes up and this encourages more workers to move to the urban sector and search for job. In addition, combining with equation (1.9), equation (1.15) yields the rural-urban wage gap as

$$\frac{w_{Mi}}{w_{Ai}} = \frac{r+\psi}{x(\varphi_i)} + 1 \tag{1.16}$$

[11] To see this, recall that the total expending on differentiated products is equal to $P_i Y_i = Y^{\alpha}$. In addition, we have $R_{ij}(\theta^*_{ij}) = \frac{1+r}{1-\delta}\frac{\sigma-\beta}{1-\beta} f_{ij}$ and for $\frac{R_{ij}(\theta_1)}{R_{ij}(\theta_2)} = (\frac{\theta_1}{\theta_2})^{\frac{\rho}{1-\rho}}$, where $R_{ij}(\theta_{ij})$is the revenue from sales to market j. Therefore, $R_{ij}(\theta_{ij}) = (\frac{\theta_{ij}}{\theta^*_{ij}})^{\frac{\rho}{1-\rho}} \frac{1+r}{1-\delta}\frac{\sigma-\beta}{1-\beta} f_{ij}$. See appendix for more details.

[12] In this paper I only discuss the equilibrium with positive entry of firms in all regions.

which is decreasing in φ_i. This suggests that the harder it is to find urban jobs, the larger the wage gap is, which is quite straightforward. Furthermore, in the steady state equilibrium the flow-in employment is the same as the flow-out employment. Therefore,

$$\frac{x(\varphi_i)}{x(\varphi_i)+\psi}N_{Mi} = L_{Mi} \tag{1.17}$$

where L_{Mi} is determined by

$$L_{Mi} = \frac{M_{ei}}{\delta}\frac{1+r}{1-\delta}\frac{\sigma-\beta}{1-\beta}\frac{\rho}{a_i}\{\sum_j \int_{\theta^*_{ij}}^{\infty} f_{ij}(\frac{\theta}{\theta^*_{ij}})^{\frac{\rho}{1-\rho}}dG(\theta)\}$$

Equation (1.15) and (1.17) depend only on N_{Mi} and φ_i if we take the total labor at each location i as given. Therefore, these two equations can be used to pin down the value of N_{Mi} and φ_i. As proved in Appendix A, there exists a unique solution. Note that in contrast with Helpman and Itskhoki (2010) in which labor market tightness is constant, φ_i in this model is endogenous and its value varies with trade cost. This feature provides additional channels through which falls in trade barriers affect welfare and makes the trade-induced labor market change more complex.

The optimal distribution of labor force across locations comes with the condition that the indirect utility equalization across all location:

$$E_i + \frac{1-\alpha}{\alpha}Y_i^{\alpha} + \frac{\bar{H}_i}{N_i^{\zeta}} = E_j + \frac{1-\alpha}{\alpha}Y_j^{\alpha} + \frac{\bar{H}_j}{N_j^{\zeta}}$$

With the presence of congestion forces, wages are not equalized across regions.

1.3.3 The impacts of international trade cost reduction

1.3.3.1 Symmetric regions

First I consider in this section symmetric locations with $\tau_{ij} = \tau_{ik}$,$f_{ij} = f_{ik} = f_x$, $f_{ii} = f_d$, for all $l, k, j = 1, 2, \cdots K$ in order to understand how the level of trade costs affects labor markets across sectors. With this assumption, the steady state equilibrium variables are the same in all locations. Changes in trade impediments have same impacts at all locations, so there is no labor movement across locations and population size at each location is fixed at $\frac{1}{K}\bar{N}$. Therefore in this section I drop the location index for convenience and use θ_d^* and θ_x^* to show the productivity cutoffs to sell locally and to other market, receptively. Total differentiating equation (1.12) and (1.13), we get

$$\hat{\theta}_d^* = -\frac{\mu_x(K-1)}{\mu_x(K-1)+\mu_d}\hat{\tau} \tag{1.18}$$

$$\hat{\theta}_x^* = \frac{\mu_d}{\mu_x(K-1)+\mu_d}\hat{\tau}$$

where $\mu_i = \frac{f_i}{\theta_i^{*\sigma-1}}\int_{\theta_i^*}\theta^{\sigma-1}dG(\theta), i = d, x$. The sign of coefficients in (1.18) implies the following lemma.

Lemma 1

Assume all locations are symmetric. As in Melitz (2003), a reduction in trade impediments raises the productivity cutoff for domestic production, decreases the cutoff to sell to other markets and reallocates labor towards the more productive firms.

Equation (1.18) also implies that the productivity threshold is independent of the labor market parameters. This property holds with symmetric regions since cutoffs only depend on the relative values of labor market tightness. We can then substitute the value of cutoffs into equations (1.15) and (1.17) to obtain the solution for N_M and φ. Since a reduction in trade costs affects labor market conditions only through the change in cutoffs, as shown in Figure 1.4, a decrease in τ has no impact on equation (1.15) but raises the steady state N_M by moving the steady state employment flow equation (1.17) upward. We prove in Appendix A the following lemma.

Lemma 2

In an equilibrium with symmetric locations, a decrease in trade costs increases the labor market tightness φ and reduces the share of labor working in the agriculture sector.

The intuition of this result is quite straightforward. The reduction in trade impediments results in the exit of the least productivity firms and increases in the market share of the most productivity firms and, hence make firms on average more productive. The urban sector wage increases less than proportionally with the average productivity due to the bargaining power of firms. Therefore, the value of filled vacancies gets larger, which encourages firms search for workers more intensively. It then becomes easier for unemployed workers to find a job in the urban sector,

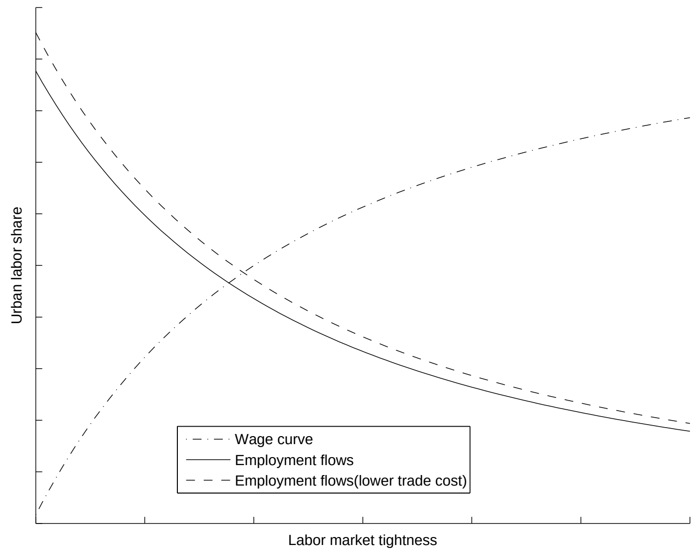


Figure 1.4: Effects of trade cost reduction with symmetric regions

raising the asset value of unemployed worker (U goes up). This drives more workers to migrate from the rural sector to the urban area, and the steady state rural wage w_A increases as well. In addition, given equation (1.9), the urban wage w_M is augmented by both the increase in the value of worker's outside option U and higher expected hiring cost $\frac{r+\psi}{1-\delta}\frac{c}{q(\varphi)}$. However, the rural-urban wage gap reduces as in equation (1.16). The increase in φ has a proportional effect on w_A but a less than proportional effect on w_M due to changes in firm's behavior.

1.3.3.2 Asymmetric regions

When all locations are symmetric, the location of each regions is irrelevant. In this section I discuss the impacts of trade cost reduction when some regions have a geographical disadvantage. In particular, I assume that only some locations can trade directly with the rest of the world and we call them international ports. Goods from other locations must be shipped through ports to the international market.

Because of the high non-linearity the model, I cannot derive its solution analytically. The impacts of location heterogeneity on properties of the steady state equilibrium in the previous section are examined with numerical examples where specific parameter values are assigned. The model is calibrated to match the labor market conditions in China in the 2000s. I choose China since it is featured with large reforms in openness policy and its agriculture sector is sizable. In addition, it is featured with serious factor misallocation across sector and space and large domestic trade cost. To consider the regional differentiation of trade impacts, it is necessary to have at least three regions located in two countries. Assume country H has two locations, labeled $c(oast)$ and $i(nland)$, while country F has only one location $f(oreign)$. Location c functions as the port in country H. Assume the trade impediments between the coastal location c and the foreign country F is lower than that between the interior location i and country F, and satisfy$1 < \tau_{ci} < \tau_{cf} < \tau_{if} = \tau_{cf}\tau_{ci}$.

I focus on equilibrium with incomplete specialization, i.e. $M_{ei} > 0$ for all i. The values of main parameters in the model are picked based on the existing literature, and the rest are determined to match the empirical evidence from China. Following a large literature of firm's heterogeneity, I assume that the probability density of firms productivity is $g(\varphi) = \gamma\varphi^{-(1+\gamma)}$, where γ satisfies $\gamma > \sigma - 1$ to ensure that the variance of the sales distribution is finite. σ is set as 4. The production function in the rural sector is given by $F(N_{Ai}) = N_{Ai}^{0.6}$. I set $r = 0.05$ as the annual interest rate. The bargaining power of worker is $\beta = 0.5$. The labor market tightness is 1.1 in China in 2011 (Xiao, 2013) and unemployment rates was around 11% in 2002, so the vacancy posing cost c is set as 1.4 and the scale of matching function is 0.6. The domestic trade cost is set as the minimum level of international trade used in the conterfactual analysis. More details of parameters values used in calibration are shown in Table 1.1.

Table 1.1: Calibration-parameter values

Parameter	Definition	Value	Source/Target
σ	Elasticity of substitution	4	Bernard et al. (2003)
c	Cost of hiring	1.4	1.1 times monthly wage (Felbermayr et al., 2011)
α	Parameter in the utility function	0.7	$0 < \alpha < (\sigma - 1)/\sigma < 1$
γ	Decay of productivity distribution	3.2	$\gamma > \sigma - 1$ to ensure that the variance of the sales distribution is finite
s	Actual rate of job separation	0.07	Unemployment rate around 11% (Giles et al., 2005)
m	Scale of matching function	0.6	labor market tightness 0.9-1.1 (Xiao, 2013)
β	Wage bargaining power	0.5	Standard
δ	Rate of firm exit	0.01	Felbermayr et al. (2011)
r	Monthly discount rate	0.42%	5% annual interest rate
N	Total population size	2	Normalization
H	Local amenity shared by worker	1	Normalization

Table 1.2: Simulation results of main variables

International trade cost	1.15	1.45	1.85	1.15	1.45	1.85
	Interior region			Coastal region		
Domestic sale productivity threshold	4.5001	4.3249	4.2446	4.5781	4.3693	4.27
International sale productivity threshold	6.966	8.6963	11.1246	6.7052	8.3246	10.6182
Urban labor	0.4193	0.3719	0.3289	0.5263	0.4277	0.3565
Total population	0.9577	0.9805	0.9904	1.0423	1.0195	1.0096
Urban labor share	43.79%	37.93%	33.21%	50.50%	41.95%	35.65%
Vacancy-unemployment rate	1.1774	0.9619	0.8106	1.2439	1.0008	0.8335
Unemployment rate	9.71%	10.63%	11.47%	9.47%	10.44%	11.33%

The results from numerical simulations are shown in Table 1.2 and Figure 1.4. The model is calibrated to obtain an economy in which is the urban employment share increases from 35.65% to 52.63% in the coastal region due to the tariff reduction. The unemployment rate decreases from 11.33% to 9.47% , while the vacancy-unemployment rate increases from 0.8335 to 1.2439. There are three propositions can be concluded from the numerical analysis.

Proposition 1

Locations that are closer to the world market (ports) has larger share of export firms, higher average productivity, higher labor market tightness and lower employment share in the agriculture sector.

Building on lemma 1 and 2, this proposition is quite intuitive. The cost of trade to the world market for coastal regions is lower than it is for interior regions. Lemma 2 implies it's more profitable for firms in the coastal cities to export than it's in the interior regions. This theoretical implication is consistent with the stylized facts in the second section in this paper. Additionally, given that lower trade impediment is accompanied with higher welfare and with free inter-regional labor mobility, labor moves towards regions with higher indirect utility until welfare is equalized across regions, make coastal regions to have higher population density than interior regions. The domestic trade cost does not only affect the equilibrium distribution of economic activities, but also shapes the pattern across space of the impacts of a reduction in international trade costs. I summarize the impacts of international trade cost in regions with different geographical locations as follows.

Proposition 2

Reductions in international trade impediments increase the domestic cutoffs at each locations, reallocate labor towards firms selling to other markets and increase the labor market tightness φ *at each location.*

Proposition 3

Reductions in international trad impediments have larger impacts on the labor market at locations with geographical advantages.

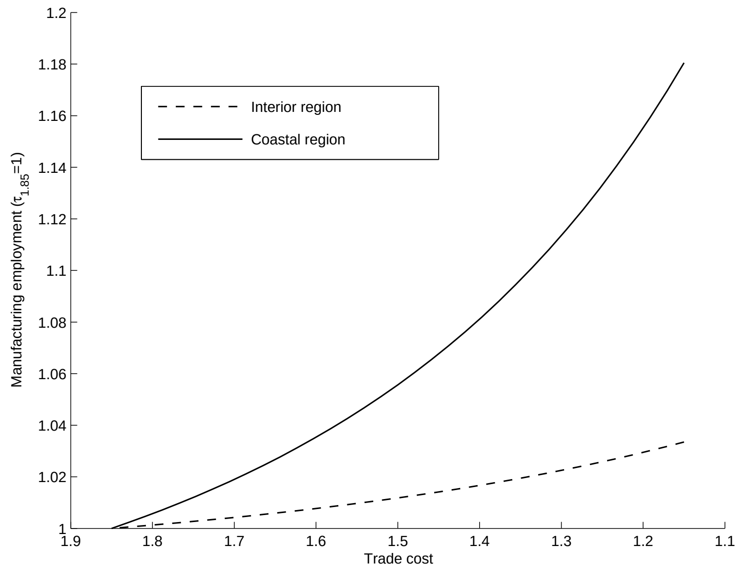
Proposition 2 states that lemma 2 still holds in an economy with asymmetric regions and indicates labor mobility from rural sector to urban sector at each region. Proposition 3 follows proposition 1. Assume a special case that the internal trade cost is extremely high, which will stop all firms in the interior region from exporting. As a consequence, the change in international trade costs has no impact in the interior area, as long as the interior region is still in the autarky status, but this change affects the coastal region as described in Proposition 2. Attracted by the higher welfare level at coastal regions, workers migrate from the interior regions until the new equilibrium is reached (as shown in Figure 1.5).

1.3.4 Welfare analysis

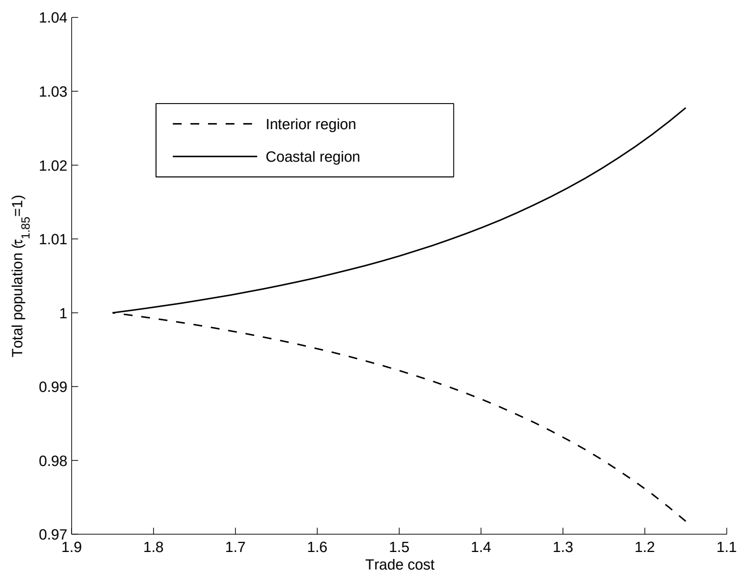
1.3.4.1 Decomposition of welfare gains

Having studied the properties of the equilibrium, I now turn to the discussion of its welfare implications. According to equation (1.2), the indirect utility function for consumers within each region is increasing in aggregate income and declining in price index of the differentiated good. Proposition 2 and 3 implies that the reduction in trade impediments increases total welfare of country H by raising E or reducing P through four channels. First, it reallocates markets shares towards more efficient firms, which impacts P negatively. Welfare gains from this channel have been discussed intensively in the literature following Melitz (2003). Second, a drop in trade cost increases the labor market tightness in the manufacturing sector. This change, on one hand, raises firms' cost of hiring per worker, thus reducing the mass of firms in the differentiated sectors. On the other hand, higher vacancy-unemployment ratio increases wages in both sectors, contributing to a higher value of total income. Third, trade liberalization leads to an expansion in the total labor force in the manufacturing sector and increases the total production of Y. Last, the reduction in international trade cost induces population to move towards regions with high average productivity cost, which increase welfare in both regions.

Among all four mechanisms, only the impact of a change in labor market tightness is ambigu-



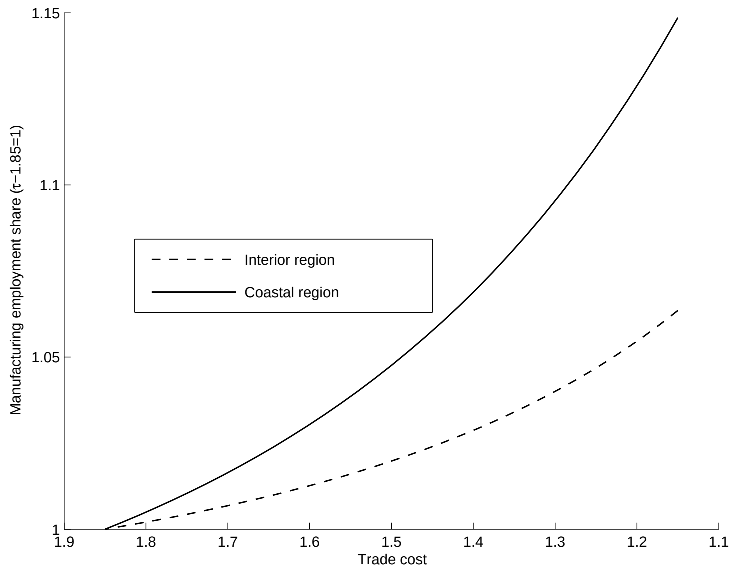
(a) International Trade cost and total regional urban employment



(b) International trade cost and total regional population change

Figure 1.5: Effects of trade cost reduction with asymmetric regions

ous. Whether or not the increase in vacancy-unemployment ratio generates welfare gains depends on the prevalence of two opposite effects. The net effect is positive only when the higher income offsets the loss of firm's entry. This mechanism is absent in Helpman and Itskhoki (2010), in which the cost of hiring is constant. Despite the ambiguity of the effect of one mechanism, the within-sector effects of trade, however, is always positive on total welfare.



(c) International trade cost and urban labor share

Figure 1.5: Effects of trade cost reduction with asymmetric regions (continue)

I use counterfactual analysis to isolate different mechanisms above. Figure 1.6 illustrates the decomposition of total trade effects. The solid line in the figure plots the welfare change as a joint result of four mechanisms. The total welfare is scaled so that the value equals 1 when international trade cost is 1.85. To get the top dotted line, I allow for firm's exit and entry, but keep the vacancy-unemployment ratio in each region and labor distribution fixed at their initial values when international trade cost is 1.85. The bottom dashed line presents the total welfare when firm can change the vacancy posting behavior freely but labor distribution is constant at their initial values. The middle dashed line summarizes what total welfare would be if we keep the same labor distribution across space at the initial values but allow labor flows between sectors.

The bottom line captures the impacts of changes within the manufacturing sector, which is a joint outcome of both change in firm's exit and entry and firm's vacancy posting behavior. The difference between the bottom line and the middle line implicitly summarizes the results of structural change, while the gap between the solid line and middle dashed line shows the effects of changes in population scale at each location . We can see that in the calibrated model, the welfare effects of vacancy-unemployment ratio is negative, which is shown by the gap between the top dotted line

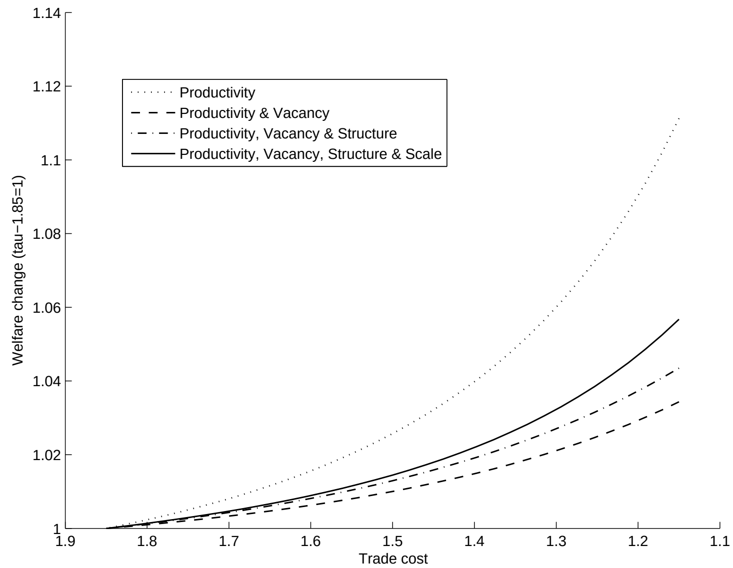


Figure 1.6: Decomposition of the welfare gains from trade

and the bottom line. The net effect of the within-sector adjustment accounts for about 60% of the total welfare gains. Quite intuitively, this ratio will be smaller if the misallocation of labor across sectors and space is more severe.

1.3.4.2 Welfare gains and changes in labor market efficiency

How do distortions in the labor market affect these results? To answer this question, I consider the population distribution at each location as given and focus on adjustment within each location[13]. The impacts of changes in labor market distortions are captured by the disparity between the decentralized competitive equilibrium and the optimal solution from the utilitarian social planner's problem. Following the conceptual tools from Lee (2008), the problem of the social planner is to maximize total net revenue by choosing the appropriate number of vacancy posted by firms in the manufacturing sector and allocating workers across sectors. Appendix A provides detailed analysis of this problem. In contrast with the competitive equilibrium described by equation (1.10) and equation (1.15), the first-best labor market tightness and labor allocation across sectors are

[13] The efficiency effects of across-space changes is quite straightforward. As implied by proposition 3, falls in trade barriers induce labor movement across regions, from the interior region (with low TFP) to the coastal region (with high TFP). This type of reallocation helps to reduce the between-region labor market distortions and generates welfare gains.

determined by

$$\frac{\partial R(l;\theta)}{\partial l} = \frac{1-\zeta}{\zeta}\varphi c + \frac{r+\psi}{\zeta}\frac{c}{q(\varphi)} \tag{1.19}$$
$$F'(N_A) = \psi\frac{-c\varphi+\frac{\partial R_i(l;\theta)}{\partial l}\frac{x(\varphi)}{r+\psi}}{r+\psi+x(\varphi)}$$

where ζ is the elasticity of $x(\varphi)$ with respect to φ[14] . Figure 1.7 shows the difference between the decentralized competitive equilibrium with the first-best choice of $\{\varphi,\ N_A\}$. In the calibrated model, the competitive equilibrium involves too few vacancies posting in the manufacturing sector and too many workers in the agriculture sector. Therefore, there exist both within-sector distortions and between-sector misallocation. I summarize features illustrated in Figure 1.7 with the following lemma.

Lemma 3

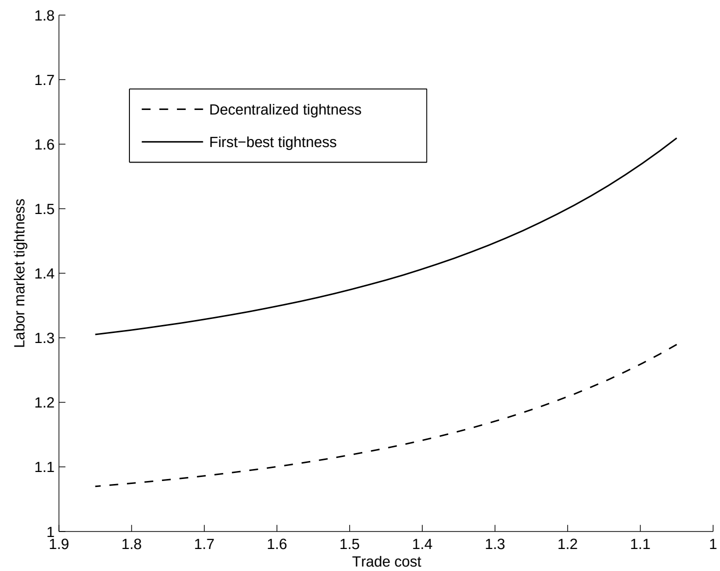
(i) Within the manufacturing sector distortion exists when the bargaining power of the worker is either too high or too low. (ii) At the same time, across section distortion is caused by the wage sharing rule in the agriculture sector. The competitive equilibrium results in too many workers staying in the agriculture sector.

The first part of this lemma is similar as the analysis in Lee (2008). Distortion exists within the manufacturing sector if the usual Hosios condition (Hosios,1990) does not hold. When the elasticity of the job-finding rate with respect to φ is too low, the appropriability problem dominates the congestion externality on the firms' side, resulting in too few vacancies. In contrast with Lee (2008), the between-sector distortion allocates too many workers in the agriculture sector, which is more consistent with the facts in developing countries. This between-sector misallocation is caused by the absence of factor markets in the agriculture sector and the sharing rule used to determine individual income. The supply price of migrants, namely the average product, is much higher than the marginal product.

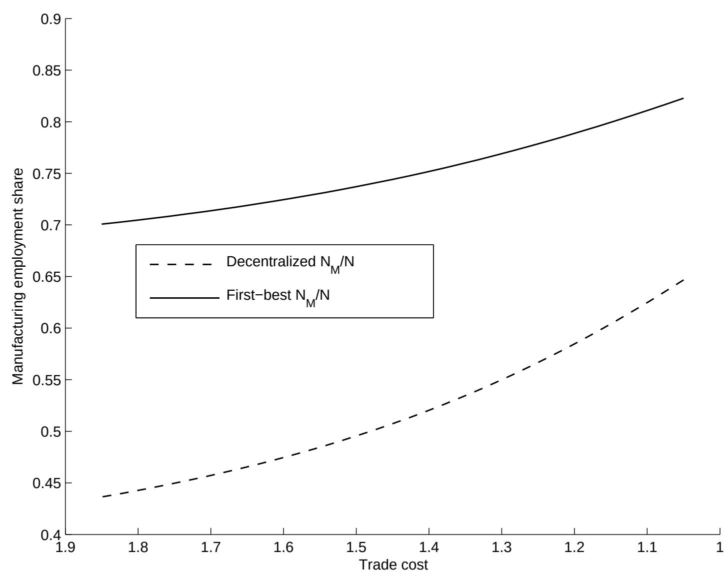
[14] Another condition used to pin down the value of φ and N_A is

$$\frac{x(\varphi)}{x(\varphi)+\psi}N_M = L_M$$

which comes from the transition condition. This equation is exactly the same as the one used in the decentralized problem.



(a) Trade cost and labor market tightness



(b) Trade cost and manufacturing employment share

Figure 1.7: The decentralized competitive equilibrium and social optimal solution

In addition, Figure 1.7 also shows that the disparity between labor market tightness in the decentralized problem and the planner's problem becomes more significant as trade barrier falls, while the employment share in the two cases converge to each other. Table 1.3 presents more details. With the international trade cost reduced from 1.85 to 1.05, the first-best level of φ increases by

23.32% while the actual φ only increases by 20.54%. On the contrary, compared with that in the planner's problem, the manufacturing employment share in the decentralized problem increases by 30.78% more. As a result, the difference between the first-best value of total revenue and the actual total revenue decreases from 7.71% to 5.51%.

One method to see the difference between the equilibrium and optimum more clearly is to check the policy scheme that can correct the distortions. Assume there exist two policy instruments $\{s,\ d\}$ that can replicate the first-best values of for the competitive equilibrium by subsidizing (taxing) firms' vacancy posting cost and agriculture wages. In other words, the values of $\{\varphi,\ N_A\}$ solved from

$$\frac{\partial R(l;\theta)}{\partial l} = \frac{\beta}{1-\beta}\frac{1}{1-\delta}\frac{\sigma-\beta}{\sigma}[\varphi + \frac{r+\psi}{\beta}\frac{1}{q(\varphi)}]c(1-s) \tag{1.20}$$

$$\frac{F(N_{Ai})}{N_{Ai}}(1+d) = \frac{\beta}{1-\beta}\frac{1}{1-\delta}\varphi_i c(1-s)$$

are the same as in the solution of equation (1.19). As shown in Table 1.3, as trade barrier falls, the tax on agriculture wage to replicate the first-best values of labor allocation across sectors decreases, and the required subsidy on the vacancy posting cost increases. This is because the reduction of trade cots moves labor out of the agriculture sector, moving the average product level towards the marginal product in the agriculture sector. In the manufacturing sector, however, since firms benefit more from the increase in average productivity in the case without labor market distortions than in that with distortions, trade has larger impact on the vacancy posting behavior of firms in the planner's problem. Therefore, the first-best value and the competitive equilibrium value of labor market tightness diverges as trade impediments are reduced.

Proposition 4

Reduction in trade cost decreases the misallocation across sectors and exacerbate the labor market distortions within the manufacturing sector.

This proposition captures a potential welfare enhancement channel that is absent in Helpman and Itskhoki (2010). In the calibrated model, the labor market distortions with 1.05 trade cost relative to 1.85 trade cost is 0.71 (5.51/7.71). Therefore, besides all four channels discussed in the

Table 1.3: Gains from trade and changes in distortions

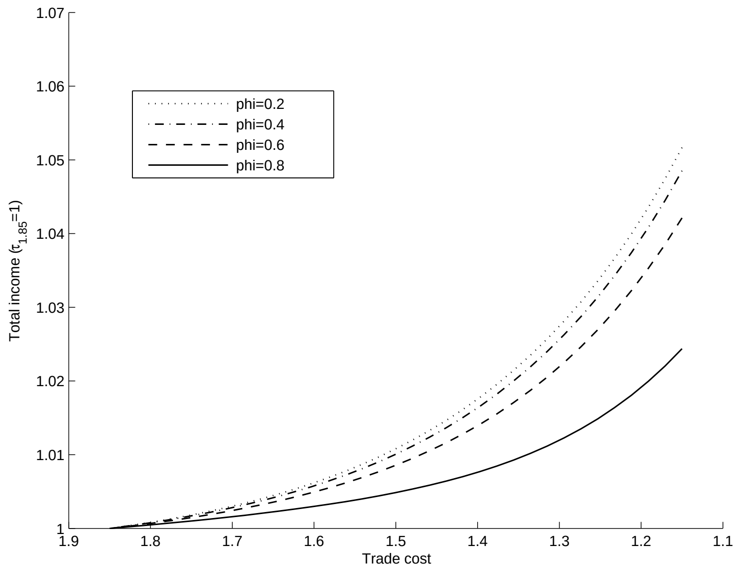
Decrease in the trade cost (initial τ=1.85)	0.2	0.4	0.6	0.8
Change in manufacturing employment share (%)	7.14	16.26	30.80	48.20
Change in first-best manufacturing employment share(%)	2.76	6.19	11.43	17.42
Gains from efficiency increase	4.37	10.07	19.37	30.78
Change in φ (%)	2.30	5.53	11.51	20.54
Change in first-best φ (%)	2.71	6.46	13.27	23.32
Gains from efficiency increase	-0.41	-0.93	-1.75	-2.77
Relative total revenue (competitive/first-best) (%)	92.29	92.74	93.50	94.49
Change in tax on w_A (%)	-0.29	-0.47	-0.60	-0.68
Change in subsidy on c (%)	0.11	0.27	0.53	0.88

previous section, the economy gains from trade through increases in labor market efficiency as well. This conclusion suggests an important policy implication that subsidies to encourage firm's vacancy posting can offset the downside of trade liberalization. In addition, this proposition implies that the trade-induced welfare gains depends on the extent to which labor market is distorted, namely the values of parameters in the agriculture production function and matching functions, and the cost of posting vacancies. As shown in Figure 1.8, larger distortion in the agriculture sector or smaller distortions in the manufacturing sector is associated with larger increases in the total welfare.

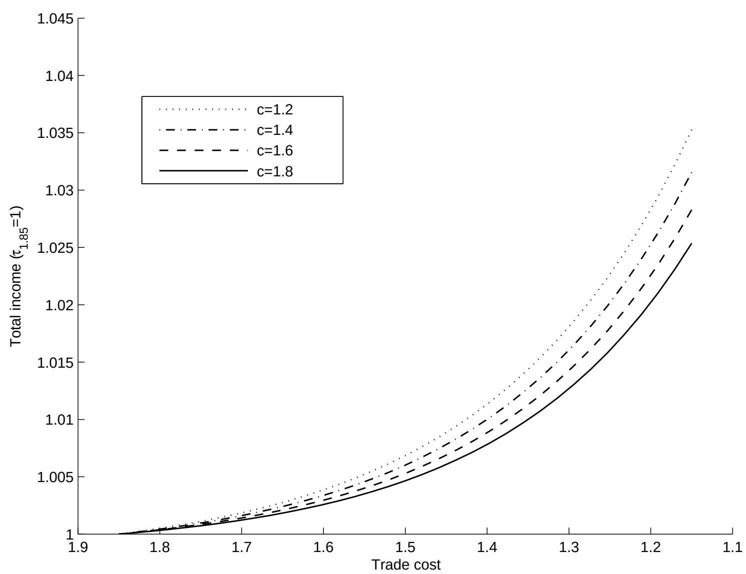
1.4 Empirical Evidence

1.4.1 Empirical strategy

This section tests the main predictions of the theoretical model that a reduction in variable trade costs reduces share of labor working in the agricultural sector and induces inter-regional labor migration. I also conduct an empirical examination of the central mechanism in the model, namely the differentiation in trade effects on regional average productivity due to the interaction between international and internal trade costs. I exploit the fact that cities in China vary in their composition of employment across industries, while tariff changes vary across industries. Although the empirical strategy in this paper is inspired by studies using micro level data to evaluate local effects of trade



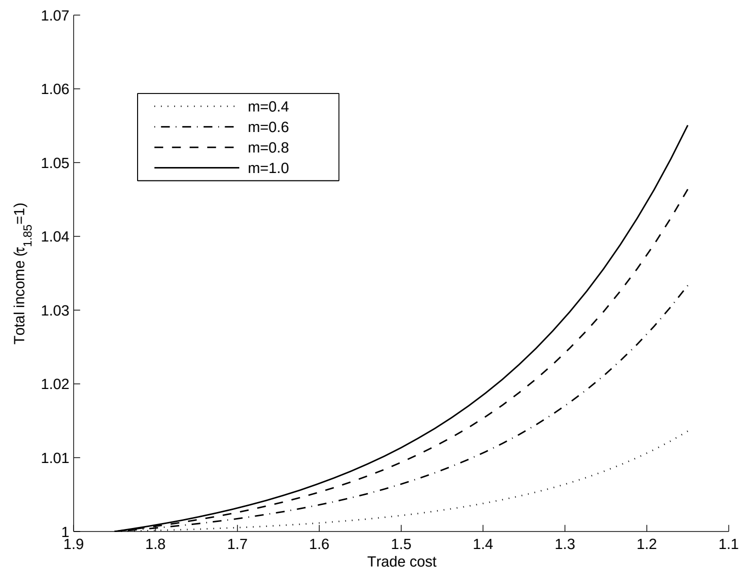
(a) Different values of labor elasticity in the agriculture production function



(b) Different values of vacancy posting cost

Figure 1.8: The welfare gains from trade and labor market distortions

(e.g. Edmonds et al. 2007; Autor et al.,2013; Kovak 2013), my analysis differs from this literature in a few aspects. First, whereas tariff reduction is the fundamental reason that induces the inter-sector and interregional labor mobility, a more direct test of the model is to consider the impacts of the rise in labor demand induced by exports. This is parallel to the analysis in Fukase (2013) who



(c) Different values of matching efficiency

Figure 1.8: The welfare gains from trade and labor market distortions (continue)

investigates the impacts of export liberalization on skill premium in Vietnam.

Second, most studies that exploit the geographic heterogeneity across regions in exposure to trade liberalization to examine the impact of trade reforms assume labor to be "sufficiently immobile" across regions. Without this assumption, it is impossible to observe how changes in wages differ in districts with large tariff cut relative to districts with little change in trade barriers because interregional labor mobility smooths out the regional price variation. The theoretical model in this paper, however, predicts that the even with perfect labor mobility, changes in employment share in the agriculture sector would still be larger in regions experiencing larger tariff declines. Therefore, unlike empirical studies investigating the relationship between regional tariff and factor prices, in which allowing for migration underestimates the impacts of trade, analysis in this paper overestimates the trade-induced structure change if labor is mobile across regions.

In fact, labor is neither perfectly mobile nor perfectly immobile in China. Biased estimation would be less likely to occur when the unit of analysis is chosen appropriately so that there is little migration between each unit. The administrative divisions of China consist of five levels: the province, prefecture, county, township, and village. There are 34 provinces, 333 districts at the prefecture level, 2,853 counties or county-level cities, 40,497 township-level regions and even more village-level regions. Numerous studies have reported that China's migration flows are features with obvious spatial patterns (Chan, 2013). First, most intra-province migrants move cross county-level units, but stay within prefectures. Second, the inter-province migration flows are directed primarily towards coastal provinces (such as Guangdong) from inland provinces (such as Sichuan), with little between coastal provinces. In addition, major flows between provinces are largely unidirectional. Therefore, treating the districts at the prefecture level as the unit of analysis and controlling for the distance of each district to China's coastline mitigates the potential bias in the estimated impacts of tariff.

The baseline specification used in this section is

$$y_{dt} = \alpha_t + \beta Export_{dt} + \gamma_d + \varepsilon_{dt} \tag{1.21}$$

where d denotes district at the prefecture level and t denotes time (2000, 2010). y_{dt} is the variable of our concern, such as the agriculture employment share, in-migration share and regional productivity. $Export_{dt}$ is the measure of prefecture d's exports exposure at time t, constructed in the way that is described with more details in the next section. γ_d is the prefecture level fixed effects, which captures all time-invariant unobservable district effects including the distance to coastline. The model predicts $\beta < 0$ in the regression of agriculture employment share, while $\beta > 0$ in the regression of in-migration share, i.e. exports increases are associated with decreases in the agriculture employment share and increases in the migration in-flows relative to the national trend.

First differencing equation (1.21) removes the constant district heterogeneity and yields

$$\triangle y_d = \theta + \beta \triangle Export_d + \triangle \varepsilon_d \tag{1.22}$$

To eliminate potential bias, I extend equation (1.22) as the following to control for time-variant district factors that might affect both the export exposure and the agriculture employment share or the in-migrants flows

$$\triangle y_d = \theta + \beta_1 \triangle Export_d + \beta_2 \triangle X_d + \beta_3 y_{d,2000} + \beta_4 Z_d + \triangle \varepsilon_d \tag{1.23}$$

where $\triangle X_d$ is a vector of differenced control variables, including the population density, teacher to student ratio, education expenditure, access to public services, indicators of infrastructure, green land coverage, and the pollution indicators in the urban area within each district. $y_{d,2000}$ is the value of y_d in 2000 and it is used to capture the potential mean reversion. Z_d denotes the fixed district features, which includes economic region dummies and the distance to coastline.

Even with all control variables, $\triangle Export_d$ may still be endogenous. For example, the composition of consumers in each district might affect the likelihood of exporting. It is also correlated with the labor share in the urban area and the number of migrants. This potential endogeneity problem is addressed with the instrument variable (IV) method, with the reduction in tariff imposed by foreign countries on their imports from China as an IV. It is constructed along the same line as $\triangle Export_d$. More details can be found in the next section.

1.4.2 Data

This section describes two principal sources of data used in the subsequent analysis: the National Population Census and the Annual Survey of Industrial Production.

1.4.2.1 National Population Census (1990, 2000, 2010)

The sector employment data and migration data, which are used to construct the dependent variables in regressions, come from the fifth and sixth national population census conducted in 2000 and 2010 by the China's National Bureau of Statistics (NBS). It covers 2283 administrative units at the county level. Data on total population, registered household population, employed population by sectors, total population above 15 years old, stock of migrants of different types, and urban and rural population are aggregated to the prefecture level for analysis in the next section. The agriculture employment share is defined as the proportion of agriculture employment in total population above 15. Migrants in the census refer to people staying in one county other than their registered residence (*Hukou*) and have left their registered residence for more than 6 months. Only information on the stock of in-migrants is available. The absolute volume of migrants is not comparable across prefectures, so I use the ratio of in-migrants to the *Hukou* population to measure the attractiveness of each prefecture to migrants. I also use the individual data from the 1990 national population census to compute the industry employment used in the instrument. This microdata set is released by the IPUMS International database from the Minnesota Population Center.

1.4.2.2 Annual Survey of Industrial Production (1998-2007)

The employment in the manufacturing sector in 2000 at the prefecture-industry-year level and regional productivity are derived from the Annual Survey of Industrial Production conducted by NBS. It covers all state-owned enterprises (SOEs) and non-SOEs whose revenue is more than five million yuan each year in the manufacturing sector. The number of observations increases from 165,118 in 1998 to 336,768 in 2007 (Brandt et al., 2014). The dataset provides rich information on more than 100 financial variables listed in the main accounting sheets. It has been used in numerous studies to estimate productivity in China (Hsieh and Klenow, 2009; Song et al., 2011; Brandt et al., 2012). Though this survey does not cover all firms in China, the dataset accounts for 60% of total manufacturing employment (Coşar and Fajgelbaum. 2013). Observations with missing key financial variables and firms with fewer than eight workers[15] are excluded in the calculation of regional productivity.

1.4.2.3 Other data

The prefecture-level control variables are constructed using data from the China City Statistics Year Book (2000, 2010) and the China County Economic Statistical Yearbook (2000, 2010). Data for 264 cities at the prefecture level are available for each year. The foreign tariff data come from the Trade Analysis and Information System (TRAINS) database, maintained by the United Nations Conference on Trade and Development (UNCTAD), aggregate using each trading partner's share in China's exports of that particular industry. Data on exports from China comes from

[15] Following Brandt et al. (2012), firms with fewer than eight workers are dropped excluded since they fall under a different legal regime.

the UN Comrade Database and is deflated using the GDP deflator from the World Bank. The original data is available at the six-digit HS product level. It is matched to the China Standard Industrial Classification (GB/T4754-1984, GB/T4754-1994 and GB/T4754-2002) at four-digit level. The distance to coastline is provided by the NASA's Ocean Biology Processing Group, which is used as a measure of world market access.

Table 1.4 presents summary statistics for export exposure per worker and agriculture employment share for years covered by the empirical analysis. The national average agriculture employment share decreased from 43.2% in 2000 to 32.0% in 2010, while the average export exposure per worker increased from 3,540 USD to 17,600 USD during this period.

Table 1.4: Summary statistics

	2000		2010		Difference
	Mean	Sd	Mean	Sd	Mean
Export exposure per worker(10,000 USD)	0.354	0.518	1.76	2.7	1.41
Agriculture employment share	0.432	0.196	0.32	0.15	-0.112
Migration ratio	0.0996	0.367	0.148	0.282	0.0481
Population density	1,189	1,032	1,080	1,087	-109
Green land	28.47	10.25	40.6	22.69	12.13
Education expenditure	13.51	4.914	17.53	4.387	4.02
Teacher to student ratio	0.0674	0.0143	0.0734	0.0254	0.006
Waste	69.55	24.84	94.6	8.001	25.05
Paved Road	5.218	3.461	10.49	5.419	5.272

1.4.3 Measures of key variables

1.4.3.1 Measures of exports induced employment

The empirical strategy relies on the geographic heterogeneity within China in exposure to trade based on the initial composition of employment. Instead of using the "district tariff" as the main control variable in regressions, I develop an export index to test the theoretical predictions in the previous sector directly. It is defined as the district-specific employment weighted sum of exports per worker, constructed with a methodology similar to the one used in Autor et al. (2013).

Specifically, the index is defined as

$$Export_{dt} = (\sum_i \frac{Employ_{id2000}}{Employ_{i2000}} * EX_{it}) * \frac{1}{Employ_{d2000}}$$

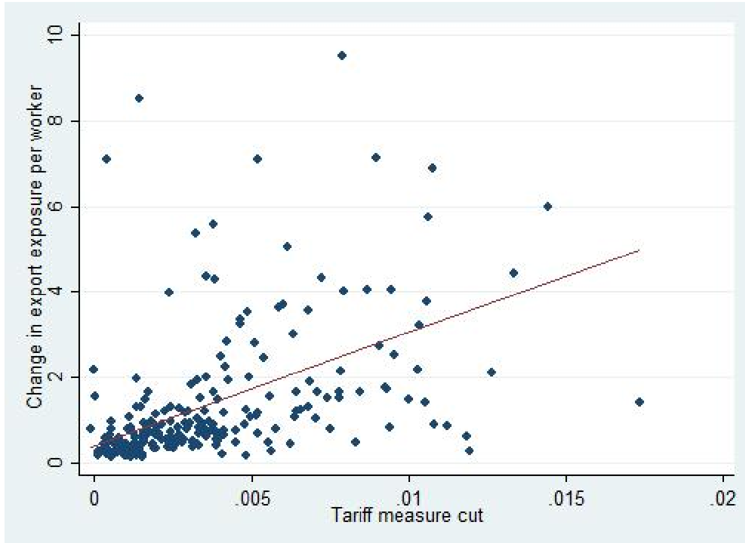
where $Employ_{idt}$ stands for the number of workers employed by industry i in prefecture d at year t. So this index depends on the concentration of employment in export-intensive industries within each location. Since the Annual Survey of Industrial Production only covers 60% of total manufacturing employment in China, I time the employment share in each industry computed using firm-level data by the total number of employment in the manufacturing sector from the national population census to get the approximation of $Employ_{idt}$ in the total population. $Employ_{dt}$ is the size of total employed population reported by the national census in prefecture d in year t, while $Employ_{it}$ is the total employment in industry i at time t. EX_{it} denotes China's exports in industry i at time t. I use the start period employment for the calculation of both $Export_{d2000}$ and $Export_{d2010}$ so that the change in the employment composition over time does not affect the measure of district export exposure. Therefore, the first-differenced form of $Export_{dt}$ is

$$\triangle Export_d = \sum_i (\frac{\triangle EX_{it}}{Employ_{i2000}} * \frac{Employ_{id2000}}{Employ_{d2000}}) \tag{1.24}$$

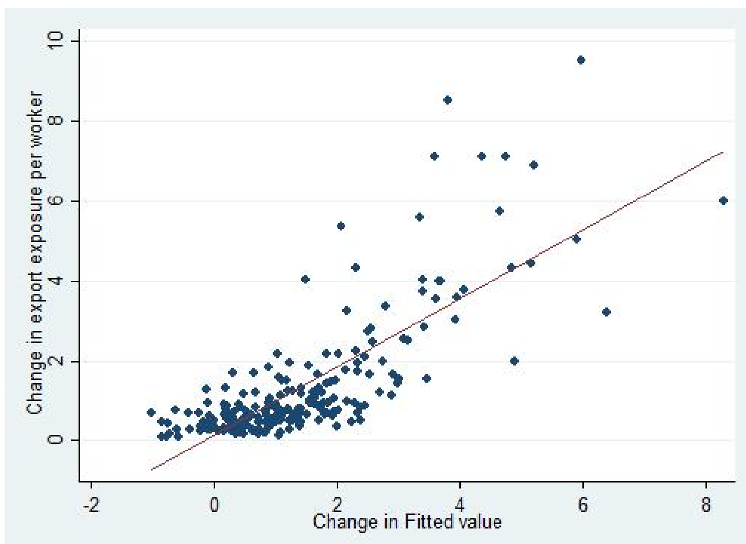
To address the potential endogeneity problem of $\triangle Export_d$ in equation (1.23), I employ the tariff cut as the instrument, which is constructed as

$$\triangle Tariff_d = \sum_i (\frac{\triangle \ln(1+\tau_i)}{Employ_{i1990}} * \frac{Employ_{id1990}}{Employ_{d1990}})$$

where $\triangle \ln(1+\tau_i)$ presents the log difference of other countries' tariffs for import from China during 2000-2010. This measure of foreign tariff cut is exogenous in the sense that it is the result of other countries trade policy and is unlikely to be influenced by the sectoral structural in China. It is also unlikely to influence the structural change and migration within China through channels other than export. In addition, it uses employment from 1990 to address the possibility that the contemporaneous employment in equation (1.24) is affected by the anticipated China's trade policy changes. Figure (1.9) reveals strong positive correlation between the change in regional export exposure and the change in the foreign tariff change.



(a) First Stage: Change in export exposure and foreign tariff



(b) Change in export exposure and Predicted values

Figure 1.9: The prediction power of the instrument variable

1.4.3.2 Measures of regional manufacturing productivity

The regional manufacturing productivity used in this paper is defined as the weighted aggregate TFP in each prefecture

$$Pr_{dt} = \sum_i s_{idt} \ln TFP_{it}$$

where s_{idt} is the plant i's share of industry output at district d, and $\ln TFP_{idt}$ is the log form of plant-level TFP constructed using the approach following Pavcnik (2002). Specifically, the CobbDouglas production function

$$\ln y_{it} = \beta_0 + \beta_1 \ln w_{it} + \beta_2 \ln m_{it} + \beta_3 \ln k_{it} + \epsilon_{it} \tag{1.25}$$

is estimated using the semi-parametric approach in Olley and Pakes (1996) in each industry, where y_{it}, w_{it}, m_{it} and k_{it} are plant i's gross output, total wage payment, intermediate inputs, and capital in year t, respectively. The effects of firms export behavior and the state-ownership are also taken into consideration in the estimation. TFP is defined as

$$\ln TFP_{it} = \ln y_{it} - (\hat{\beta}_1 \ln w_{it} + \hat{\beta}_2 \ln m_{it} + \hat{\beta}_3 \ln k_{it})$$

where $\hat{\beta}_i$ (i=1,2,3) are estimated coefficients in equation (1.25). Appendix D provides more details of the estimation procedure. Table 1.5 shows the estimated coefficients in equation (1.25) and average $\ln TFP$ in each main industry. There is large variation of the input coefficients across industries. Additionally, we could see a steady increase in the measured TFP across years.

1.4.4 Main findings

1.4.4.1 Basic results

Table 1.6 presents the primary estimates of the effects on increase in export on the agriculture employment share and migration patterns. Each column reports a different version of equation (1.23). The OLS results are given in the first two columns. Column (3) and (4) report results with the IV approach. China is divided into 8 regions, and I use region dummies in all regressions to capture unobserved regional trends. Standard errors are clustered by regions to account for spatial correlations.

For regressions where the only explanatory variable is the change in export exposure, the coefficients contradict predictions of the theoretical model but are statistically insignificant, while regressions with the initial value of the dependent variables supports the theoretical implications. This might be caused by mean reversion. Prefectures with larger change in trade exposure might be

Table 1.5: Estimates of Olley-Pakes TFP by industry

Industry	Labor	Materials	Capital	lnTFP1998	lnTFP2000	lnTFP2002	lnTFP2005
13	0.0533	0.8783	0.0396	0.489	0.5866	0.6241	0.6244
14	0.0623	0.9048	0.0307	0.3791	0.429	0.4137	0.5119
15	0.0883	0.8815	0.0358	0.4334	0.4639	0.4644	0.5796
17	0.0665	0.8801	0.0254	0.5183	0.535	0.571	0.6417
18	0.1115	0.819	0.0391	0.6427	0.6579	0.6437	0.7755
19	0.0693	0.8756	0.03	0.5383	0.5458	0.5492	0.6165
20	0.1451	0.8105	0.0523	0.4833	0.7484	0.7073	1.0753
21	0.1034	0.8683	0.0299	0.4991	0.479	0.5382	0.7656
22	0.0731	0.8811	0.0242	0.5083	0.5488	0.5749	0.7735
23	0.1056	0.8685	0.0425	0.3629	0.3687	0.4049	0.6253
24	0.0962	0.8531	0.0329	0.5599	0.5618	0.549	0.7063
25	0.0374	0.8837	0.0282	0.696	0.6474	0.7204	0.5323
26	0.0789	0.8533	0.0386	0.5297	0.581	0.6088	0.6388
27	0.0996	0.8358	0.0589	0.4143	0.4979	0.5269	0.7385
29	0.08	0.8459	0.0653	0.2946	0.3639	0.4042	0.5537
30	0.0954	0.8352	0.0461	0.5301	0.5324	0.6	0.8543
31	0.077	0.8723	0.0328	0.4637	0.5243	0.5347	0.7778
32	0.0436	0.9019	0.0314	0.4333	0.4694	0.4968	0.4529
33	0.0604	0.8735	0.0204	0.6609	0.6686	0.7487	0.6743
34	0.0777	0.846	0.047	0.5314	0.5384	0.5747	0.6221
35	0.074	0.8734	0.0366	0.4326	0.4505	0.4699	0.5779
36	0.0887	0.878	0.0302	0.395	0.4402	0.4619	0.5981
37	0.1002	0.8644	0.0314	0.4551	0.4944	0.5299	0.6419
39	0.0751	0.8623	0.0387	0.5335	0.585	0.5808	0.5915
40	0.1436	0.8237	0.0386	0.5982	0.6647	0.6627	0.9054
41	0.1206	0.8366	0.0368	0.5494	0.6132	0.6498	0.8315
42	0.0703	0.867	0.0225	0.6865	0.7364	0.7531	0.8095

Notes: The Chinese industries are classified as: (13) food processing; (14) food manufacturing; (15) beverage; (17) textiles; (18) apparel; (19) leather, fur, feather products; (20) wood processing and wood, bamboo and palm fiber products manufacturing; (21) furniture; (22) paper and paper products; (23) printing and reproduction of recording media; (24) education and sporting goods; (25) petroleum and nuclear fuel processing; (26) chemicals and chemical products; (27) medicines; (28) chemical fibers; (29) rubber; (30) plastic; (31) non-metallic minerals; (32) ferrous metal smelting and rolling processing; (33) non-ferrous metal smelting and rolling processing; (34) fabricated metal; (35) general machinery; (36) special machinery; (37) transportation equipment; (39) electrical machinery; (40) communications equipment, computers and other electronic equipment; (41) instrumentation and office machinery; (42) artwork and other manufacturing. Other industries not listed in the table are dropped due to the small sample size in the estimation of TFP

Table 1.6: The effects of export exposure on migration across sectors and space

	OLS		2SLS	
	(1)	(2)	(3)	(4)
		A. △Agriculture share		
△Export exposure per worker	0.0103	-0.0093*	0.0193*	-0.0456*
	(0.0060)	(0.0048)	(0.0094)	(0.0240)
Constant	-0.123***	0.185**	-0.130***	0.320***
	(0.0096)	(0.0502)	(0.0136)	(0.0700)
Agriculture share 2000	No	Yes	No	Yes
△Prefecture controls	No	Yes	No	Yes
Region dummies	Yes	Yes	Yes	Yes
Distance to coastline	Yes	Yes	Yes	Yes
Observations	259	228	238	213
R-squared	0.493	0.69	0.475	0.59
		B.△Migrants ratio		
△Export exposure per worker	-0.0437	0.0551***	-0.0139	0.107**
	(0.0260)	(0.0118)	(0.0490)	(0.0476)
Constant	0.113***	-0.0488*	0.0799	-0.0719**
	(0.0315)	(0.0232)	(0.0608)	(0.0352)
Migrants ratio 2000	No	Yes	No	Yes
△Prefecture controls	No	Yes	No	Yes
Region dummies	Yes	Yes	Yes	Yes
Distance to coastline	Yes	Yes	Yes	Yes
Observations	259	228	238	213
R-squared	0.163	0.881	0.109	0.853

Note: Standard errors in parentheses are cluster in region.
[*] $p < 0.05$, [**] $p < 0.01$, [***] $p < 0.001$

places where the initial agriculture employment share was already quite low in 2000, thus experienced less reduction in the agriculture employment during trade liberalization between 2000 and 2010. Therefore, the specification generating estimates in column (2) and column (4) is the preferred specification. The difference between the OLS and 2SLS estimates indicates that the potential simultaneity problem attenuates the point estimates towards zero.

Results in Panel A of Table 1.6 supports the theoretical implications of the relationship between increases in the export exposure and relative decrease in the agriculture employment share. The coefficients are significant at the 5 percent level. To find out whether the effects of export exposure is economically significant, consider the average employment-weight export exposure increased from 0.354 ($10,000) to 1.76 ($10,000) from 2000 to 2010, the point estimates in column (4) suggest a 6.4% decline in the agriculture employment share in a district experiencing the average increase. While the average decrease in agriculture employment share is 11.2% between 2000 and 2010 (see Table 3), the rising export exposure explains more than 50 percent of the decline during this period.

We next move to the impact of export increase on the relative attractiveness of prefectures to migrants. The preferred specification in Panel B suggests that during 2000-2010, the migrants to *Hukou* population ratio in the prefecture at the 75th percentile of export exposure growth (1.50) increased by 11.66 percentage points more than in a prefecture at the 25th percentile (0.41).

1.4.4.2 Heterogeneity in the trade effects

The model predicts that the effects of trade cost reduction on structural change decline over distance to the coastline. To test this prediction, I divide China into four bins based on the Eculidian distance of each cities to China's coastline and estimate the modification of equation (1.23):

$$\triangle y_d = \theta + \sum_{b=1}^{4} \beta_b(\triangle Export_d * D_b) + \sum_{b=2}^{4} \gamma_b D_b + \eta_1 \triangle X_d + \eta_2 y_{d,2000} + \triangle \varepsilon_d \qquad (1.26)$$

where D_b are dummies which takes the value of 1 when a prefecture belongs to the distance bin b. Results are presented in Table 6. The effect of the increase in the export exposure on the agriculture employment share is largest in the distance bin 150-300km, where the point estimate is around -0.06 for both the OLS and 2SLS estimations. It then decreases over distance to the coastline, which supports the theoretical implication of the heterogeneity in the effects of international trade. β_1 is smaller than β_2, but this is not inconsistent with the model, since both the first and second distance bins belong to the coastal area, while the second bin is closer to the interior region than the first one and associated with lower migrating cost for migrant workers.

I also run the 2SLS estimates of equation (1.23) for four distance bins separately. The point estimates of interests is still largest in the second distance bin but not statistically significant. Results are reported in column 3 to column 6 in Table 1.7.

Table 1.7: Heterogeneity in the effects of trade

Dependent Variable	Full sample		0-150Km	150-300km	300-650km	650-1200km
△Agriculture share	OLS	2SLS	2SLS	2SLS	2SLS	2SLS
	(1)	(2)	(3)	(4)	(5)	(6)
△Export exposure per worker	-0.0212**	-0.0342*				
× Coastline 0-150km	(0.00823)	(0.0190)				
△Export exposure per worker	-0.0616**	-0.0622				
× Coastline 150-300km	(0.0229)	(0.0400)				
△Export exposure per worker	-0.0182	-0.0519				
× Coastline 300-650km	(0.0366)	(0.0339)				
△Export exposure per worker	-0.0098	-0.00844				
× Coastline 650-1200km	(0.0200)	(0.0668)				
△Export exposure per worker			-0.0578**	-0.0748	0.212	0.0318
			(0.0275)	(0.0678)	(0.537)	(0.0876)
Constant	0.244**	0.289***	0.387***	0.317***	-0.335	0.0706
	(0.0783)	(0.0807)	(0.0944)	(0.0917)	(0.885)	(0.179)
Agriculture share 2000	Yes	Yes	Yes	Yes	Yes	Yes
△Prefecture controls	Yes	Yes	Yes	Yes	Yes	Yes
Distance bin dummies	Yes	Yes	No	No	No	No
Observations	221	206	76	39	47	44
R-squared	0.622	0.617	0.643	0.748	0.207	0.746

Note: Standard errors in parentheses are cluster in region.
[*] $p < 0.05$, [**] $p < 0.01$, [***] $p < 0.001$

Table 1.8: The effects of export exposure on productivity

	(1)	(2)	(3)	(4)
Dependent Variable: $\triangle$lnTFP	OLS	2SLS	OLS	2SLS
$\triangle$Export exposure per worker	0.0196***	0.0282***		
$\triangle$Export exposure per worker			0.0182***	0.0244***
$\times$ Coastline 0-150km			(0.00280)	(0.00502)
$\triangle$Export exposure per worker			0.0606**	0.0939***
$\times$ Coastline 150-300km			(0.0183)	(0.0314)
$\triangle$Export exposure per worker			-0.0437	-0.00983
$\times$ Coastline 300-650km			(0.0445)	(0.0305)
$\triangle$Export exposure per worker			0.0241	0.0236
$\times$ Coastline 650-1200km			(0.0571)	(0.0505)
Constant	0.371***	0.375***	0.372***	0.355***
	(0.0649)	(0.0651)	(0.0617)	(0.0643)
TFP in 2000	Yes	Yes	Yes	Yes
$\triangle$Prefecture controls	Yes	Yes	Yes	Yes
Observations	260	239	258	237
R-squared	0.659	0.658	0.619	0.621

Note: Standard errors in parentheses are cluster in region.
[*] $p < 0.05$, [**] $p < 0.01$, [***] $p < 0.001$

1.4.4.3 Trade effects on manufacturing productivity

The underlying mechanism of the theoretical model is the productivity increase in the manufacturing sector induced by the trade impediments reduction. Employing the same identification strategy used for the analysis of labor mobility across space and sectors, I get significantly positive coefficient on the export exposure index. The value in column (2) of Table 1.8 suggests that an average increase in average employment-weight export exposure (from 0.354 to 1.76) raises the value of lnTFP by 0.04, while the average increase in the regional weighted average productivity ($\ln TFP$) is 0.09.

The estimated effects of export on productivity by distance distribution are presented in column (3) and (4) in Table 1.8. The effect is more than two times larger in the second distance bin, where the estimate is 0.0939, than in the last distance bin. The magnificence of coefficients on the interaction term is not monotonically increasing across distance, which is not perfectly consistent with the model. However, the effect of the increase in export exposure is statistically significant only in the first two distance bins, implying that the effects in regional further than 300 kilometers away from China's coastline are not precisely estimated.

1.4.5 Robustness checks

In this section, I discuss several robustness checks of the empirical results presented in Table 1.6. The first concern is the unit of analysis. As stated before, analysis with local markets requires labor to be "sufficiently immobile" across regions, otherwise labor migration smooths out price variations caused by difference in trade exposure. Therefore, in the regression of immigration ratio, the magnificence of the export exposure coefficient is expected to decreases if the unit of analysis is changed from prefecture to county[16] . However, the model predicts that regions with export increase would experience larger change in the agriculture employment in the case when migration is allowed than that in the case without interregional migration. Therefore, the effects of export exposure would be overestimated when we use a more detailed unit of analysis. Table 1.9 presents the results. Compared with Table 1.6, we can see that both coefficients are more statistically significant due to the increase in sample size, while there magnificence of coefficients move towards the direction as predicted.

I next turn to results from regressions with additional controls or alternative measure of openness. I only present results estimated with the IV method. The first column in Table 1.10 discusses factors in the agriculture sector that pushing migrants towards the manufacturing sector. Pushing factors discussed intensively in the literature includes low productivity, poor economic conditions, exhaustion of natural resources, and mechanization of certain processes reduce labor requirement in rural areas. Column (1) presents the results of the regression with rural population density, production of grains per capita and agriculture machines owned by each household. The incorporation of additional controls into the regression does not change our main results. Column (2) presents the results with import exposure per worker as additional controls. The point estimates are quite similar as that in Table 1.6.

[16] This is because there are more labor flows between counties than between prefectures.

Table 1.9: The effects of export exposure on migration across sectors and space(county level)

	(1)	(2)	(3)	(4)
Dependent Variable	△Agriculture share		△Migrants ratio	
	OLS	2SLS	OLS	2SLS
△Export exposure per worker	-0.0106**	-0.0492**	0.0230***	0.0503***
	(0.00440)	(0.0247)	(0.00590)	(0.0185)
Constant	0.0553	0.229**	-0.0178*	-0.0387*
	(0.0448)	(0.0985)	(0.00932)	(0.0229)
Agriculture share 2000	No	Yes	No	Yes
△Prefecture controls	No	Yes	No	Yes
Region dummies	Yes	Yes	Yes	Yes
Distance to coastline	Yes	Yes	Yes	Yes
Observations	1,730	1,631	1,730	1,631
R-squared	0.334	0.253	0.297	0.227

Note: Standard errors in parentheses are cluster in region.
[*] $p < 0.05$, [**] $p < 0.01$, [***] $p < 0.001$

Table 1.10: Robustness checks

	(1)	(2)	(3)	(4)
	A. △Agriculture share			
△Export exposure per worker	-0.0432*	-0.0424*	-0.0458*	-0.0162
	(0.0223)	(0.0228)	(0.0244)	(0.0124)
Constant	0.222**	0.304***	0.320***	0.176**
	(0.105)	(0.0714)	(0.0697)	(0.0730)
Agriculture share 2000	No	Yes	No	Yes
△Prefecture controls	No	Yes	No	Yes
Region dummies	Yes	Yes	Yes	Yes
Distance to coastline	Yes	Yes	Yes	Yes
Observations	206	213	213	213
R-squared	0.612	0.608	0.589	0.576
	B. △Migrants ratio			
△Export exposure per worker	0.138**	0.105**	0.109**	0.0493
	(0.0567)	(0.0414)	(0.0471)	(0.0361)
Constant	-0.0660	-0.0717**	-0.0703*	-0.0939*
	(0.0588)	(0.0356)	(0.0363)	(0.0548)
Migrants ratio 2000	No	Yes	No	Yes
△Prefecture controls	No	Yes	No	Yes
Region dummies	Yes	Yes	Yes	Yes
Distance to coastline	Yes	Yes	Yes	Yes
Observations	206	213	213	213
R-squared	0.827	0.856	0.851	0.641

Note: Standard errors in parentheses are cluster in region.
[*] $p < 0.05$, [**] $p < 0.01$, [***] $p < 0.001$

The next two columns examine the issue with alternative measures of international trade exposure. Column (3) uses the gross export, which includes both exports and re-exports, as the main explanatory variable. Both the magnitude and statistical significance remain unchanged. The last column, however, shows that net-export, the difference between exports and imports, does not have significant impact on migration across space and sectors. This is not inconsistent with the model, since import might have opposite effects on firms' behavior compared with exports. In addition, the instrument is weak in predicting the export exposure than the net export change, as indicated by the Wald F-test in the first stage.

1.5 Conclusion

This paper develops a new general equilibrium model that brings together the dual economy structure, trade between and within countries, structural change across sectors, and factor mobility across space. I show that within each region a reduction in trade impediments raises the average productivity. As a consequence, firms post more vacancies and workers migrate from the rural sector to the urban sector. In addition, reductions in international trade impediments have larger impacts on the labor market at locations with geographical advantages, inducing spatial movements of labor towards regions closer to the global market. Therefore, the economy gains from trade through increase in productivity, expansion of the manufacturing sector, and reallocation of labor across locations. Empirical evidence with China's population census data further confirms the theoretical implications.

In addition, by comparing the decentralized competitive equilibrium with the socially optimal solution, I show that falls in trade barriers exacerbate the existing distortions caused by matching frictions but decrease the misallocation of labor across sectors and space. Trade can significantly reduce labor market distortions if between-sector distortions are quite large. It implies a potential channel through which the economy can gain from trade. It also suggests important policy implications that subsidies to encourage firms to search for workers more insensitively can offset part of the downside of trade liberalization.

Chapter 2

The Dynamics of Globalization and Human Capital Accumulation

2.1 Introduction

The discussion on the impacts of trade liberalization on wage inequality originated over the concerns of the increase in skill premium in developed countries. There has been an extensive literature following the Heckscher-Ohlin (HO) framework where a reduction in trade impediments raises the skill premium in skill-abundant countries. However, growing empirical studies have shed lights on two insights that are generally overlooked in the HO literature. First, globalization is associated with increasing inequality in developing countries as well, which are usually unskilled-abundant (Goldberg and Pavcnik, 2007; Verhoogen, 2008; Amiti and Cameron, 2012; Harris and Robertson, 2013). Second, the distributional impact of trade liberalization is changing over time (Chao and Yu, 1997; Das, 2002; Bond et al, 2003; Robertson, 2007; Brülhart et al, 2012[1]), which is accompanied by an increase in education investment (Arbache et al., 2004; Edmonds et al., 2010; Atkin, 2012; Shastry, 2012[2]).

This paper contributes to the literature by developing a theoretical framework that is able to reproduce these two stylized facts. Despite the intensive discussions on the effect of trade on wage inequality, until recently there has been surprisingly little theoretical work on the dynamics in this

[1] Robertson (2007), for example, uses data from the Monthly Industrial Survey and shows that while entering NAFTA increases the skill premium in Mexico on impact, there is a subsequent fall of wage inequality in the 2000–2005 period.

[2] Edmonds et al. (2007) find that trade liberalization in India reduced the costs of schooling and raised school enrollment. Atkin (2012) shows that the growth of export manufacturing in Mexico during 1986-2000 increased school dropout. Shastry (2012) demonstrate that districts where experience greater growth in information technology jobs after trade liberalization also experience larger increase in school enrollment and smaller increases in skilled wage premium.

distribution effect of trade or the impacts of trade on education investment in the trade literature. A growing literature has emphasized the consequences of introducing endogenous skill acquisition into trade models (Bond et al. 2003; Moro and Norman, 2015; Falvey et al.,2010; Blanchard and Willmann, 2011; Harris and Robertson. 2013; Davidson and Sly, 2014; Auer, 2015). However, these models are built in the HO framework and cannot explain the increase in the skilled labor supply in developing countries. With endogenous factor endowments, trade liberalization in these dynamic HO models leads to a divergence in income across countries by raising the skilled labor supply in developed countries and decreasing it in developing countries. On the contrary, my framework allows for endogenous plant-location decisions, which generates the possibility of increases in inequality in developed and developing countries simultaneously.

In particular, I consider a dynamic general equilibrium model with two countries, which are symmetric except for their efficiency in using skilled labor. Two goods are produced within each country; one is produced with constant returns by a competitive industry, while the other good is produced by imperfectly competitive Cournot firms with increasing returns technology and its production procedures can be geographically fragmented. Firms choose among different organization types, including domestic firms, vertical multinational enterprises (MNEs), and horizontal MNEs. Individuals are born as unskilled labor and can either work for their whole life as unskilled labor or spend a fixed period of time to pursue an education that enables them to provide high-skill labor and get high wage after graduation. In addition, workers are assumed to be heterogeneous in their relative ability to provide skilled labor. Due to the opportunity cost of education, only workers above an ability threshold receive a surplus from their investment on education. Consequently, the total labor supply within a country is determined by a threshold of individual type. The sector with fragmented production is more skilled labor intensive compared with the other sector.

The simulation results show that trade-induced changes in the returns to education influence the incentives for workers to invest on education. As a result, the ability threshold above which workers seek education is changed and, over time, affects the total skill supply and thereby impacts the skill premium. This indicates a non-monotonic transition path when the economy moves from the original equilibrium to the new one after trade cost is reduced. However, unlike models following the HO framework where trade liberalization always induces divergence in the world income distribution, the exact impacts of trade cost reductions depends on the change in active types of MNEs. As in Markusen (2002), when domestic firms in the skill-abundant country are replaced by vertical MNEs with headquarters in that country, the reduction in trade cost increases the skill premium in both the skill-abundant country and skill-scarce country. In addition, the relative increase in skilled labor supply is larger in developing countries than that in developed countries, which indicates a convergence in skilled labor supply and total income across countries.

The framework of my model draws on the insights of Findlay and Kierzkowski (1983), which incorporates the formation of labor skills through education into the standard two-sector general equilibrium model of international trade for the first time. A growing literature has extended it with different assumptions of how the supply of skills is endogenously determined (Bond et al. 2003; Moro and Norman, 2010; Falvey et al.,2010; Blanchard and Willmann,2011; Auer, 2015). Predictions in these models differ from the static HO model in two important dimensions. First, although differences in relative factor endowments across countries are still the direct driving force of trade, they are endogenously determined by characteristics in each economy, such as the quality of educational institutions, duration of education, and life expectancy. Second, the impacts of trade are heterogeneous across groups with different ages or ability levels, which is consistent with the labor economics literature which concludes that earning profiles depend not only on education but also on these other individual characteristics.

These two features are maintained in this paper. The model in this paper considers the efficiency of skilled labor as the fundamental source of the differences in relative factor supply across countries. The simulation results indicate that the stock of skilled labor is large in countries with high efficiency of skilled labor. In addition, in my model, individuals who become skilled workers vary in their ability to supply efficient human capital. Therefore, the benefit from education is heterogeneous in the population. In emphasizing the heterogeneity in trade impacts, my paper is most closely related to Auer (2015). With a model featuring a continuous distribution of worker abilities, Auer (2015) shows that a trade-induced increase in the skill premium reduces the ability threshold above which workers choose to invest on education and induce more entry into the skilled labor force.

However, unlike Findlay and Kierzkowski (1983) and its extension, in which trade liberalization leads to divergence of the world income distribution by inducing skill accumulation in a skilled labor abundant country and skill de-accumulation in the skilled labor scarce country, I introduce MNEs into the model to explain the convergence in the income between some developing and developed countries in empirical studies. Due to the geographically fragmented production process of MNEs, my model shows that reducing trade impediments is possible to increase skill premium and human capital accumulation in both countries.

The literature has investigated various channels through which MNEs raise skill premium in developing countries. For example, foreign affiliates of MNEs with headquarters in developed countries might have access to superior production technique, which requires more skilled labor than pure domestic firms. It is also possible the wage level in the foreign affiliate is linked to that in the parent company. This paper follows the assumption in Markusen (2002) that factor intensities vary across sectors, firm types, and production activities. The reduction in trade impediments shifts factors out of the unskilled labor intensive sector due to the expansion in the affiliation production of MNEs in the unskilled labor abundant country and reallocate factor towards headquarter production in the skilled labor abundant country. As a result, the relative wage of skilled labor increases in both countries. The skill labor supply adjusts to this change, with a larger increase in education in the developing countries than in developed countries. This leads to a convergence in skilled labor supply and total income across countries. To date only Hoffmann (2003)has addressed both the endogenous investment decision and the endogenous accumulation of human capital, but with a relatively simple setup of human capital accumulation.

My analysis also contributes to the literature by providing an entire picture of the transition path after a reduction in international trade costs. The discussion of transition path is essential to get the correct evaluation of trade effects. As emphasized in Danziger (2014), however, it introduces significant technical challenges, since the evolution of the economy consists of a path of interdependent endogenous variables rather than a series of independent static equilibria. The consideration of the non-monotonic transition path yields interesting results. On impact trade induces a jump in the skilled premium both countries. Over the transition, however, the skill premium moves towards the opposite directions in both countries due to the change of skilled labor supply.

I then examine the theoretical implication in the context of China's trade reform after the implementation of its opening up policy. I treat metropolitan and non-metropolitan areas in each prefecture as local labor markets to take advantage of the staggered programing timing across prefectures and detect the casual effects the program has on enrollment behaviors by comparing children in prefectures already reached by the program with children in prefecture not yet reached. This local-labor-market approach follows the work by Autor et al. (2013) and Dix-Carneiro and Kovak (2015). The analysis is restricted within the period of 1973-1990, when the restrictive *Hukou* system was a strong constraint for interregional migration. The regression results suggest that the opening up policy increases enrollment rate by 10% at both the junior middle school level and the secondary school level. In addition, the magnitude of the effects declines over time, which further confirms predictions of the simulation results.

The structure of the paper is as follows. Section 2 generates a general equilibrium model where the production of one goods can be fragmented and heterogeneous workers decide human capital accumulation endogenously. This section also derives the steady state condition in the autarky case for benchmark calibration. Section 3 describes the simulation results of the steady state effects of trade in the case with and without MNEs. The transition path of wages and labor supply in each country after globalizing markets is presented as well. I discuss the empirical strategy and results in section 4 and 5 respectively. The last section concludes.

2.2 Theoretical Framework

There are two countries (i and j) producing two homogenous goods (X and Y) with two factors of production, unskilled labor (L) and skilled labor (S). Both factors are mobile between industries but internationally immobile. Y is produced with constant returns by a competitive industry and traded without costs. X is produced by imperfectly competitive Cournot firms with increasing returns to scale technology, and its production and headquarters can be geographically fragmented. Firms producing X choose among 3 firm types:

- Type-d_i : National firms that maintain a single plant, with headquarters in country i. They may or may not export to country j.
- Type-h_i : Horizontal (market-seeking) MNEs that maintain plants in both countries, with headquarters located in country i.They only sell products locally.
- Type- v_i: Vertical (efficiency-seeking) MNEs that maintain a single plant in country j, with headquarters in country i. They may or may not export to country i.

2.2.1 The basic setup

2.2.1.1 Preferences

Assume for each unit of time, a mass of δ_i worker is born. δ_i is also the age-independent death rate in country i. Let N_i denote the constant population size. Consumers are assumed to have a Cobb-Douglas utility function between goods. The representative consumer receiving X_{ict} unit X of and Y_{ict} unit of Y in country i gets:

$$U_{it} = X_{ict}^{\gamma} Y_{ict}^{1-\gamma}$$

where $X_{ict} = M_{it}^d X_{iit}^d + M_{jt}^d X_{jit}^d + M_{it}^h X_{iit}^h + M_{jt}^h X_{jit}^h + M_{it}^v X_{iit}^v + M_{it}^v X_{jit}^v$, with X_{ij}^k as the sales of type-k firm with headquarters in country i and sales in market j, $k = d, h, v$. M_i^k is the total number of type-k firm with headquarters in country i. The representative consumer's problem is to maximize his lifetime utility by solving:

$$\max U_i = \sum_t (\tfrac{1-\delta_i}{1+r_i})^t X_{ict}^{\gamma} Y_{ict}^{1-\gamma}$$

$$\text{s.t.} \sum_t (\tfrac{1}{1+r_i})^t (p_i X_{ict} + Y_{ict}) \leq \sum_t (\tfrac{1}{1+r_i})^t E_{it}$$

where $E_{it} = w_{iSt}S_{it} + w_{iLt}L_{it}$, with w_{iL} and w_{iS} as wages of unskilled and skilled labor in country i at time t respectively. r_i denotes the discount rate.

2.2.1.2 Production of X and Y

The production function of Y is in the CES form, which requires both unskilled labor (L_{iy}) and skilled labor (S_{iy}). Since Y is traded without cost, the price of Y is the same in the two countries, and its price is normalized to one. The production function of Y_i is

$$Y_i = [L_{iy}^{\alpha} + (A_i S_{iy})^{\alpha}]^{\frac{1}{\alpha}} \tag{2.1}$$

where A_i is the exogenous effectiveness of skilled labor in country i. It is the main driving force of variations in the steady-state labor supply. The production of X is similar as in Helpman (1984). A firm that wants to produce a given variety has to hire both skilled labor and unskilled labor in the headquarter to produce a firm-specific asset and can serve its affiliations, The production technology is similar as Y_i:

$$H_i = [L_{ix}^{\beta} + (A_i S_{ix})^{\beta}]^{\frac{1}{\beta}} \tag{2.2}$$

where H_i is total volume of headquarter production. Plants then use these firm specific inputs and unskilled labor to produce X with the technology

$$X_{ij} = min\{a_j H_i, b_j L_j\} \tag{2.3}$$

where is X_{ij} the final output of firms with headquarters in country i but maintain plants in country j. As in Markusen (2002), the headquarters activities are assumed to be more skilled-labor-intensive than production firms. In addition, the overall X sector is assumed to be more skilled intensive than Y_i.

Firms in the X sector incur "iceberg" transportation cost τ. Additionally, we assume that the fixed costs for different firm types with headquarters in country i are

$$fc_i^d(w_iS, w_iL) = w_{iS}F_i^d + w_{iL}G$$
$$fc_i^h(w_{iL}, w_{iS}, w_{jL}, w_{jS}) = w_{iS}F_i^h + w_{iL}G + w_{jS}F_j^h + w_{jL}G \tag{2.4}$$
$$fc_i^v(w_{jL}, w_{iS}, w_{jS}) = w_{iS}F_i^v + w_{jS}F_j^v + w_{jL}G$$

where F_i^k denotes the fixed cost incurred in units of skilled labor in country i associated with headquarters for type-k firms, while G denotes cost incurred in units of unskilled labor associated with plants. w_{iS} and w_{iL} are wages of a unit of efficient skilled labor and unskilled labor, respectively. I assume that the amount of unskilled labor required for a plant is the same regardless of the location of the plant.

There are three important assumptions about the fixed costs in Markusen (2002), which are maintained in this paper. First, it is assumed that the total fixed costs of a type-h firm are less than double the fixed costs of a type-d firm, since the two plants of a type-h firm share important knowledge from their headquarters. Second, managerial activities require some additional parent country skilled labor for type-h firms, since they have plants in the other country. Finally, assume that a type-v firm requires more skilled labor than type-d firm due to the costs of technology transfers with the production fragmentation. These assumptions can be shown with inequalities as

$$2F_i^d > F_i^h + F_j^h > F_i^d < F_i^h \tag{2.5}$$
$$F_i^h + F_j^h > F_i^v + F_j^v > F_i^d$$

All values are associated with firms headquarted in country i. Therefore, when a firm is replaced by anther type of firm due to the reduction in trade cost, the fixed cost incurred in units of skilled labor will be changed.

2.2.1.3 Labor supply

Now let's turn to the total supply of skilled and unskilled labor, which is exogenous in general trade models. Workers in country i can spend time educating themselves for a fixed period of time

T_i. If they choose to get education, they enter the labor force after finishing education and start supplying θ units of efficient skilled labor if they are of type θ. Therefore, the total wage each skilled labor can earn is θw_{iS}, which varies across different worker types. Workers who never obtain education supply one unit of unskilled labor from the beginning of their lives. The cost of getting education for an individual born at time period t is the opportunity costs, comprised of the unskilled wage during education and the unskilled labor income thereafter. Its present value is

$$\sum_{z=t}^{t+T-1} w_{iLz}(\frac{1-\delta_i}{1+r_i})^{z-t} + \sum_{z=t+T}^{+\infty} w_{iLz}(\frac{1-\delta_i}{1+r_i})^{z-t}$$

while the benefit is the additional income from supplying skilled labor from time $t+T$ on, with the present value as

$$\sum_{z=t+T}^{+\infty} (\theta_t w_{iSz})(\frac{1-\delta_i}{1+r_i})^{z-t}$$

I restrict the decision to take place at the moment of birth. Since the benefit of education is an increasing function of θ, there exists a threshold θ^*_{it}, such that it is optimal for individuals to choose education for all $\theta \geq \theta^*_{it}$. Worker of type $\theta^*_{it}$is indifferent between going to school or not, and the threshold is found by solving

$$\sum_{z=t}^{t+T-1} w_{iLz}(\frac{1-\delta_i}{1+r_i})^{z-t} + \sum_{z=t+T}^{+\infty} w_{iLz}(\frac{1-\delta_i}{1+r_i})^{z-t} = \sum_{z=t+T}^{+\infty} (\theta^*_{it} w_{iSz})(\frac{1-\delta_i}{1+r_i})^{z-t} \tag{2.6}$$

The total supply of human capital is given by the sum over past education decisions adjusted for the probability of survival and whether a worker is still in school. Given the density function of θ as $f_i(\theta)$, the transition function of skilled labor supply is

$$S_{it+1} = (1-\delta_i)Si_t + S_{int+1} \tag{2.7}$$

where S_{nt+1} is the number of efficient skilled labor supplied by individuals graduating from the education sector at time $t+1$, and satisfies

$$S_{int} = (1-\delta_i)^T \delta_i N_i \int_{\theta^*_{it-T}}^{1} f_i(\theta)\theta d\theta$$

Note that S_{nt} is not the same as the size of total population who supply skilled labor, which equals $(1-\theta^*_{it})N_i$. This is because the units of efficient labor each skilled labor supply vary across worker types.

2.2.2 Steady state solution

For simplification, assume the duration of education to be one period [3] and θ is uniformly distributed along $[1,0]$[4] . Since we have constant price in steady state, we can get rid of the subscript t and rewrite equation (6) as:

$$\sum_{z=t}^{+\infty} w_{iL}(\frac{1-\delta_i}{1+r_i})^{z-t} = \sum_{z=t+1}^{+\infty} (\theta_t^* w_{iS})(\frac{1-\delta_i}{1+r_i})^{z-t}$$

which can be simplified as

$$(1-\delta_i)\theta_{it}^* w_{iS} = (1+r_i)w_{iL} \tag{2.8}$$

The number of efficiency skilled labor supplied in steady state is

$$S_i^* = 0.5(1-\delta_i)N_i[1-(\theta_i^*)^2] \tag{2.9}$$

and the size of unskilled labor supply is

$$L_i^* = N_i\theta_i^* \tag{2.10}$$

The number of individuals who are getting education is $\delta_i(1-\theta_i^*)N_i$.

2.3 Simulation Results

The setup of the dynamic general equilibrium system introduces challenges to solve the model numerically. Therefore, I present simulation results in this section to show the main propositions of my model. To conduct conterfactual analysis we need benchmark data. I consider a economy with two symmetric countries in the benchmark. All parameters are the same across countries. First, to ensure that the X sector is always more skilled-intensive than the Y sector, the elasticity of substitution in the CES cost function is set to 1.5 in the Y sector, and 2 in the X sector. In

[3] The length of education matters for the composition of factor supply. All else are equal, country with longer length of education has lower skilled labor supply. However, changes in the value of T does not change our conclusion of the effects of trade cost reduction.

[4] Another common distribution used in the literature is the Pareto distribution, with which one can discuss the effects of heterogeneity on the trade effects. I use the simplest assumption in this paper to focus on other aspects of the model. The exact distribution of θ does not matter for the conclusion in this paper.

addition, I assume the interest rate $r = 0.2$ and death rate $\delta = 0.1$ in both countries[5] . A is assumed to be 1. Both trade and MNEs are prohibitive in the benchmark. The corresponding skilled labor and unskilled labor cost shares are shown in Table 2.1. The productivity threshold θ^* is around 0.79, which is also the share of individuals who choose not to get an education among the whole population. The share of unskilled labor in the total employment in the Y sector is 92%, while only 75% of the total employment in the X sector are unskilled workers.

Table 2.1: Important shares in the benchmark

Variables	Values
Consumption share of X	0.50
Consumption share of Y	0.50
Unskilled labor share in Y sector	0.92
Unskilled labor share in X sector	0.75
Wage premium	1.67
The ability threshold	0.79

In this section, I first discuss how these parameters influence the equilibrium values of endogenous variables, such as factor price and factor supply, in the autarky case. I then use simulation results to discuss impacts of trade cost reductions in the case without MNEs and compare it with the impacts in the case where factor supply is exogenous. After showing how the trade cost reduction induces skill accumulation only in skilled labor abundant country in models without MNEs, I then move to the discussion of how the incorporation of MNEs influences the impacts of trade cost reduction. I present conditions under which the model is able to reproduce stylized facts discussed at the beginning of this paper.

2.3.1 Steady state comparatives

2.3.1.1 Determinants of factor price and factor supply

According to equation (8)-(10), the total stock of skilled and unskilled labor in the steady state is mutually determined by the skill premium $\frac{w_S}{w_L}$, death rate δ, and discount rate r, while the

[5] Since all parameters are the same in country i and country j, I get rid of the country subscript here and in section 3.1.1.

skill premium is endogenous and is influenced by the efficiency of skilled labor A.

Consider first the impacts of the efficiency parameter A on skill premium and skilled labor supply. As shown in Figure 2.1 panel (a), for a given value of r and δ, larger A is associated with higher value of the skill premium and lower level of the ability threshold θ^*. Therefore, for any two countries with the same discount rate and death rate, the country using skilled labor relatively more efficiently will be the skill abundant country with a high value of skill premium. The intuition is quite straightforward. Large A is associated with high productivity of skilled labor, which implies large skill premium, or in other words, large returns to education. This implies all rest equal, the incentives for individuals to invest on human capital is relatively strong in this country. As a consequence, the stock of skilled labor is relatively large in equilibrium.

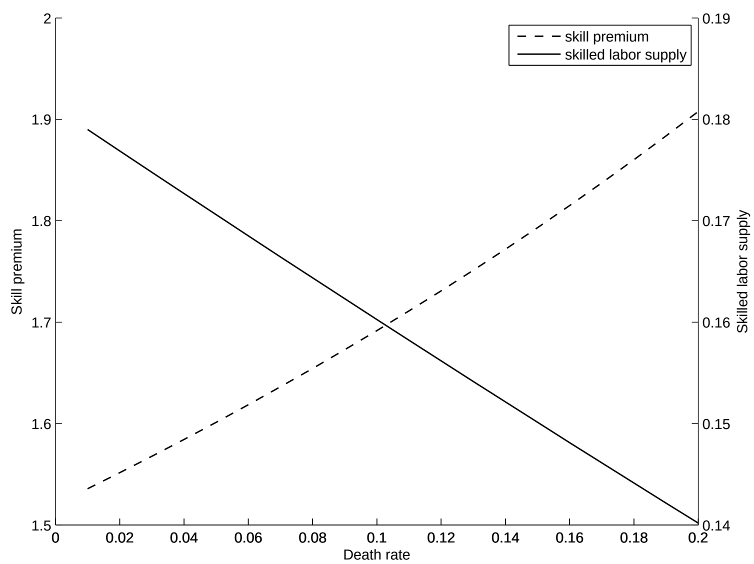
Figure 2.1 panel (b) shows a different pattern of skill premium and skilled labor supply when all rest constant but the value of death rate varies across countries; for a given level of A, a rise in the value of δ raises the value of the relative skilled labor wage but decreases the total supply of skilled labor. It is due to the fact that the discounted benefit of education is relatively low with a high death rate. This reduces the incentives for individual to get an education, leading to a low skilled labor stock in equilibrium. Skill premium is higher due to the lower stock of skilled labor in country with a large δ.

Table 2.2: Parameter values, skill premium and labor supply

	Small A	Large A
Small δ	loww_S/w_L, θ could be either high or low	low θ ,w_S/w_Lcould be either high or low
Large δ	high θ ,w_S/w_L could be either high or low	high w_S/w_L,θ could be either high or low

An interesting conclusion here is that the link between factor stock and factor costs can break down; a high stock of skilled labor can appear in a country with either low skill premium or high skill premium, as long as the value of A is large enough (as shown in Table 2.2). Similarly, a country with high skill premium is not necessarily the skilled labor abundant country. The potential discrepancy between factor stock and factor prices implies that it may lead to inaccuracy if one simply treats the skilled labor abundant country as the country with low skill premium in discussion on the

(a) Impacts of the efficiency parameter



(b) Impacts of the death rate

Figure 2.1: Determinants of skill premium and skilled labor supply

determinants and effects of globalization. This conclusion is one dimension in which my model departures from previous models with fixed factor supply.

Lemma 1

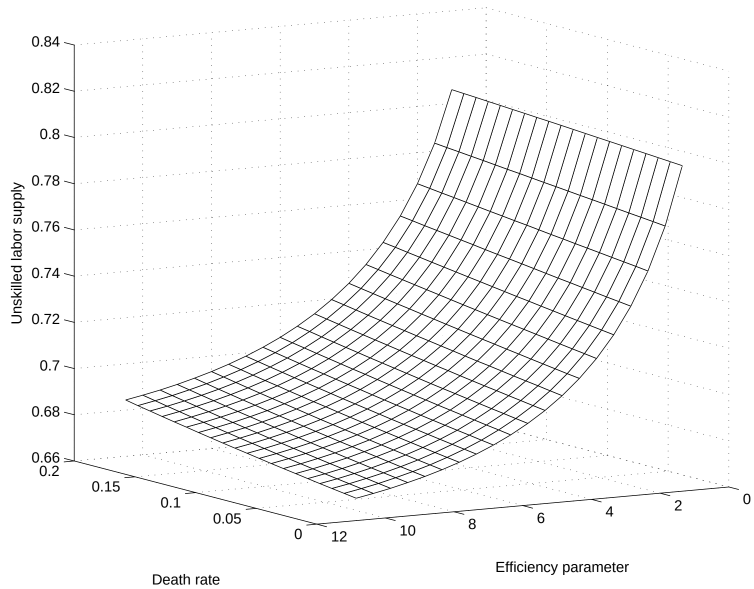
The factor stock and factor price do not have a one to one mapping.

In addition, the pattern in the price of X, which is more skilled labor-intensive compared with Y, is the same as the ability threshold θ^*, or the share of unskilled labor in total population. They both decrease in A and increases in δ. The idea is that for a given level of A, the country with large discount rate has relatively high skill premium according to Figure 2.1. Therefore, the price of X is relatively high in this country. If all the rest are equal, the country that can use skilled labor more efficiently has relatively high skill premium as well. However, it also needs less skilled labor to produce one unit of X compared with countries with smaller A. The difference in skill premium among countries is less proportionate than the difference in the efficiency parameter due to the adjustment of factor supply. As a consequence, the price of X decreases in A. This indicates that the price of X is always lower in the skilled labor abundant country than the other country in autarky, despite of the value of skill premiums (Figure 2.2 panel (a) and (b)). Moreover, the country using skilled labor more efficiently has higher wage of both skilled and unskilled labor, thus higher total income. This conclusion is consistent with Auer (2015), although the setup of production in my model is more complicated than that in Auer (2015).

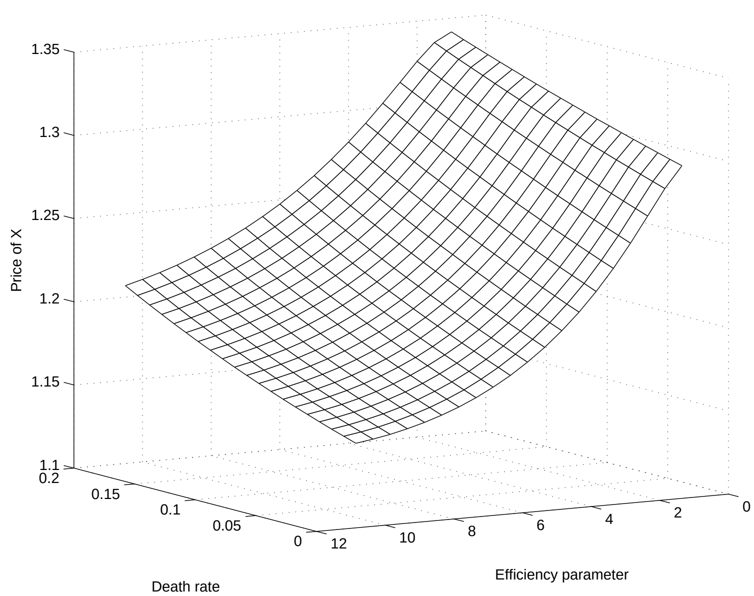
Lemma 2

With all else equal, countries that can use skilled labor more efficiently have high skill premium, large stock of skilled labor, and high income. In addition, these countries can produce the skilled labor intensive good with a low cost in autarky.

Although this proposition holds regardless of other parameters' values, the extent to which the cross-country differences in production efficiency translate into variations in factor abundance and skill premium is indeed dependent on the elasticity of substitution between skilled and unskilled labor, or the value of α and β. As mentioned above, there are two opposite effect of a change in A. Intuitively, when skilled labor and unskilled labor are not very substitutable, the price effects can offset a larger part of the differences in technology compared with it can do in the case where the two factors are more substitutable. Countries have much more similar factor stock and skill premium as a result (see Figure 2.3).



(a) Efficiency parameter, death rate, and unskilled labor supply



(b) Efficiency parameter, death rate, and price of X

Figure 2.2: Pattern of the price of X and unskilled labor supply

To consider the heterogeneity in the impacts of trade cost reduction, the most important factor is the relative price of X. A low value of the price is either associated with a large A or small δ. In the following analysis, I assume country i uses skilled labor more efficient than country j does. So country i stands for developed countries, while j is the developing countries. The death rate δ

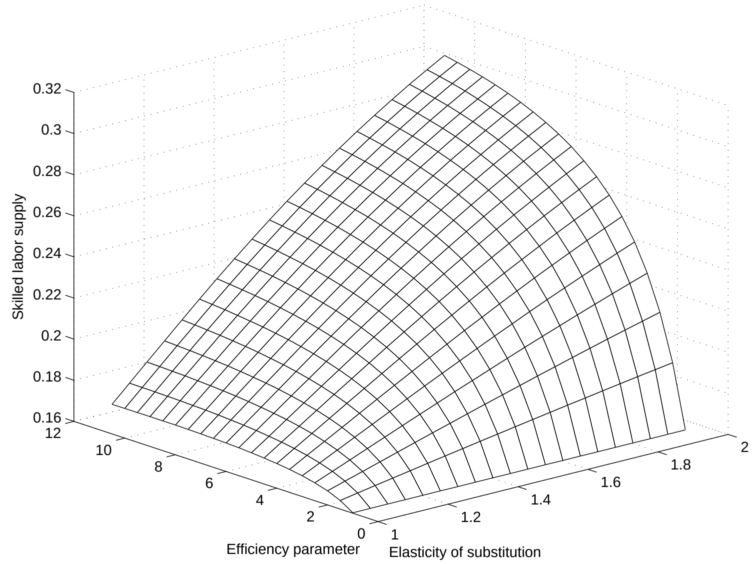


Figure 2.3: Elasticity of substitution and the heterogeneity in skilled labor supply

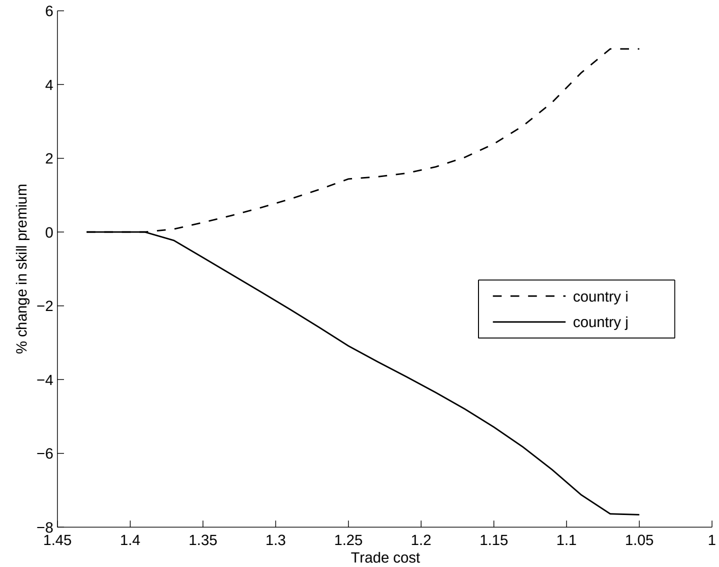
is the same across countries for simplification. As a result, country i is more skilled-labor abundant than country j[6] .

2.3.1.2 Effects of trade cost reductions without MNEs

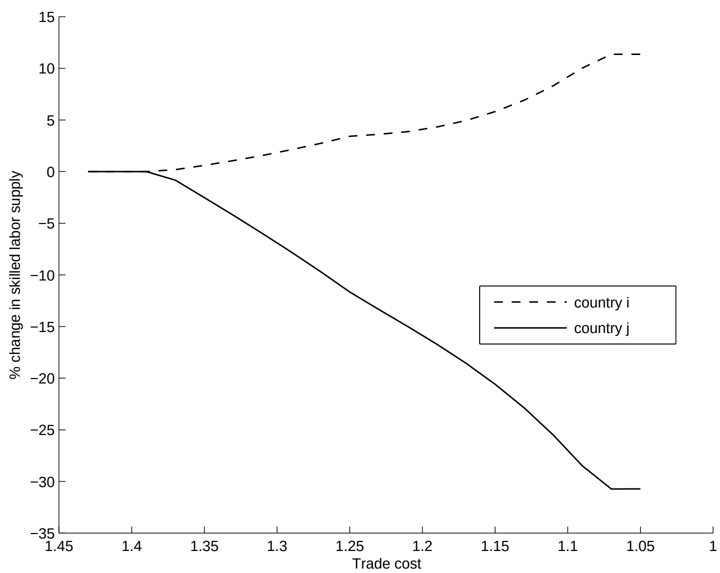
With the discussion on the autarky steady state equilibrium and lemma 2, increases in trade volume is expected to induce an expansion in the sector X in country i and the production of X is cheaper. This is similar as the implication of the HO framework with fixed factor endowments. The simulation result in our model provides support of this. It also shows that reduction in trade cost induces an increase in the total output of X, which reduces its price in both countries. Despite the decrease in the price of the skill-intensive good, the relative price of skilled labor is raised in country i, accompanied by an increase in the supply of skilled labor. The opposite happens in country j (as shown in Figure 2.4). This indicates that trade leads to a "concentration" of skilled labor in the country that can use skilled labor more efficiently, even though there is no reallocation of labor across countries. The following proposition summarizes the impacts of trade in the case without

[6] On can also assume the only difference between countries is the value of δ, or all three parameters are different across countries. It only makes the discussion more complicated, but doesn't change any model implicates about trade patterns and trade effects.

MNEs.



(a) Trade cost reduction and skill premium



(b) Trade cost reduction and skilled labor supply

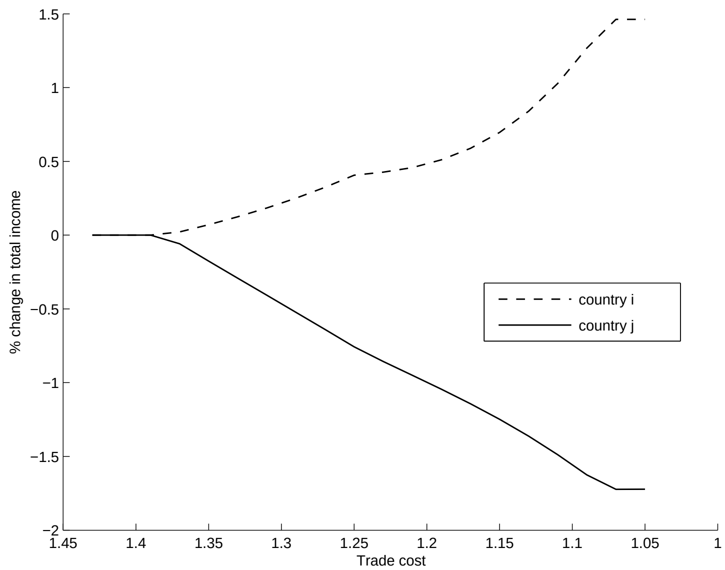
Notes: Values along the vertical axis are percentage change compared with values when trade cost is 1.45

Figure 2.4: Impacts of trade cost reduction without MNEs

Proposition 1

When MNEs are prohibited, reductions in trade cost increases skill premium and human capital accumulation in developed countries. The opposite happens in developing countries. The *total income diverges across countries.*

Since the skill premium increases and the share of unskilled labor in the total population decreases in the skilled labor abundant country, trade cost reduction increases the total income in country i. The opposite happens in country j. Therefore, trade induces a divergence in the total income across countries in the general equilibrium (Figure 2.5). This is similar as the partial equilibrium in Auer (2015).



Notes: Values along the vertical axis are percentage change compared with values when trade cost is 1.45

Figure 2.5: Divergence of total income without MNEs

2.3.1.3 Effects of trade cost reductions with MNEs

The trade literature has long recognized that there are various reasons to explain the fragmentation in the production process of MNEs. Horizontal MNEs, also known as the market-seeking MNEs, arises as a substitute for exporting and locate production in the destination market to avoid trade costs (Buckley and Casson, 1981; Markusen, 1984; Markusen and Venables, 2000; Helpman et al., 2004), while vertical MNEs are traditionally desired to take advantage of international factor price differences and fragment the production process internationally to increase efficiency (Helpman, 1984; Markusen, 1995; Braconier et al., 2005).

Therefore, when both trade and production fragmentation are allowed, the composition of firms in each country varies with the value of parameters of the economy.Table 2.3 presents the set of firm active in cases with different A and τ when all else equal. It supports the following lemma.

Lemma 3

The set of active firm types depends on heterogeneity in the efficiency parameter across countries and trade cost τ.

The value along the vertical direction presents the size of efficiency parameter in country i while A_j is fixed at 1. The notes under the figure explain the meaning of the numbers in each cell. As we can tell from the table, if trade cost is high and two countries are similar in A, and δ, type-d and type-v firms will be dominated by type-h firms to avoid trade cost; while when τ is small and two countries are similar, type-d firms is dominant due to its low fixed cost. If the discrepancy between two countries is significant, then the type-v has its advantage compared with type-d firms by locating headquarters where skilled labor is cheap. In cases shown as the left bottom corner in Table 2.3 where A_i is much greater than A_j and trade cost τ is quite small, the only active firm type is the vertical MNEs with headquarters in country i. In some cases, multiple firm types can exist simultaneously. This is similar as models in Markusen (2002) in which factor endowments are fixed.

However, the endogeneity of factor supply makes my model different from the original framework in two dimensions. First, the source of variations in the set of firm types active in each cell is the efficiency parameter in the production function, instead of the factor endowments. Second, by comparing Table 2.3 and Table 2.4, we can see that when skilled labor supply cannot adjust to trade-induced changes in skill premium, the trade cost required to make type-v firm to be the only dominant type is much lower compared to that in the case with factor adjustment. This is because the heterogeneity in skill supply induced by technology differences is reinforced with trade cost reduction in the case with endogenous human capital accumulation. Therefore, the benefit of type-v firm is larger in that case.

Table 2.3: Set of firm types active in equilibrium

A \ τ	1.28	1.26	1.24	1.22	1.20	1.18	1.16	1.14	1.12	1.10	1.08	1.06	1.04	1.02	1.00
1.0	0.011	0.001	0.001	0.011	0.011	110	110	110	110	110	110	110	110	110	110
1.2	0.01	0.01	0.01	0.01	0.01	110.01	110	110	110	110	110	110	110	110	110
1.4	0.01	0.01	0.01	0.01	0.01	0.01	110.01	110	110	110	110	110	110	110	110
1.6	0.01	0.01	0.01	0.01	0.01	0.01	0.01	110	110	110	110	110	2	112	110
1.8	0.01	0.01	0.01	0.01	0.01	0.01	0.01	102	112	112	112	112	2	12	12
2.0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	102	102	102	102	2	2	2	2
2.2	0.01	0.01	0.01	0.01	0.01	0.01	0.01	102	102	102	2	2	2	2	2
2.4	0.01	0.01	0.01	0.01	0.01	0.01	0.01	102	102	102	2	2	2	2	2
2.6	0.01	0.01	0.01	0.01	0.01	0.01	0.01	102	102	2	2	2	2	2	2
2.8	0.01	0.01	0.01	0.01	0.01	0.01	0.01	102	102	2	2	2	2	2	2
3.0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	102	2	2	2	2	2	2	2
3.2	0.01	0.01	0.01	0.01	0.01	0.01	2.01	102	2	2	2	2	2	2	2
3.4	0.01	0.01	0.01	0.01	0.01	0.01	2.01	102	2	2	2	2	2	2	2
3.6	0.01	0.01	0.01	0.01	0.01	0.01	2.01	2	2	2	2	2	2	2	2
3.8	0.01	0.01	0.01	0.01	0.01	0.01	102	2	2	2	2	2	2	2	2

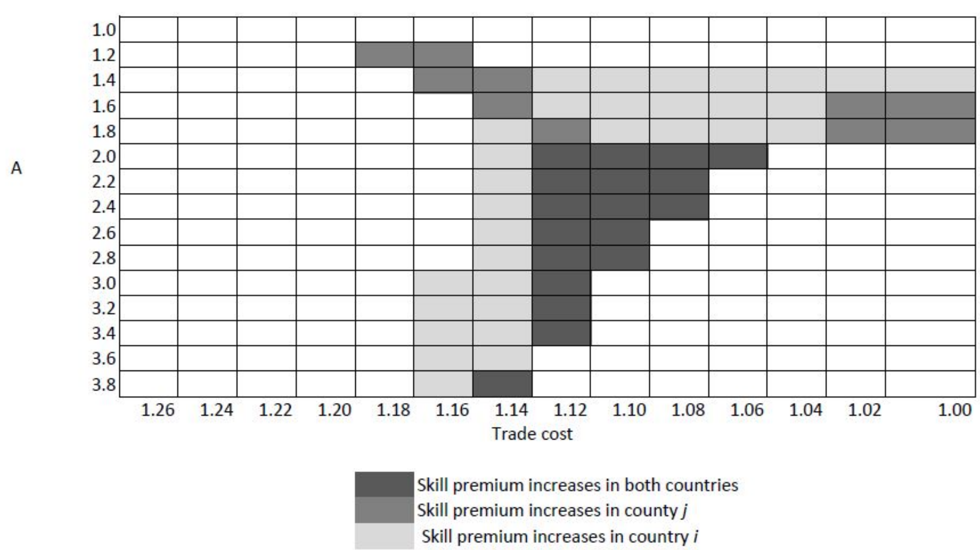
Notes: The value in the cell $=I_i^d + I_i^v + I_i^h + I_j^d + I_j^v + I_j^h$, where I_i^d=100 if type-d_i firms active, 0 otherwise; I_i^v=2 if type-v_i firms active, 0 otherwise; I_i^h=0.01 if type-h_i firms active, 0 otherwise; I_j^d=10 if type-d_j firms active, 0 otherwise; I_j^v=0.2 if type-v_j firms active, 0 otherwise; I_j^h=0.001 if type-h_j firms active, 0 otherwise.

Table 2.4: Set of firm types active in equilibrium-without human capital adjustment

A \ τ	1.28	1.26	1.24	1.22	1.20	1.18	1.16	1.14	1.12	1.10	1.08	1.06	1.04	1.02	1.00
1.0	0.011	0.011	0.011	0.011	0.011	110	110	110	110	110	110	110	110	110	110
1.2	0.011	0.011	0.011	0.011	0.011	110.01	110	110	110	110	110	110	110	110	110
1.4	0.011	0.011	0.011	0.011	10.011	110.01	110	110	110	110	110	110	110	110	110
1.6	0.011	0.011	0.011	0.011	10.011	110.01	110.01	110	110	110	110	12	110	12	2
1.8	0.011	0.011	0.011	10.01	10.01	10.01	110.01	110	12	112	110	12	12	12	2
2.0	0.01	0.01	0.01	10.01	10.01	10.01	110.01	112	12	112	112	12	12	12	2
2.2	0.01	0.01	0.01	0.01	10.01	10.01	10.01	112	12	112	112	12	12	12	2
2.4	0.01	0.01	0.01	0.01	0.01	10.01	10.01	112	12	12	12	12	12	12	2
2.6	0.01	0.01	0.01	0.01	0.01	0.01	10.01	112	12	12	12	12	12	12	2
2.8	0.01	0.01	0.01	0.01	0.01	0.01	10.01	112	12	12	12	12	12	12	2
3.0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	112	12	12	12	12	12	12	2
3.2	0.01	0.01	0.01	0.01	0.01	0.01	0.01	112	12	12	12	12	12	12	2
3.4	0.01	0.01	0.01	0.01	0.01	0.01	0.01	112	12	12	12	12	12	12	2
3.6	0.01	0.01	0.01	0.01	0.01	0.01	0.01	112	12	12	12	12	12	12	2
3.8	0.01	0.01	0.01	0.01	0.01	0.01	0.01	112	12	12	12	12	12	12	2

Notes: The value in the cell $=I_i^d + I_i^v + I_i^h + I_j^d + I_j^v + I_j^h$, where I_i^d=100 if type-d_i firms active, 0 otherwise; I_i^v=2 if type-v_i firms active, 0 otherwise; I_i^h=0.01 if type-h_i firms active, 0 otherwise; I_j^d=10 if type-d_j firms active, 0 otherwise; I_j^v=0.2 if type-v_j firms active, 0 otherwise; I_j^h=0.001 if type-h_j firms active, 0 otherwise. Notes: Labor supply is fixed at the level in autarky equilibrium

As one can expect, the impacts of trade cost reduction become more complicated when MNEs are incorporated into the model. It is now dependent on the exact change in active firm types. Figure 2.6 shows a full picture of the impact of trade cost reduction on skill premium by comparing the relative wage of skilled labor in each cell with the value on its left. For example, if a reduction in trade cost shifts the economy from (h_i) to (d_i, v_i), which means the horizontal type of MNEs are replaces by domestic firms in country i and vertical MNEs with headquarters in country i, only the skill premium in country i increase. This is because there is an expansion of headquarter services in country i. In addition, the production of X in country j is reduced and the opposite happens in country i. Therefore, the effects of trade are essentially the same as previously discussed in the case without MNEs: a decrease in the trade cost induces a switch of skilled labor from the unskilled labor abundant country to the skilled labor abundant country, enlarging the discrepancy in factor supply between countries. However, the existence of MNEs mitigates this effect, since the production process of X is geographically fragmented, which reduces the use of skilled labor in country i and increases it in the country j. This result holds as well in the case when the economy is shifted from (h_i) to (v_i,h_i).



Notes: This figure compares the skill premium in each cell with the value on its left.

Figure 2.6: Impacts of trade cost reduction on skill premium with MNEs

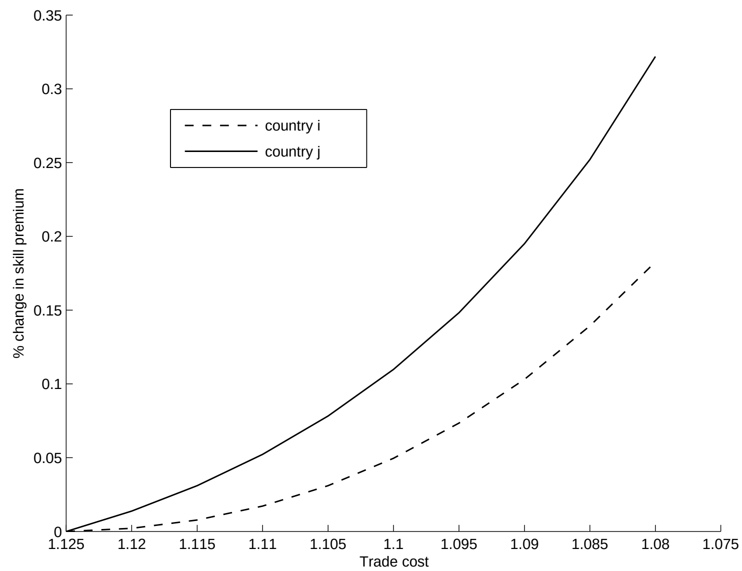
On the contrary, if the economy is switched from (h_i) to $(d_i,\, d_j)$, then expansion in headquarter production in country j increases the skill premium only in the skilled labor scarce country. When the reduction in trade impediment moves the economy from (d_i,v_i) to (v_i), skill premium will be increased in both countries. The intuition is that in country i, there is a transfer of skilled labor from the plant production of X to the headquarter services; while in country j, the number of vertical MNEs plants is increased, which reallocates resources from the production of Y sector to the fixed cost and affiliation production in the X sector. Similar story happens when the economy is in the state $(d_i,\, v_i)$. Although there is no change in the active firm type, the reduction in trade cost still reduces the production of d_i and increases the production of v_i firms. Figure 2.7 and 2.8 presents an example of this case. Trade cost is reduced from 1.12 to 1.07, and all values on the vertical axis are percentage change compared with the value before the trade cost reduction. We can see that skill premium, the stock of skilled labor, and total income increase in both countries, with a larger change in country j than in country i. This indicates a convergence in income across countries. The following proposition summarizes the impacts of trade cost reduction in the case with MNEs.

Proposition 2

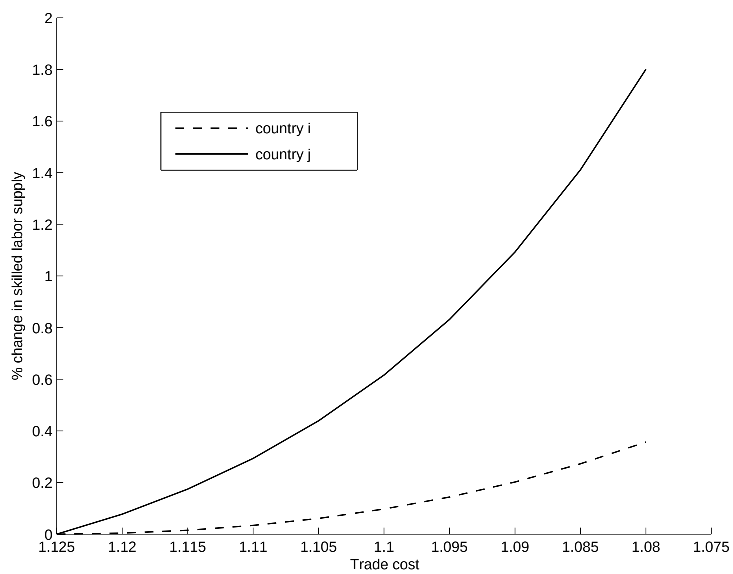
When MNEs are allowed, the impacts of trade cost reduction depends on change of active firm types. When the reduction in trade impediments increases the affiliation production in developing countries and shifts resources towards the skilled labor intensive sector, the skill premium and skilled labor supply increases in both countries. There is a converge of factor endowments and total income across countries.

2.3.2 Transition path

In this section I evaluate the effects of trade liberalization on human capital accumulation and skill premium by solving the transition path from one steady state equilibrium to a new steady state after trade liberalization. In the first period, the factor supplies are fixed since it takes one period for new students to finish education. This assumption allows us to compare the long-run



(a) Trade cost reduction and skill premium

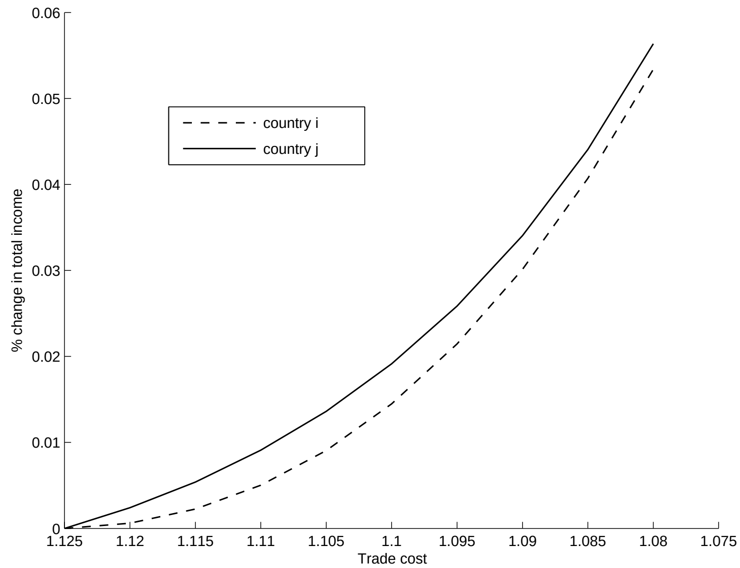


(b) Trade cost reduction and skilled labor supply

Notes: Values along vertical axis are percentage changes compared with the values when trade cost is 1.125.

Figure 2.7: Impacts of trade cost reduction with MNEs

effects of trade opening with labor market adjustment with the results of static models. Though the general equilibrium effects of trade depend on the choice of parameters as discussed before, the analysis of transition path is similar. Despite the value of parameters, the basic insight is that the trade-induced increase (decreases) in the skill premium on impact encourages skilled labor



Notes: Values along vertical axis are percentage changes compared with the values when trade cost is 1.125.

Figure 2.8: Convergence of total income with MNEs

accumulation (dis-accumulation), raising (reducing) the number of skilled labor, which offsets part of the initial trade effects. As a result, the transition path of skill premium is non-monotonic in all cases. Therefore, I only present a particular case where trade cost reduction increases skill premium and skilled labor supply in both countries. A_i is set to be 2.2 and $A_j = 1$. The initial iceberg transportation cost is 1.125 and investment is liberalized. Results of this experiment are given in Table 2.5.

Table 2.5 shows the impact of trade cost reduction (from 1.125 to 1.08) along the transition path. As discussed in the previous section, with the existence of MNEs, reduction in trade impediment may increase the relative return of skilled labor in country i and country j. Therefore, we can see the skill premium increases dramatically in country i and j on impact. Over the transition, however, the skill premium moves towards the opposite directions in both countries. In particular, the skill premium in country i is increased by 0.50% on impact while this increase is reduced to 0.34% after five years. The equilibrium impacts on skill premium is only 0.18%. A similar pattern appears in country j, The trade-induced increase in skill premium reduces from 2.41% to 0.94% after five years. Figure 2.9 provides a clear picture of this change over time. It reproduces the

Table 2.5: Changes along transition path with trade liberalization

	impact	5 years	10 years	Steady state
X sector output in country i	-92.92%	-91.65%	-91.35%	-91.40%
X sector output in county j	53.23%	52.53%	52.38%	52.41%
Y sector output in country i	33.42%	32.90%	32.77%	32.78%
Y sector output in country j	-12.23%	-12.03%	-11.98%	-11.99%
Employment ratio (S_x/S_y) in country i	-28.52%	-28.18%	-28.09%	-28.10%
Employment ratio (S_x/S_y) in country j	35.99%	32.92%	32.02%	31.86%
Skill premium in country i	0.50%	0.34%	0.25%	0.18%
Skill premium in country j	2.41%	0.94%	0.46%	0.32%
Ability threshold in country i	0.00%	-0.25%	-0.21%	-0.18%
Ability threshold in country j	0.00%	-0.53%	-0.37%	-0.32%
Skilled labor stock in country i	0.00%	0.50%	0.41%	0.36%
Skilled labor stock in country j	0.00%	2.96%	2.07%	1.81%
Unskilled labor stock in country i	0.00%	-0.25%	-0.21%	-0.18%
Unskilled labor stock in country j	0.00%	-0.53%	-0.37%	-0.32%
Students in country i	0.00%	0.60%	0.50%	0.43%
Students in country j	0.00%	3.21%	2,24%	1.96%

Notes: Trade cost reduces from 1.125 to 1.08

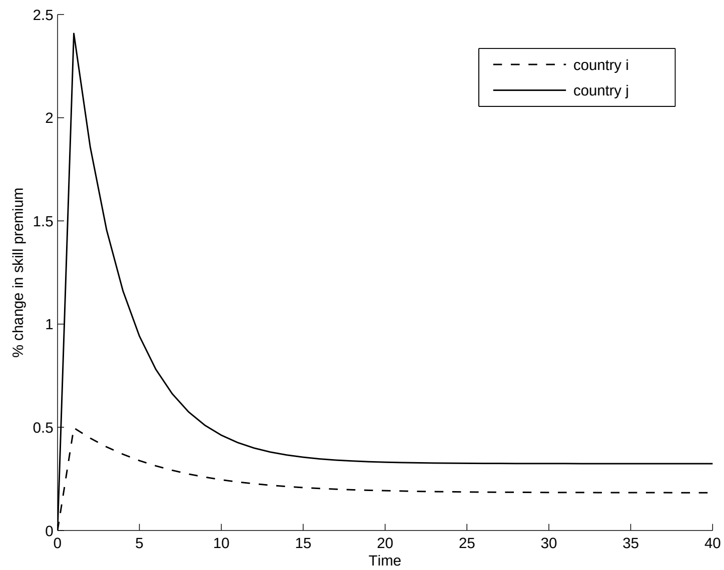
stylized facts discussed at the beginning of this paper. There is also a jump in student enrollment in both countries right after trade liberalization, which decreases along the transition path as well.

With respect to the output of X, the dynamics are much simpler. There is no reversal pattern over the transition. It can be seen that the output of X sector keeps decreasing in country i but increasing in j. The increase on impact is due to the switch of X production from country i to country j, and the later trend can be considered as a result of the decreasing in wage premium in country j.

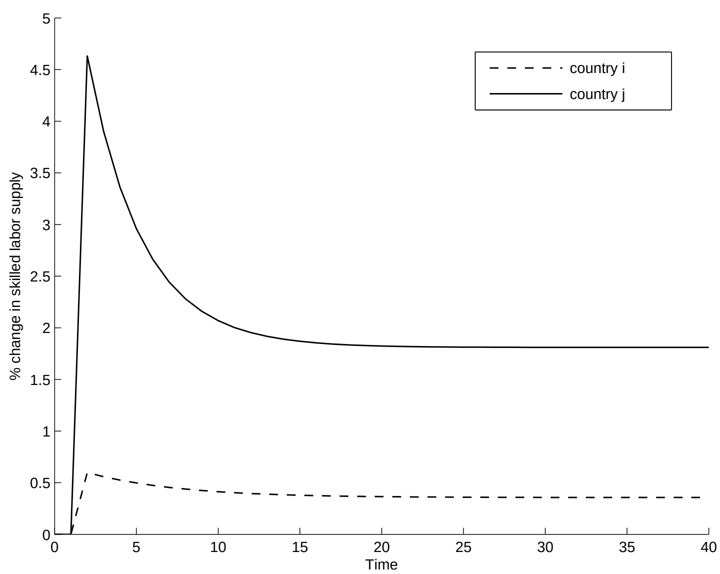
Proposition 3

When human capital investment is allowed to adjust to the trade-induced change in skill premium, the transition path of skill premium with a reduction of trade cost is non-monotonic.

Since the movement of variables over transition is driven by human capital accumulation, the magnitude of changes depends on the incentives to obtain education. For example, the lower the iceberg transportation cost, the larger the jump in the production of X sector and the skill premium in country i at the moment of trade opening. Consequently, the fall in skill premium and skilled labor supply in country i along the transition path is more obvious than that in the case with high



(a) Transition path of skill premium



(b) Transition path of skilled labor supply

Notes: Values along vertical axis are percentage changes compared with the intial values before the reduction of trade cost.

Figure 2.9: Transition path after trade cost reduction with MNEs

iceberg transportation cost.

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2.4 Empirical Approach

There two important theoretical implications to be tested in this section. First, the model indicates that the expansion of affiliation production of the MNEs in the skilled labor intensive sector increases human capital investment in developing countries. Second, this impact is most significant on impact, and its magnificence decreases over time. To detect the impact, I borrow the insights from the literature of the trade impacts on local labor markets and treat each prefecture in China as a local labor market. The basic identification strategy takes advantage of the time pattern in the implementation of the opening up policy in China.

2.4.1 China's opening policy in the 1980s

China started its open door policy in late 1978 with the establishment of four Special Economic Zones (SEZs) in Shenzhen, Zhuhai, Shantou in Guangdong Province and Xiamen in Fujian Province. These SEZs functioned as the experimental free trade zones and export-processing zones. To attract foreign direct investment and promote foreign trade, the local governments in SEZs were given the freedom to offer favorable terms for foreign investors. For example, companies in the export processing industry enjoyed a variety of special right, such as importing without going through the state-owned foreign trade companies and tax exemption for products and imported raw materials. Other incentives included, but were not limited to, preferential fees for land or facility use, favorable arrangements with project duration and the type of ownership. As a result of special foreign trade policy, the economy of Guangdong Province has undergone a fundamental shift away from second-tier foreign trade and becomes a major exporting province. In the subsequent 15 years, Guangdong and Fujian's export growth rate is twice that of other regions of China.

Given the success of SEZs, the Chinese government extended the opening up policy to another fourteen coastal cities (Dalian, Qinhuangdao, Tianjin, Yantai, Qingdao, Lianyungang, Nantong, Shanghai, Ningbo, Wenzhou, Guangzhou, Zhanjiang, and Beihai) and Hainan Island in 1984 and then to the entire coastal area in early 1988 (termed as the "coastal development strategy"). Later in the 1990s, the implementation of the open policies was gradually extended throughout China. The preferential policies granted to the fourteen coastal cities are also applied to another fifty-two cities, including all capital cities of inland provinces and the major cities along the Yangtze River. Additionally, more than fifteen border cities and counties were declared open border cities, among which some were authorized to offer coastal FDI preferential policies, while others were mandated to expand their existing border trade ties with neighboring. The time pattern in the implementation of opening up policy across cities provides the identifying variation in our analysis. Our study with a difference-in-difference method takes advantage of the staggered programing timing and detects the casual effects the program has on enrollment behaviors by comparing children in prefectures already reached by the program with children in prefecture not yet reached.

2.4.2 Empirical specification

The empirical strategy in this paper is straightforward. The local-labor-markets, which are defined as the metropolitan and non-metropolitan areas in each prefecture, vary in the time of their exposure to the opening up policy. The simulation results suggest larger increases in school attendance in prefectures exposed to larger changes in trade impediments and export values[7] . I examine this implication with the base specification:

$$E_{it} = \beta_1 SEZ_{it} + \beta_2 SEZ_{it} * OPEN_{it} + d_t + \epsilon_{it} \tag{2.11}$$

where E_{it} is the enrollment rate in prefecture at time. SEZ_{it} is a dummy which takes the value of one if a prefecture is a member of the treatment group of special economic zones. I consider prefecture as treatment group members if they are within 100 kilometers of the four SEZs established in 1980. We will return to the identification of SEZ_{it} below with the nonparametric method employed in

[7] An important assumption of the empirical strategy is that the education decision is made by individuals rather than the government and adjusts to changes in expected future income. The Law for Compulsory Education, which proclaims the compulsory provision of nine-year basic education in China, didn't exist until 1986 and it was not well implemented during a long period after 1986. As shown in Figure 2.10, the enrollment rate at the junior secondary school level was quite low during the period of our concern.

Redding and Strum (2008). $OPEN_{it}$ indicates whether the opening up policy was implemented in prefecture at time t. The coefficient β_2 captures the treatment effect of opening up policy on the relative school enrollment of the treatment group of prefectures, and it is expected to be positive based on the prediction of the model. d_t is a set of year dummies, allowing for national wide effect impacting all prefectures,such as other national policies. In the extended version of equation (11), I also include a set of controls for each prefecture, including the per capita ownership if agricultural land and number of school teachers per 100 student. Standard errors are clustered at prefecture level to take consideration of serial correlation over time.

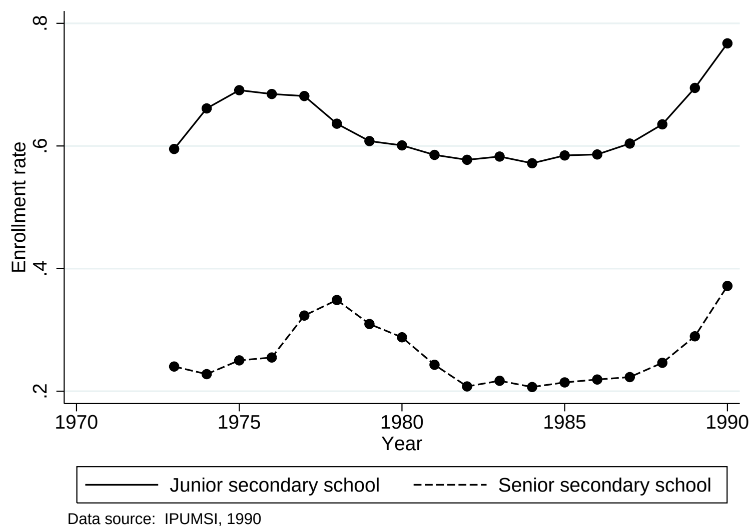


Figure 2.10: Enrollment rate reconstructions

The second main prediction of the model is that the magnitude of the impacts of trade cost reduction should declines monotonically over time. So I divide years during 1973-1990 into three periods and substitute the single interaction term in equation (11) with a set of iteration terms between SEZ_{it} dummies and period dummies to examine the heterogeneity in the treatment effects over time.

2.4.3 Data description

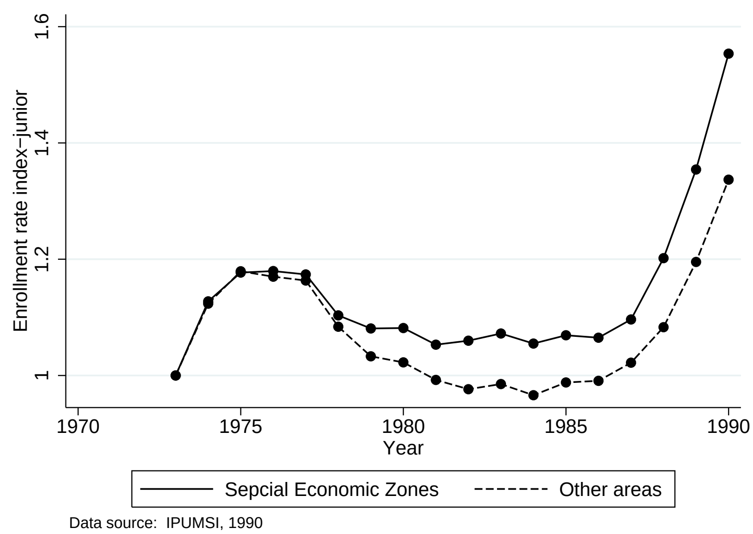
The key variable in the analysis of the dynamic impacts of trade impediment reduction on human capital investment is the regional level enrollment rate (E_{it}) for each year during 1980-1990. However, detailed data of enrollment rate is not available at the prefecture level. My analysis relies primarily upon the enrollment reconstructions based on the microdata from the 1990 China Population Census conducted by the National Bureau of Statistics (NBS). It is available in IPUMSI provided by the Minnesota Population Center. This data set includes 11,835,947 individual from all 347 cities in China. I use the information on education and age of each individual to reconstruct the total population size and enrollment status at each grade during 1973-1990. The estimated enrollment rate of is shown in Figure 2.10.

Note that the estimated enrollment rate is subjected to several shortcomings. First, the reconstructed population size in each year might be inaccurate due to the lack of information on people who died by the time of the census. This problem would not be serious as long as there is no systematic difference in death rate across education group in different regions. Moreover, variations in the education system across prefectures make it impossible to reconstruct the exact individual enrollment status in each year before 1990. The difference in difference method makes the first problem less than a concern if there are no systematic variations in the death rate by education level and cohort across regions. To address this problem, I employ an alternative measure of human capital investment following the work of Duflo (2001).The methodology is detailed in the section of robustness checks.

2.5 Impact of Trade on Skill Premium and Education

2.5.1 Main difference in difference results

Before we approach to the difference-in-difference analysis, I compare the trends in enrollment rate of the treatment group and control group. Figure 2.11 provides the support of equal trend assumption for the difference-in-difference method. Enrollment is normalized to an index relative to its 1973 value, which is the beginning of the period of our concern. We can see that before the start of the opening up policy, both the treatment and control group experienced decreases in the junior secondary school enrollment rate and senior secondary school enrollment. However, staring from the year of 1978, SEZs experience larger increase in the enrollment than the control cities. The discrepancy between the two groups gets closer when we approach 1990.



(a) Junior secondary school enrollment rate

(b) Senior secondary school enrollment rate

Figure 2.11: Enrollment rate comparison

Table 2.6 contains the basic findings. The effect of the opening up policy on enrollment rate is estimated separately for the junior secondary school and senior secondary school and for two different measures of SEZ. Column (1) and (2) present the results of regressions when we only consider the four SEZs opened in 1980 as the treatment group and exclude the second group of SEZs from the control group, while Column (3) and (4) give the estimations of equation (11) with all fourteen SEZs in 1984 as the treatment group. The coefficients on the treatment group dummies are statistically insignificant in most cases, indicating that the equal trend assumption is satisfied for our difference-in-difference method. The key coefficient on the interaction term is positive and statistically significant, which is consistent with the prediction of the simulation results. Specifically, at the junior secondary school level, the average enrollment effect is about 4.02 percentage point, while the average enrollment rate before the opening up policy is around 57%. This suggests that the opening up policy increases enrollment rate by 8%. Similarly results are found at the secondary school level. The coefficient before the interaction term implies that the opening up policy increases enrollment by around 10%.

Table 2.6: Main regression results

Dependent variable: Enrollment rate	Junior (1)	Senior (2)	Junior (3)	Senior (4)	Junior (5)	Senior (6)	Junior (7)	Senior (8)
SEZ	-0.00317	-0.0202	0.0484**	0.0116	-0.0160	-0.0191		
	(0.0356)	(0.0244)	(0.0197)	(0.0161)	(0.0369)	(0.0243)		
SEZ*OPEN	0.0402**	0.0206	0.0237***	0.0301***				
	(0.0196)	(0.0189)	(0.00908)	(0.0115)				
SEZ*Year 1980-1986					0.0383***	0.0227**		
					(0.0120)	(0.00957)		
SEZ*Year 1987-1990					0.0258	0.0187		
					(0.0332)	(0.0280)		
SEZ0-100km*OPEN							0.0329*	0.0125*
							(0.0196)	(0.0088)
SEZ100-400km*OPEN							0.00834	-0.00969
							(0.00974)	(0.0105)
SEZ400-800km*OPEN							-0.00974	-0.0268***
							(0.00887)	(0.00990)
SEZ8-1100km*OPEN							-0.0117	-0.0303***
							(0.00781)	(0.00707)
Constant	0.577***	0.234***	0.589***	0.239***	0.577***	0.234***	0.601***	0.241***
	(0.0116)	(0.00792)	(0.00959)	(0.00660)	(0.0116)	(0.00792)	(0.0118)	(0.00795)
Year Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4,338	4,338	6,246	6,246	4,097	4,097	6,246	6,246
R-squared	0.080	0.137	0.107	0.159	0.055	0.108	0.099	0.162

Standard errors are cluster at the prefecture level.

*** p<0.01, ** p<0.05, * p<0.1

The results from regression examining the heterogeneity in the enrollment effects of the open door policy over time are listed in column (5) and column (6). The magnitude of the coefficient on the interaction term decreases over time, confirming the prediction of our theoretical model. The difference in enrollment rate between the SEZs and non-SEZs is greatest during 1980-1986. To show the evolution of the treatment effects over time more clearly, I also introduce interaction terms between SEZ dummy and individual years into equation (11). The coefficients of the interaction term are plotted in Figure 2.12, which provides further support of the simulation results.

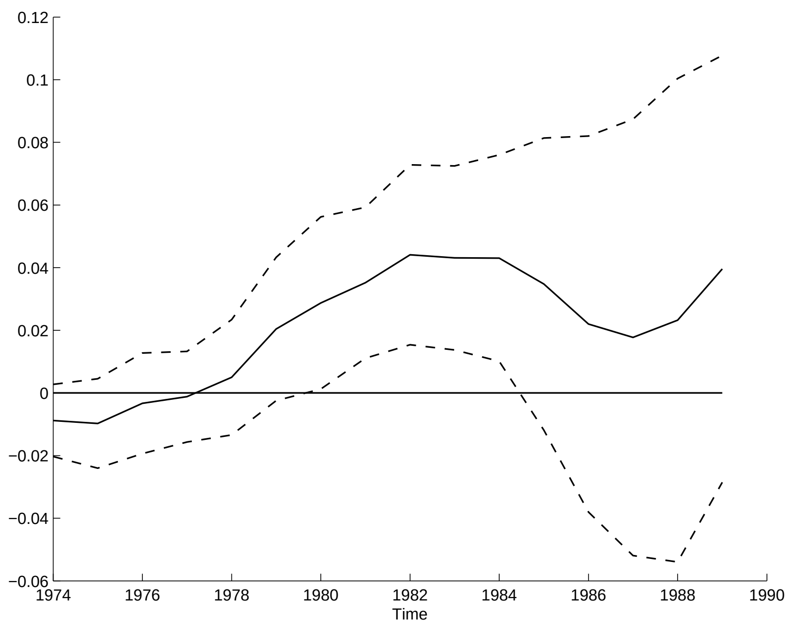


Figure 2.12: Coefficient of the interactions SEZ*year dummies

To get the results in column (7) and column (8) I substitute the SEZ dummies with dummies for cities lying in different distance bins from the SEZs. The estimated coefficients on the interaction between the distance cells outside 100km are statistically insignificant and their magnitudes are much smaller than the coefficient on the interaction term for 0-100km. I use the nonparametric strategy employed in Redding and Sturm (2008) to examine my choice of the distance used to define SEZs. The average estimated treatment effect within 100km of the four special economic zones is significantly different from the average treatment effect across other cities.

2.5.2 Robustness check

2.5.2.1 Other controls

Table 2.7 presents various extension of equation (11) with additional controls. Column (1) shows the results of regressions with province dummies to capture regional specific features. The human capital effects of the opening up policy would be biased if the choice of SEZs is correlated with omitted prefecture-level time-varying factors that affect school enrollment. To address this concern, I constructed the teacher to student ratio and GPD level from the Comprehensive Statistical Data and Materials on 50 Years of New China. The result of regressions with these controls is listed in column (2). It is also possible that the allocation of SEZs might be negatively correlated with the development level of each prefecture, thus the estimate could confound the effect of the opening up policy with mean reversion that would have taken place even in its absence. Therefore, I also include the interaction between year dummies and the GDP per capita, as well as the interaction between year dummies and enrollment rate in 1978 and the corresponding results are shown in column (3). To get the results in column (4), I extend the previous regression by adding government expenditure share on education and scientific research for each year at the province level as a measure of education related policy changes. Neither the magnitude nor the statistical significance of the coefficient on the interaction term between open and SEZs is sensitive to the including of these time-varying province measures of education quality. In addition, controlling for the initial development level makes the estimates higher, which rules out the possibility that the estimates in Table 2.6 are biased upward by mean reversion. The last column in Table 2.7 shows the heterogeneity in the impacts of the opening up policy over time with the full specification of the regression and the previous pattern does not change.

2.5.2.2 Heterogeneous response across gender groups

To test whether the results in Table 2.6 are driven by a particular gender groups, I conduct all previous regression analysis by gender. Column (3) and (4) in Table 2.8 show the effects of the

Table 2.7: Robustness checks-other controls

	(1)	(3)	(4)	(5)	(6)
Junior secondary school Enrollment rate					
SEZ	-0.0546	0.235***	0.0374	0.330***	0.369***
	(0.0392)	(0.0739)	(0.168)	(0.0738)	(0.118)
SEZ*OPEN	0.0402**	0.0429**	0.0745***	0.0471***	
	(0.0197)	(0.0171)	(0.0262)	(0.0171)	
SEZ*Year 1980-1986					0.0477**
					(0.0239)
SEZ*Year 1987-1990					-0.0137
					(0.0398)
Constant	0.680***	0.132**	-0.283**	0.111*	-0.0933
	(0.0198)	(0.0627)	(0.135)	(0.0669)	(0.0790)
Year dummies	Yes	Yes	Yes	Yes	Yes
Observations	4,338	3,755	3,755	3,461	3,521
R-squared	0.611	0.289	0.416	0.287	0.258
Senior secondary school enrollment rate					
SEZ	-0.0256	0.253	0.217	-0.00163	0.161
	(0.0366)	(0.164)	(0.147)	(0.146)	(0.124)
SEZ*OPEN	0.0206	0.0373*	0.0535***	0.0672***	
	(0.0189)	(0.0213)	(0.0204)	(0.0204)	
SEZ*Year 1980-1986					0.0483***
					(0.0148)
SEZ*Year 1987-1990					0.0412
					(0.0390)
Constant	0.253***	-0.122*	-0.113*	-0.190**	-0.153**
	(0.0223)	(0.0650)	(0.0634)	(0.0795)	(0.0612)
Observations	4,338	3,461	3,755	3,755	3,521
R-squared	0.465	0.255	0.269	0.394	0.238

Standardized errors are cluster at the prefecture level
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

opening up policy for female while the last two columns presents the results for male. All coefficients of the interaction term are still positive and statistically significant. The magnitude is similar for both genders, with the estimates of boys slightly higher than that of the girls at both the junior and senior secondary school level.

A relevant concern is that the findings in Table 2.6 are driven by the fact that the SEZs are close to the coastlines rather than the implementation of the opening up policy. Therefore, I estimate the previous regression (11) using only coastal cities. The estimates remain statistically significant.

Table 2.8: Robustness checks-restricted samples

Dependent variable: Enrollment rate	(1) Junior	(3) Senior	(4) Junior	(5) Senior	(6) Junior	(2) Senior
SEZ	-0.0329	-0.0360	-0.0303	0.00130	0.0228	0.0211
	(0.0385)	(0.0271)	(0.0477)	(0.0178)	(0.0244)	(0.0149)
SEZ*OPEN	0.0365*	0.0369*	0.0407*	0.0279**	0.0431***	0.0321***
	(0.0203)	(0.0200)	(0.0228)	(0.0118)	(0.0159)	(0.0114)
Constant	0.608***	0.256***	0.497***	0.184***	0.651***	0.280***
	(0.0187)	(0.0146)	(0.0135)	(0.00835)	(0.0106)	(0.00800)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,044	1,044	4,338	4,338	4,338	4,338
R-squared	0.173	0.233	0.052	0.094	0.119	0.184

Standardized errors are cluster at the prefecture level
*** p<0.01, ** p<0.05, * p<0.1

2.5.2.3 Other measures of school enrollment

As noted above, it is impossible to reconstruct the exact individual enrollment status in each year before 1990 due to variations in the education system across prefectures. To provide further supportive evidence of my previous findings, I employ an alternative measure of human capital investment across years following the methodology in Duflo (2009). In particular, instead of equation (11), I estimate the following regression:

$$S_{ijk} = \beta_1 SEZ_j + \beta_2 SEZ_j * YOUNG_i + d_k + \epsilon_{it} \qquad (2.12)$$

where S_{ijk} is the years of schooling of individual i in region j born in year k. SEZ_j is the same as before, a dummy which takes the value of one if a prefecture is a member of the treatment group of special economic zones. $YOUNG_i$ is a dummy indicating whether the individual i belong to the "young" cohort. which is defined as 6-12 years old, at the time when the opening up policy started. d_k is the cohort fixed effects. The estimates of β_2 is 0.497 and statistically significant.

2.6 Conclusion

General trade models usually take factor endowments as exogenously given, which omits the dynamic interaction between globalization and human capital accumulation. There are a few exceptions in the literature, but they still fail to explain the trade-induced human capital investment in developing countries. To fill this gap, this paper combines the framework in Auer (2015), in which skilled labor supply are endogenously determined by individuals' choice of education, with the knowledge-capital model of MNEs in Markusen (2002). By developing a $2\times2\times2$ dynamic general equilibrium model with production fragmentation and endogenous education decision, I investigate the effects of trade cost reduction on the steady state equilibria, as well as the entire transition path.

I first present the steady state comparatives of an economy in autarky and show how factor endowments are determined by features of the economy. All rest equal, the simulation results show that countries using skilled labor more efficiently have relatively high skill premium, large stock of skilled labor, and high income. In addition, these countries can produce the skilled labor intensive good with a low cost in autarky. Consequently, in a world without MNEs, trade liberalization leads to an increase in the skill premium and total income in the skilled labor abundant country. Although there is no international migration in my model, the results suggests the reduction in trade costs leads to a "concentration" of skilled labor to the country using skilled labor relatively more efficiently and trade "favors" the developed country.

This conclusion does not hold when MNEs are incorporated in to the model. The distribution effect of trade cost reduction is determined by the change of active firm types, which is mutually determined by the value of transportation cost and the discrepancy between countries. This highlights that controls, such as the variation of efficiency of skilled labor and death rate across countries, is important in the analysis of trade-wage studies when MNEs exist. It is proved that when the reduction in trade cost expands the scale of vertical MNEs with headquarters in developed countries, the skill premium and skilled labor supply increase in both the skilled labor abundant country and the skilled labor scarce country. There is a convergence in the income distribution across countries.

I also present the non-monotonic dynamic responses of human capital accumulation to the trade cost reduction over transition. The change of signs and magnitude of the trade effects along the transition path is caused by the interaction between factor prices and factor supply: rises in skill premium right after the reduction in trade impediments induces human capital investment, which further changes factor prices. The dynamics implies that it is important to specify the time frame in discussions on the distribution effects of trade cost reduction. Theoretical studies with only discussion on steady state equilibria underestimate the distributional impacts in the short-run , while empirical research using income data within short period overestimates the actual overall effects of trade.

The theoretical implications are supported by the empirical evidence in the context of China's implementation of its opening up policy in the 1980s. The results of the difference-in-difference method suggests that the opening up policy increases enrollment rate at the junior secondary school level by 8% and enrollment rate at the senior secondary school level by around 10%. The results are robust with additional controls and alternative measure of education investment.

The conclusion in this paper highlights the importance of education policy in complementing the trade policies. Although in the short run trade increases the wage inequality, this adverse impact of trade is mitigated by the increase in education investment. In the long run countries with good education facilities might experience large increases in educational attainment and small changes in the income distribution, while in countries with frictions that stops workers from investing on education, the adverse distributional impacts of trade might last long. In addition, this paper also highlights the important role of MNEs in shaping the world income distribution. Combined with endogenous human capital accumulation, expansions in vertical MNEs lead to a convergence in total income between developed and developing countries.

Chapter 3

Capital Markets in China and Britain, 18th and 19th Century: Evidence from Grain Prices

3.1 Introduction

All societies, past and present, are faced with the problem of how to allocate capital in ways conducive to economic growth. Capital markets are essential-in their absence the surplus income of the savers cannot be easily matched to the productivity-enhancing projects of the investors[1] . Even as it is widely recognized that the financial development of a country is important for economic growth, it has been difficult to distinguish historically decisive differences between capital markets in different countries.

In this paper, we turn the focus towards two prominent economies, China and Britain, and ask whether there were significant differences in the interest rates and the integration of capital markets over the 18th and 19th centuries that can inform the very different growth trajectories the two regions experienced in the 20th century. While a considerable amount of new data has been brought to bear recently on the question of the timing of the worldwide divergence in incomes between Northwest Europe and China (Allen et al. 2011, Broadberry et al. 2014), determining the cause of this divergence has proved to be a much greater challenge (Needham 1969, Pomeranz 2000, Lin 2014). The answer to this question, however, has broad significance for microeconomic and macroeconomic factors, and goes to the heart of the role of the financial system for growth

[1] The link between financial development and growth has long been emphasized (Bagehot 1873, Schumpeter 1911, Gurley and Shaw 1955). Rousseau (1999), Mitchener and Ohnuki (2007) and Rosenthal and Wong (2011) provide discussions, and Levine (2005) a broader review.

(Bagehot 1873, Schumpeter 1911, Levine 2005), as well as its relation to the political environment (Rajan and Zingales 2003, Rosenthal and Wong 2011) and social organization (Greif 1989).

By the 18th century in China, historical evidence indicates that farmers moved their assets back and forth between cash and grain by trading with merchants or by bringing the grain to local markets[2] . There is evidence that merchants and farmers in Britain had been engaged in this type of trade as well from the late-Middle Ages onwards[3] . Based on these facts, we employ a storage model as the framework with which to estimate regional interest rates from monthly grain prices. Since stored grain is an asset and competes with other assets to convert current into future consumption, regional grain price movements will necessarily reflect interest rates (Working 1933, Kaldor 1939). As grain is being bought and sold over time this activity between buyers and sellers establishes a connection between the grain price and the capital market.

Much of the analysis on capital markets in the existing literature has been on the level of interest rates (Rosenthal and Wong 2011 review comparative work on China and Europe, Ch. 5). A relatively low interest rate, or price of capital, indicates not only that the economy is not constrained by the lack of capital, but it also points to relatively low levels of risk in capital market transactions. North and Weingast (1989) for example argue that institutional improvements resulted in a capital response; specifically, the level of interest rates on government loans declined. Low interest rates may also affect the rate of technological change by giving relatively strong incentives to mechanize and invest in machinery, thereby–as has been argued–pulling Europe ahead of other parts of the

[2] Described in a memorial from the 18th century by a Qing official named Tang Pin in Da Qing li chao shilu (1964), Gaozong (Qianlong) reign 286: 24b-25a (4154-55); see Pomeranz (1993, p. 32). Agriculture's intertemporal aspects and the link to other parts of the capital market are also illustrated in the following description of the Xu family (Fujian, 19th century): "Except for the import and export trade of the Chunsheng and Qianhe shops, the Xu's had quite a few storefronts and much arable land for renting in Taiwan. Their real estate was mainly distributed in towns of Lugang, Fuxing and Xiushui in Zhanghua County, collecting more than 2,000 dan of grain as rent per year.... Not only selling to rice-purchasers, the Xu's also processed the grain themselves and transported it to the mainland for sale. In addition, they even set foot in loaning business, often lending money and grain to other firms and people with interest.... In the operation of their businesses, they adopted diversified investment strategies: managing Chunsheng and Qianhe shops, investing extra capital in other firms and directly doing business in partnership with others." (Chen 2010, p. 433, based on Lin and Liu 2006). Also see Zhang (1996), Pan (1996) on rural borrowing and merchant credit.

[3] Everitt (1967) describes the private trading in England, which arose to supplement the town markets and fairs that had been in operation already over the 16th and 17th centuries. These private traders consisted of travelling merchants and salesmen who purchased in advance grains and other goods, connecting the village peasant to the wider intertemporal market.

world (Allen 2009). A common basis for obtaining a comparison of interest rates is crucial. It turns out that it is not too difficult to find evidence depicting interest rates in Europe as being relatively low and Chinese interest rates as being fairly high; however, because numerous aspects of these transactions are often unobserved, it is typically not possible to compare a given contracted interest rate with another one. Pomeranz (1993), for example, notes that while there are many interest rates for China's Shandong province, "most cannot be used in systematic comparisons... because they omit information about who was charged a particular rate, what security there was, how interest was paid, and so forth" (1993, p.32). Thus, selection biases and other issues preclude a simple comparison of interest rates and offer at face value little certainty to the question of whether China was capital strapped while Britain was capital abundant (Rosenthal and Wong 2011).

We tackle the issue of comparability with a framework that provides a common foundation across different economies. To confirm the method is sound, we choose our approach by calibrating the storage model to key features of U.S. capital markets in the early 19th century and comparing the estimated results with actual bank interest rates (source: Bodenhorn and Rokoff 1992). In addition, we account for variation in storage and other grain-specific costs by using information on historical climate, transport routes, and cropping patterns in our comparison of Britain and China.

Our estimated interest rates go a long way towards overcoming the main limitations in reported rates from individual written contracts. Our main focus, however, is not the level of the interest rate but the integration of the capital market and a comparison thereof across regions. Although the literature has generally given most emphasis to interest rate levels, it is well known that even in highly developed capital markets regional interest rate levels vary due to various observed and unobserved factors. Thus, our preferred measure of capital market performance is the integration of capital markets. Analogous to the analysis of commodity markets and the so-called "law of one price", the emphasis is not on price (i.e. interest rate) levels but on barriers to arbitrage in the capital market.

Low capital market integration is a sign of high barriers to the division of labor, to the allocation of investment as well as high levels of risk, whereas highly integrated markets ensure that capital can flow to the location of efficient use. Studies of early capital markets, for example Mitchener and Ohnuki (2007) in the case of Japan, often focus on the integration of the market. After we calculate regional interest rates in Britain and China in the period of 1770 to 1860, we compare the integration of capital markets by examining the correlation of interest rates across regions within each country.

Most of what we know about early financial integration is based on the 19th century U.S[4] . We provide, to our knowledge, the first study of financial market integration using interest rates for the 18th century[5] . In the main empirical section of the paper, we show results from assessing the most comprehensive set of grain prices available for China and Britain—a data set with nearly 20,000 interest rates—which we use to evaluate the performance of capital markets. In addition to presenting comprehensive new interest rates for large parts of China and Britain, we also show how grain price interest rates can be employed for studying capital markets in other countries where information on regional interest rates is scarce. A better understanding of the divergence between China and Europe can distill lessons on the causes of economic development more broadly. Our paper thus extends studies on the historical role of financial development on countries in Europe and North America (Davis 1965, Sylla 1969, Rousseau 2003, Hoffman, Postel(Vinay, and Rosenthal 2011), and the case of Japan (Mitchener and Ohnuki 2007, 2009).

We find typical annual rates in China of about 7.5% compared to about 5.4% in Britain, and that storage costs are important for applying this grain price approach to interest rates. Without netting out storage costs our estimates would be about 40% higher[6] . Our findings show that although interest rates were lower in Britain than in China, the difference is not so large as to be wholly consistent with the often-drawn picture of a highly capital-strapped Chinese economy. The

[4] Good (1977) and Brunt and Cannon (2009) study 19th century Austria and England, respectively.

[5] Other evidence on China's capital market development includes Zelin (2006) who shows that salt merchants were able to raise substantial funds in southern Sichuan during the late 19th to early 20th centuries, and Pomeranz (1993) who discusses the variation in 20th century regional interest rates in Shandong province. Li and van Zanden (2013) discuss interest rates in China's Yangzi Delta and the Netherlands. Before the 19th century, work on capital market integration has typically relied on interest rate proxies, e.g. the number of real property transactions (Buchinsky and Polak 1993).

[6] These figures are nominal; interest net of inflation would be preferred. We could obtain real interest rates by deflating with the regional price of grain. We have not done so here to maintain comparability with the literature, which focuses on nominal rates.

implication is that any weakness of the Chinese financial system does not center on interest rate levels.

Comparing the performance of British versus Chinese capital markets, we find that the spatial correlation of regional interest rates in British capital markets was substantially greater than regional integration in China. Integration levels for the Yangzi Delta come close to the British average at distances below 200 kilometers, while at larger distances interest rate correlations in Britain are twice those of the Delta, and three or more times higher than elsewhere in China. Notably, the advantage that England had over China in the late 18th century with respect to the integration of commodity markets (Shiue and Keller 2007) appears to be small when compared to the British advantage in terms of capital markets. Thus, even though China might not have been as capital scarce as generally thought, the lower integration of capital markets means that capital was not flowing to the location of efficient use. Our results suggest that in this respect capital market development might have been a critical factor in explaining the divergence in income that becomes apparent by late 18th century.

The remainder of the paper is as follows. Motivating our approach, the following section reviews the existing direct evidence on interest rates in China. We then introduce and calibrate a simple storage model to infer interest rates from monthly grain price changes. We describe the data in section 3. Our empirical results on comparative interest rates and capital market integration are given in section 4, which also discusses the influence of a number of factors on the results. We return to the question of why capital market performance, in light of our results, may have led to the income divergence between Northwest Europe and China in the concluding section 5.

3.2 The Grain Price Approach to Capital Markets

3.2.1 Early modern interest rates in China: what do we know

There are numerous but scattered interest rates that can be found for China. These sources provide support for the notion that the riskiness of the loan affected the reported interest rates charged, and also that credit was used regularly by farmers to purchase fertilizer or consumption goods (Pan 1996, Huang 1990). We know that entrepreneurs invested in large commercial ventures (Zelin 2006), and that merchants involved in long-distance trade in grain acted as intermediaries between farmers and brokers in physically carrying the grain to market. Most of the long-distance trade in China consisted of grain and textiles, and merchants were able to secure loans from domestic banks at just 10% per year in some places prior to the 19th century (Zhang 1996, p. 127). Recorded information about rates for more rural areas tends to be much more sparse and limited. Anecdotally, Qing official Chen Hongmou claimed that private loans taken in the spring for grain and repaid in the fall had interest of 30-40% (Rowe 2001, p. 285)[7] . Another Qing contemporary, Wei Jurui, observed that peasants borrowing 20-30 taels were required to pay as much as 200-300 taels at the end of a year (cited in Zhang 1996, pp. 102-3), an example that suggests how interest rates might become worthy of official record once they reached especially high levels.

Although direct interest rates can be useful, the main concern is the limited and possibly distorting information contained in them because of selection biases. First, many available sources are for the late 19th century, with much fewer observations available for the 18th century[8] . Second, the spread of the rates that are available tends to be fairly large, reflecting the fact that the terms of loans are highly variable and not specifically observed[9] . In addition, the relative riskiness of the borrower and the relationship between the borrower and lender is often unknown to an outside observer, but likely would have been known to the lender and therefore incorporated into the rate on the loan. Therefore, from these scattered sources or records that have survived we cannot learn much about the mean or the overall distribution of the rates. Furthermore, the rates may be subject to potentially serious biases resulting from selection and unobserved idiosyncratic factors. Given that,

[7] The Qing dynasty was in place between the years 1644 and 1911.

[8] Lieu (1937) and Chao (1977) cite interest rates in the silk and cotton industries in the Yangzi Delta during the 20th century; see also Shiroyama (2004). Dyke (2011) cites interest rates concerning traders in Canton. Interest rates for areas outside of major urban trading centers can also be found. Pomeranz (1993) studies interest rates from Shandong province, while Li and van Zanden (2013) report figures for the Lower Yangzi area. In 1890, rates on short-term loans in the cotton industry reportedly varied from 6 to 14.6%. Rates on long-term loans in Shanghai were around 10.5%. In the Canton trade, short-term loans in the 1880s averaged between 12 and 15%, while government loans in the 1910 period ranged between 5.3 and 7%. See also the Discussion in subsection 4.1 below.

[9] Although the Qing state prohibited high interest rates of above 3% per month and total interest that exceeded the loan, officials were unable to enforce the statute (Isett 2006, pp. 362-3).

it would be challenging to attempt to conduct a comparative study based on available transactions of interest rates from China and Britain.

There are other reasons why one needs to use caution in assuming the rates are representative. Most importantly, if China had had extremely high interest rates it would have had to be a highly capital-strapped economy. Pomeranz (2000), however, largely dismisses the capital market hypothesis by noting that capital surplus was unlikely to have been a constraint given that China had a similar fraction of high-status individuals in its population as England, and that the savings rate, even for low-income farmers, was substantial (pp. 178-188). In addition, not only were groups of individuals able to amass large sums of capital for trade or for joint projects (Zelin 2006), these groups did not seem to be extraordinarily rare. To the contrary, not only did family lineages mobilize capital but also groups of individuals who were not blood relatives adopted the social and communal organizations set up by family lineages to maintain cooperation in the business shareholding unit (Faure 1995, Chung 2010).

In light of these concerns we use a storage model and within(harvest year grain price variation to comparatively study capital markets. This allows us to address many factors that induce biases when using observed interest rates. One might be concerned that by focusing on borrowing and lending in agricultural markets we could miss some part of the overall capital market. Three observations reduce our concerns that this is the case. First, while not all grain entered the market for intertemporal trades, agriculture was by far the largest part of China's economy for the period examined, and it remained an important sector in Britain, especially in the earlier part of our sample. Second, not only were grain producers connected to the market through merchants, but merchants also arbitraged across goods, trading grain for non-agricultural products. Although we are focusing on grain prices, general equilibrium effects mean we are also capturing aspects of the economy at large. Finally, below we examine whether grain price variation is informative for the performance of early capital market at large in an instance where this performance is known: the case of 19th century U.S. capital markets. As we will see, the grain price approach captures several salient features of capital market performance.

3.2.2 Theoretical framework

What would a grain storage model imply about the rates of interest in the economy? Consider a merchant living in region i at time t who can buy Q_{it} units of grain from a farmer at price P_{it}. The merchant can store the grain for one period and sell it at time t at a price P_{it+1}. Instead of buying the grain, the merchant can also invest the costs of buying the grain ($P_{it}Q_{it}$) in a risk-free asset and receive $(1 + \rho_{it})$ times $P_{it}Q_{it}$ at time $t + 1$, where ρ_{it} is the rate of return on a risk-free asset. The merchant and farmer would contract on an agreement that specifies the merchant's purchase price from the farmer (P_{it}) as well as the price at which the farmer buys back the grain from the merchant,F^j_{it+1}, where j denotes the particular transaction.

At what price F^j_{it+1} will the merchant store the grain? This depends on the costs and benefits of grain storage. We distinguish three types of costs. First, there is the opportunity cost related to the risk-free rate, which captures the fact that if the merchant does not buy grain from the farmer he has an income of no less than $(1+\rho_{it})P_{it}Q_{it}$ at time $t+1$, whereas if he stores the grain for one period, then no interest is earned. Second, when the merchant stores the grain the potential income is tied up in the granary and subject to risk. In particular, by storing grain the merchant faces the risk that the grain market between$t$ and $t + 1$ does not perform as expected. We denote the interest rate inclusive of risk factors by r^j_{it}, where $r^j_{it} \geq \rho_{it}$. Third, grain does not store perfectly but is subject to spoilage (mold, mice, etc.). Per-unit storage costs are denoted as cit. The benefit of storage is the value of the marginal unit of grain storage, which is usually referred to as convenience yield[10] . We denote the convenience yield by b_{it}.

Givenr^j_{it} , c_{it}, and b_{it} as well as the current price P_{it}, for the merchant to be indifferent between storing and the alternative investment, the price F^j_{it+1} in the contract between merchant and farmer would have to be

$$F^j_{it+1} = P_{it}(1 + r^j_{it} + c_{it}) - b_{it} \tag{3.1}$$

or, in other words the price specified in the contract,F^j_{it+1}, has to be such that risk-inclusive interest

[10] The convenience yield exists because positive grain inventories may allow meeting unexpected demand, for example.

and storage costs net of the convenience yield are covered.

To apply this approach empirically we make a number of assumptions. First, we do not observe the transaction-specific risk for each contract; consequently, the superscript j is dropped and it is assumed that we capture the average level of risk, r_{it} (with $r_{it} \geq \rho_{it}$). Second, since we do not observe the price F^j_{it+1}in the contract we assume that it is equal to the spot price of grain in period $t+1$, that is $F^j_{it+1} = P_{it+1}$[11] . Finally, we do not observe the convenience yield; in most applications, b_{it} is inferred from an asset-pricing equation with data on forward price, expected spot price, storage costs, and the riskless interest rate. Here, we set b_{it} equal to zero and assess the role of the convenience yield for the results by building on the evidence that convenience yields are inversely related to inventory levels. While we do not observe inventories, in section 4.2 we employ information on the level and the volatility of regional grain prices to identify periods in which inventories were likely to be high and, correspondingly, convenience yields low, and contrast these results with our main findings.

Under these assumptions equation (3.1) can be rewritten as

$$\hat{p}_{it} \equiv (P_{it+1} - P_{it})/P_{it} = r_{it} + c_{it} \tag{3.2}$$

Equation (3.2) shows that in a storage equilibrium the rate of grain price change is equal to the risk-inclusive interest rate r_{it} plus grain-specific factors cit. We will refer to $\hat{p}_{it}$ as the carry cost of grain.

To characterize the relationship between grain storage and interest rates we employ a standard model of commodity storage along the lines of Williams and Wright (1991). The equilibrium storage and pricing behavior of our model is shown in Figure 3.1. Beginning with the first price (solid line) we see that upon arrival of the new grain from the harvest, the price falls, reaching a first minimum in period 8. This is the beginning of the new harvest year. The price rises until period 18 when the maximum is reached, and the cycle repeats itself.

[11] With a positive risk premium, the forward price will be lower than the expected future spot price. We assume that there is no difference in risk, as well as tolerance of risk, in the inter-temporal trade of grain in China and Britain. Regarding temporal variation, see the analysis of time-varying convenience yields in section 4.2.

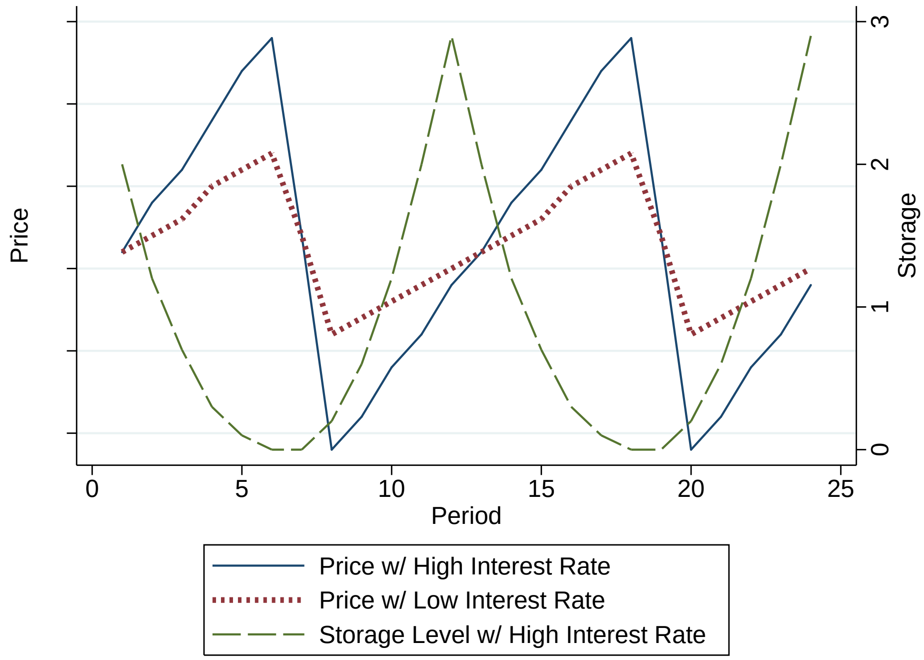


Figure 3.1: Interest rate and price in a model of storage

Between period 8 and period 12, storage level and price rise together, while after period 12 the price increase is accompanied by declining storage. The last unit of stored grain is withdrawn just before the new harvest arrives. The new grain supply causes a fall in price; in this way, storage has the consequence of dampening price fluctuations.

Figure 3.1 shows a second price series, denoted with a dotted line. Notice that it has lower amplitude and is flatter than our earlier price series. This second equilibrium price is computed for a lower interest rate than in the first case, with all else equal. The key finding is that the steeper the increase of the price within the harvest year, the higher is the interest rate that agents face. This is the basis for the approach of inferring interest rates from grain prices. In principle, the approach can be applied to other storable commodities. What makes grain particularly attractive in this context is that the see-saw price pattern of Figure 3.1 is more discernable for grain than for other commodities given that grain is typically harvested only once per year; furthermore, grain price data (but not prices of other commodities) is available regionally for our sample at a high-frequency level.

3.2.3 Capital market performance: interest rates and market integration

This section describes our implementation of equation (3.2) to estimate interest rates. We also discuss why the integration of capital markets, rather than interest rate levels, is our preferred measure of capital market performance.

Equation (3.2) implies that differences in interest rates between two economies are equal to differences in their carry costs only if storage costs are the same. Therefore, we adopt two approaches to comparing interest rates. The first is to make certain assumptions on average storage costs in China and Britain, and the second is to model storage costs in terms of observables.

First, if storage costs over all regions and years in China are no different from those in Britain, equation (3.2) implies that the difference between the average Chinese carry costs, $\hat{p}_{it}$, over all regions and years minus the average British carry costs is equal to the difference in their interest rates. Thus, as our first comparison of interest rate levels, we will compare average carry costs across countries while assuming that storage costs are the same on average.

Second, we account for differences in storage costs using climatic data. It is well known that climate greatly influences storage costs. This is true particularly for the extent of rainfall and wetness, which, for example, influences the presence of mold and pests. Furthermore, interregional trade can affect within harvest-year price fluctuations and therefore measured interest rates[12] . Therefore, we also adjust for differential access to trade that regions within each country would have had.

To capture the roles of climate and interregional trade we adopt the following regression approach[13] :

$$c_{it} = \beta_0 + \beta_1 climate_{it} + \beta_2 trade_i + u_{it} \tag{3.3}$$

where u_{it} is assumed to be a well-behaved mean-zero error term. $Climate_{it}$ is a measure of wetness

[12] Shiue (2002) presents evidence from 18th century China.

[13] Extending this approach below we also account for the effect of multiple harvests per year.

in region i at time t, as detailed in the appendix. Since the strongest determinant of low cost transportation prior to steam technology was whether or not shipping was feasible by water, our measure of $trade_{it}$ is waterway access to rivers, canals, and the coast.

Using equations (3.2) and (3.3) the influence of interregional trade, storage, and other weather-related costs can be purged from carry costs using a regression approach:

$$r_{it} = \hat{p}_{it} - c_{it} = \hat{p}_{it} - \beta_0 - \beta_1 climate_{it} - \beta_2 trade_i - u_{it}, \forall i, t \quad (3.4)$$

Estimating equation (3.4) yields our grain interest rates.

To see the advantage of evaluating capital market performance by examining market integration instead of interest rate levels, suppose that instead of being mean-zero, uit contains systematic but unobserved components, denoted by xit,

$$u_{it} = x_{it} + e_{it} \quad (3.5)$$

and e_{it} is a well-behaved mean-zero error term. To the extent that over some period x_{it} does not change, $x_{it} = x_i, \forall i, t$, the correlation in the adjusted carry costs (equation 3.4) of two regions i and i' is equal to the correlation in their interest rates because time-invariant factors drop out[14] . Plausibly, there are many factors that differ across regions but do not change differentially over (parts of the) sample period. An example is storage technologies: as long as storage technologies do not change differentially over some period, the correlation of the adjusted carry costs in two regions provides valid information on their capital market integration. In contrast, interest rate level-comparisons are not identified under these conditions.

We are not the first to shed light on historical capital markets by examining the behavior of grain prices (Working 1933, 1949, Kaldor 1939, McCloskey and Nash 1984, Taub 1987, Pomeranz 1993, Brunt and Cannon 1999, 2009, Clark 2001, and Shiue 2002). While we find the approach appealing, one might be concerned about how much of capital market development can be captured through this approach. Given that we are resorting to the method in the absence of consistent

[14] It is sufficient that there is no differential change in x_{it}.

interest rates, what can we say about the accuracy of the approach in the context of economies in which markets may not have been perfect[15] ? Furthermore, even if one accepts that high-frequency price changes of stored commodities provide information on interest rates, to what extent does intertemporal trade in grain provide information on the capital market at large? We contend that while the model may be misspecified it can still provide new insights, and furthermore we provide to the best of our knowledge the first comparison between grain price interest rates and bank interest rates for any economy: in our case, for the early 19th century U.S., a context in which both grain prices and bank rates are to some degree available. In addition to a new form of validation of the grain price approach to studying capital markets, this yields information about both the potential and limitations of this approach, arguably important for studying capital markets in historical and contemporary economies where consistent interest rates are unavailable.

As we will see in the next section, the grain price approach captures some of the major features of early U.S. capital markets.

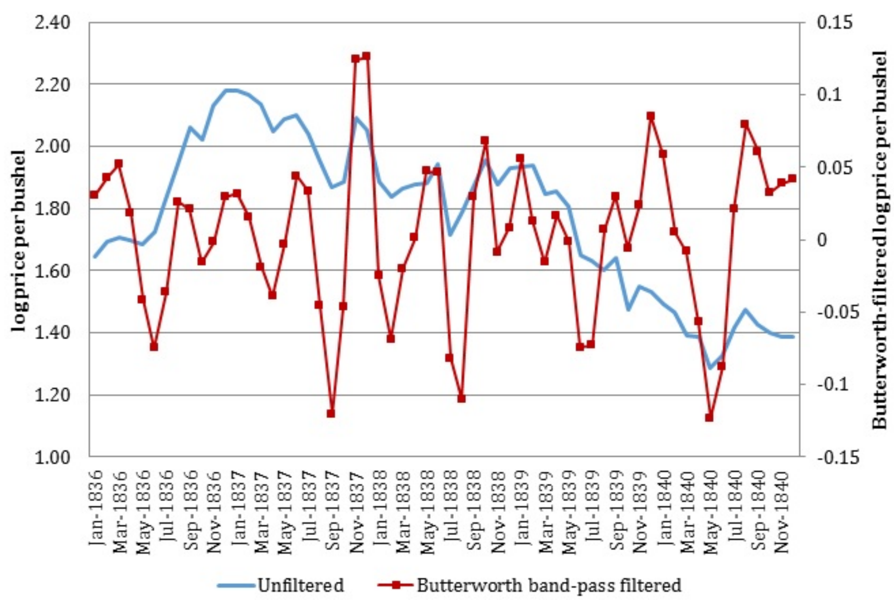
3.2.4 The grain price approach to capital markets: A calibration to U.S. data

This section evaluates the predictions of the storage model we have laid out above by comparing capital market performance based on grain price data according to the storage model with actual bank interest rates[16] . Using wheat prices for five U.S. cities (Indianapolis, New Orleans, New York, Philadelphia, and Richmond), we ask whether the grain price approach captures key aspects of the early 19th century U.S. capital market[17] . If it does, there is reason to believe that our grain price approach is also informative for comparing capital markets in Britain and China.

Recall that our grain price approach utilizes the within-harvest year price gradient during periods of storage (see Figure 3.1). The (log) price of a bushel of wheat in Philadelphia for the years 1836 to 1840 is shown in Figure 3.2. In addition to the see-saw pattern of the harvest cycle,

[15] A critique of the approach along these lines is Komlos and Landes (1991).
[16] The bank interest rates are shown in the Appendix, Table B.1. The Richmond and Indianapolis figures are for entire states, Virginia and Indianapolis, respectively, implying a varying degree of spatial aggregation. See section 4.2 on the influence of region size for the results.
[17] The U.S. grain price data is from Jacks (2005, 2006).

the Philadelphia wheat price seems to also be affected by shocks and stochastic trends. Therefore, in addition to the raw price series we employ filtered grain price series, where the filters are designed to bring out the cyclical, twelve-month harvest pattern and suppress other influences. We perform a grid search over time-series filters (and their parameters) to choose the filtering technique that yields the closest possible match between the capital market performance based on the grain price approach and that implied by the observed bank interest rates. For this analysis we have considered all major time series filtering techniques (see Canova 2007, Ch. 3 for an introduction). The results for several key filters are reported in Table 3.1[18] .



Sources: Jacks (2006) and own calculations.

Figure 3.2: Filtered vs. unfiltered Philadelphia wheat prices, 1836-40

[18] We have also considered exponential, Holt-Winters, Kalman and Hodrick-Prescott filters, among others, finding that they do not perform as well as those shown in Table 3.1.

Table 3.1: Capital market performance in 19th century United States using bank interest rates vs. grain price rates

	Bank interest rates	Grain price interest rates				
		Grain price	Moving average	Baxter-King	Christiano-Fitzgerald	Butterworth
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Interest rates						
(i) Mean	0.058	0.074	0.269	0.197	0.127	0.029
	(0.018)	(0.507)	(1.802)	(1.113)	(0.337)	(0.241)
(ii) Mean of t-statistic of OLS on bank rate		1.63	1.05	1.98	1.91	2.17
		(1.40)	(1.52)	(0.65)	(0.46)	(0.57)
Panel B: Capital market integration						
Bilateral interest rate correlations						
(iii) Mean	0.25	0.73	0.80	0.72	0.54	0.46
	(0.33)	(0.16)	(0.09)	(0.15)	(0.28)	(0.30)
(iv)Correlation w/ capital market integration pattern based on (1)		0.72	0.61	0.75	0.69	0.72

Notes: Bank interest rates in column 1 are from Bodenhorn and Rokoff (1992); Grain price is one-month change of log grain price in August, September, October, November, and December. Moving average using 2 lags, the month itself, and 2 leads; Baxter King, filters below 4 months, above 12 months, moving average of order 10 Christiano and Fitzgerald, filters below 3 months, above 12 months; Butterworth, filters below 3 months (order 8), and above 12 months (order 2). Standard deviation in parentheses.

Column 1 of Table 3.1 shows several measures of 19th century U.S. capital market performance based on Bodenhorn and Rokoff's (1992) bank interest rates. Panel A is based on the interest rates themselves. Results in Panel B are based on characteristics of the integration of the U.S. 19th century capital market. We begin in the upper left corner of Table 3.1, which shows that the average of the bank interest rates in the five cities between 1815 and 1855 (as shown in Table B.1) was 5.8%, with a standard deviation of 0.018. In the lower part of column 1 of the table, we report results on bilateral interest rate correlations, a standard measure of capital market integration. For this we compute the bilateral correlation between any city pair (with n = 5, there are n(n-1)/2 = 10 bilateral correlations). The average bilateral correlation based on the bank interest rates in these cities is equal to 0.25 (row (iii), column 1).

We are interested in whether the grain price approach to capital markets succeeds in capturing major features of the U.S. capital market. Columns 2 to 6 of Table 3.1 report results for five alternative grain price models. For each of the five models the gradient of the within-harvest year price cycle is computed as the average price change in the months of August through December. Given that for these months we typically see month-to-month price increases, these months are taken to be the storage periods in the analysis[19] .

Employing the grain price approach with simply log price, we compute a mean interest rate of 7.4% (row (i), column 2). This is not too different from what we find using bank interest rates (5.8%, column 1). Furthermore, for the two most important markets, New York and Philadelphia, the grain price approach comes even closer to the bank interest rates (6.1% versus 5.3%, respectively). The grain price approach captures the average bank rate quite well, but the standard deviation is much larger than that of the bank interest rates. One reason for this may be that strong price shocks are picked up as very high or low interest rates (see Figure 3.2).

Next, we examine the degree to which the grain price approach matches the time series variation of bank interest rates. For example, Philadelphia bank interest rates were 6.5%, 3.4%,

[19] Figure 3.1 indicates that the interest rate affects price gradients in all periods between low and high price. The focus on periods with consistent price increases despite shocks and stochastic trends improves the performance of the grain price approach.

and 6.1% in the years 1833, 1834, and 1835, respectively (Table B.1). Does the grain price approach pick up these types of swings in interest rates? To find out we run, city-by-city, simple OLS regressions of the grain price interest rate on the bank interest rate[20] . There is generally a positive correlation between bank and grain price rates in the time series. We report the average t-statistic of this regression across five cities in row (ii) of Table 3.1. Employing the log wheat price, the average t-statistic is equal to 1.6. This is based on a relatively small number of observations, the years between 1815 and 1855 for which we have bank interest rates for each of the cities.

The main reason for preferring market integration as the measure of capital market performance is time invariant determinants of price changes. In Panel B we compare the grain price approach to the bank interest data in this respect. Employing the log wheat price the grain price approach yields interest rates that across all n(n-1)/2 = 10 city pairs have an average correlation of 0.73 (row (iii)), which is higher than the average bilateral correlation of bank interest rates (see row (iii), column 1).

Arguably the most important of the four criteria reported in Table 3.1 is given in row (iv). Here we ask whether the grain price approach accurately reflects differences in the strength of capital market integration. Does the grain price approach match the relatively high capital market integration between New York and Philadelphia, for example, when this is compared to New York's lower capital market integration with New Orleans? To see this, we take the 10 bilateral interest rate correlations implied by the bank interest rates as well as the 10 bilateral interest rate correlations based on the grain prices, and evaluate how strongly the two sets of capital market integration measures are correlated with each other. Table 3.1 reports a correlation of 0.72 when grain interest rates are based on the log grain price (column 2, row (iv)).

The remaining columns of Table 3.1 report results for the same criteria of capital market performance using alternatively filtered grain prices. These are a moving average (column 3) as well as the filters proposed by Baxter and King (1999), Christiano and Fitzgerald (2003), and Butterworth

[20] To do so we have linearly interpolated the small number of missing values for New Orleans and Indianapolis; see Table B.1.

(1930) (columns 4, 5, and 6, respectively). The results in column 6 employ the Butterworth filter as a bandpass filter which suppresses stochastic cycles both at high and low frequencies to emphasize the harvest cycle in grain prices[21] .

We see that except for the Butterworth-filtered figure the filtered interest rates tend to be higher than the bank rates (Table 3.1, row (i)). The time-series movements of the interest rates are best described by the grain rates based on the Butterworth filter, where the regression on the observed bank rates city-by-city yields a t-statistic of about 2.2 (Table 3.1, row (ii), column 6).

Turning to the analysis of capital market integration in Panel B of Table 3.1, we find that just as in the case of the raw grain prices of column 2, interest rates based on filtered grain price series imply a higher level of capital market integration than implied by the bank interest rates (row (iii))[22] . Finally, we find that the correlation between the capital market integration implied by the bank interest rates and that based on filtered grain interest rates is between 0.6 and 0.75 (row (iv)). The highest figures are obtained for the Baxter and King filter, followed by the Butterworth filter. The fact that these models, as well as the raw grain prices of column 2, yield correlations of about 0.75 indicates that differences in capital market integration across regions are picked up well by the grain price approach to capital markets. To keep the number of reported results manageable we will focus below on the raw grain prices as well as the Butterworth filter (columns 2 and 6). Among the filtered series the Butterworth filtered series has the best all-around performance: not only does it exhibit a high correlation with observed capital market integration (row (iv)) and matches the time series (row (ii)) but it also predicts a variability of capital market integration that is close to that implied by the bank rates (see the standard deviation of the bilateral interest correlations, row (iii)).

Overall this analysis has shown that the grain price approach captures key features of the performance of the early U.S. capital market. It is therefore reasonable to assume that within-

[21] See the notes of Table 3.1 for information on the parameters chosen for each filter; we set the parameters so as to match the capital market performance implied by the observed bank rates as closely as possible.

[22] This may be in part due to weather shocks affecting regional grain prices; in the comparison of China and Britain below this will be addressed by employing historical weather data.

harvest year grain price changes also contain information on capital markets in Britain and China. Furthermore, given that the correlation between regional market integration based on bank interest rates and grain interest rates is about 0.75, it must be the case that capital markets in agriculture are quite closely related to other, non-agricultural capital markets.

Having validated the approach, the following section introduces our data on Britain and China.

3.3 Data

The source of the grain prices for Britain is the British government's Corn Returns, which were printed in the London Gazette newspaper. The Corn Returns were created to provide a reference market price of domestically-produced wheat that would inform taxation and the regulation of international trade of wheat. Our sample consists of the average monthly price of wheat for the period 1770 to 1860, in up to 52 counties (see Appendix Table B.2 for a list). The sample of British prices consists of around 48,000 monthly grain price observations, which are quoted in shillings per bushel.

The Chinese grain prices are administrative records from the Qing grain price recording system, which covered each of the 28 provinces from 1662 to 1911. We focus on prices for the years 1770 to 1860 in up to 252 regions (prefectures) located in 20 provinces (see Appendix Table B.3 for a list of prefectural markets and provinces). We focus on the crops with the most wide-spread coverage in China: rice in two different qualities (first-grade [shangmi] and second-grade [zhongmi]), wheat (xiaomai), and millet (sumi) (see Table B.4 for summary statistics). Wheat accounts for one-third of the observations in China, as climatic conditions in a large part of China are conducive to growing wheat. There are more than 318,000 monthly grain price observations, which are quoted in tael per shi.

Historical weather data for China and Britain used to account for climatic influences on prices are constructed from State Meteorological Society (1981) and Pauling et al. (2006), respectively. The data for China comes from 120 weather stations, which allows drawing contour maps with climate ranging from 1 (a lot of rainfall leading to very wet conditions) to 5 (little rainfall leading to very dry conditions), with 3 being the normal level of rainfall in that region. The climate in each prefecture is equal to that at the geographically closest weather station. Figure B.1 summarizes this data on climate over time across the Chinese prefectures. We have employed the precipitation reconstructions of Pauling et al. (2006) to calculate five climate categories in Britain analogous to the Chinese data; see Figure B.2.

The influence of inter-regional trade on grain price behavior is accounted for by employing information on the ease of waterway transport: regions with access to navigable rivers, canals, or coastline had substantially lower transport costs and more trade[23] . Finally, we address differences in cropping patterns in China, most importantly the possibility of having multiple harvests per year in certain Southern areas.

The Appendix provides more details on the sources and construction of these data. In some key dimensions there existed similar patterns in Britain and China. First, the variability of (log) grain prices in the two countries is very similar, with coefficients of variation of about 0.35 in both areas (see Table B.4). Second, the variability of the weather in a given region is similar in Britain and China as well, with a standard deviation of wetness of 1.16 in Britain, compared to 0.98 in China.

While it was our goal to ensure the highest possible level of comparability of the British and Chinese data, some differences remain that we note here. One difference is the British grain price information tends to be highly complete for a given year; sample size variations tend to be due to political considerations and macro policies such as the Corn Laws (1815 to 1846). In contrast, the Chinese data is less complete, but it is also less subject to changes in the sample composition for systematic reasons. Another difference is that the Chinese administrative region (the prefecture) corresponding to the price reports is typically larger than the British administrative region. We conduct a number of robustness checks below that confirm that this and other differences do not determine our main findings.

[23] Our analysis abstracts from overland transport; on England's turnpikes, see Bogart (2005).

We now turn to the empirical results.

3.4 Empirical Results

3.4.1 Preliminaries: carry costs and interest rates

We begin by computing the carry costs of grain, $\hat{p}_{it}$, which is equal to the risk-inclusive interest rate plus the storage cost (equation 3.2). As in the analysis of the U.S. capital market we focus on price changes during storage months, as the price gradients are more informative compared to periods of flat or falling prices[24] . Furthermore, we give greater weight in the analysis to years, regions, and grains for which more high-frequency changes are recorded because these data tend to be of higher quality[25] .

The results are shown in Table 3.2, column 1. The mean monthly carry cost for British counties based on the log wheat price series is about 0.85%, or 10.2% per year[26] . In contrast, across all Chinese regions and based on all grains, the mean is about 13.7% annually. If we assume that the broadly defined storage costs in China and Britain were the same on average across all years and all regions, then British interest rates were substantially lower than China's during the sample period.

[24] Storage months are defined as months when carry costs are typically 5% or more per year; we also show that a broader criterion, all months of price increases, yields the same qualitative results.

[25] Specifically, the weight is the share of non-zero month-to-month changes in a given year, so that if for one year 10 monthly changes are non-zero and in another only 6, for example, the observations receive weights of 10/12 and 6/12, respectively. We also focus on the central 95% carry costs for each grain by discarding values below percentile 2.5 and above percentile 97.5.

[26] We compute annual rates in this paper as 12 times the monthly rate.

Table 3.2: Grain interest rates: the influence of weather, trade, and harvest patterns

		Carry costs			Interest rate	Interest rate broad
Adjustments		None	Climate	Climate & Waterway	Climate & Waterway & Harvest Patterns	Climate & Waterway & Harvest Patterns
		(1)	(2)	(3)	(4)	(5)
Panel A. Unfiltered data						
	Mean in %	10.248	5.271	5.348	5.348	5.348
Britain		(30.924)	(30.804)	(30.795)	(30.795)	(30.795)
	n	4,074	4,074	4,074	4,074	4,074
	Mean in %	13.732	9.374	9.440	9.200	6.258
China		(29.350)	(29.040)	(29.088)	(29.077)	(24.544)
	n	15,152	15,152	15,152	15,152	18,586
Panel B. Bandpass-filtered data						
	Mean in %	8.209	4.891	5.415	5.415	3.204
Britain		(26.868)	(26.808)	(26.772)	(26.772)	(15.684)
	n	4,102	4,102	4,102	4,102	4,115
	Mean in %	9.612	7.616	7.482	7.501	4.023
China		(26.064)	(25.800)	(25.934)	(25.814)	(15.946)
	n	13,403	13,403	13,403	13,403	19,736

Notes: Table shows statistics for the carry costs of grain with various adjustments in columns (1) to (3); statistics for the preferred grain interest rates are shown in column (4). "Interest rate broad" is calculated using grain price gradient in all months that typically exhibit price increases. Standard deviation given in parentheses.

Results based on bandpass filtered price series using the Butterworth filter are shown in the lower part of column 1. These carry costs are generally lower than for those based on the unfiltered time series, consistent with the idea that time series filtering succeeds in removing stochastic trends. According to the filtered series, British carry costs average around 8.2% per year while Chinese carry costs are around 9.6%.

Additional analysis for China shows that the difference in carry costs by grain is small, which is plausible because storage costs are unlikely to vary greatly across grains. We also find that the British advantage of lower carry costs holds not only across all grains but also specifically for wheat. These results are shown in Table B.5.

3.4.1.1 Grain interest rates

This section calculates our regional interest rates by purging from the carry costs the influences of weather shocks, inter-regional trade, and harvest differences, as described in section 2.3 above. The analysis is performed separately for the (log) price series and the Butterworth-filtered series. Results are shown in columns 2 to 5 of Table 3.2, Panels A and B, respectively.

In the first step we consider the influence of climate by adjusting for differences in rainfall. In line with other evidence, our results indicate that climate has a substantial influence on carry costs. Our climate-adjusted carry costs, which would hold had the climate been the best possible in every year, are around 4 to 5 percentage points lower than before (column 2, Panel A). Because Britain and China are similarly affected, however, adjusting for climate does not change the ranking between Britain and China.

Next, we turn to the additional influences of interregional trade (column 3). In comparison to climate, interregional trade turns out to matter less. Our results imply that if no region had waterway access, carry costs would be higher by only 0.07 percentage points in either Britain or China (column 3, Panel A). Adjusting for multiple harvests in China has a relatively small effect as well (compare columns 3 and 4, Panel A).

Column 4 presents our grain price interest rates. Annually for the years 1770 to 1860, we obtain about 15,000 rates for Chinese prefectures and about 4,000 rates for British counties. The mean for Britain in Panel A is about 5.3%, compared to a mean for China of about 9.2%. Adjusting the bandpass filtered carry costs for climate, interregional trade, and harvest differences yields a broadly similar picture (Panel B). In particular, adjusting for climate differences has a larger effect than inter-regional trade and harvest patterns. The average interest rate for Britain now is about 5.4%, compared to 7.5% for China. Whether we remove stochastic trends by filtering the grain prices or not, the typical interest rate for Britain was substantially lower than in China according to our analysis, with an order of magnitude of around 30 to 40%.

In addition, we note that even when the analysis is based on all months that typically see price increases (instead of a smaller set of storage months), British interest rates are found to be lower than China's (see column 5). This does not substantially change when we adjust carry costs for climate, inter-regional trade, and harvest patterns in one step instead of sequentially (not reported). Neither does the finding of lower British interest rates disappear when we account for the unobserved convenience yields in a number of different ways[27] .

If China's interest rates are higher on average than Britain's, how about interest rates in China's more highly developed areas, such as Jiangsu province at the mouth of the Yangzi river, or Guangdong province in the South? Our average unfiltered interest rate for Jiangsu and Guangdong provinces is 8.2%, compared to 9.3% in China outside of Jiangsu and Guangdong provinces. While these figures confirm what is known about comparative development within China, the implied heterogeneity is not large enough to bring about parity of interest rates in Britain and China's more developed areas.

[27] For example, we have computed interest rates during years of low volatility, with volatility of year t measured by the average of the variation in year$t-1$, t, and $t+1$ prices, for each month. Convenience yields will tend to be low at times of low volatility, and indeed we estimate lower rates with the lower 75 percent of times in terms of volatility. At the same time, the convenience yield adjustment does not change the finding that British rates are lower than China's (3.9% versus 6.2%, both for wheat, not filtered). Section 4.2 below reports additional results on the role of convenience yields.

3.4.1.2 Discussion

Employing a standard commodity storage model we estimate typical interest rates for China between 7.5 and 9.2%, with a midpoint of about 8.35% (Table 3.2, column 4). How does this figure compare to other estimates? For the Yangzi Delta, Li and van Zanden's (2013) report figures for the 18th and early 19th century which imply annual rates between roughly 5 to 25%. For the late 19th century, annual interest rates faced by trading firms and cotton factories in Canton and Shanghai ranged between 6 and 15% (Shiroyama 2004, Dyke 2011). The midpoint of these estimates is about 13%. This is higher than our estimate of about 8.35%, and a natural question is what might explain the difference between the two sets of estimates.

First, all interest rates include the risk associated with that particular transaction. In the case of the grain interest rates the risk concerns transactions within harvest years rather than the risk involved in the harvest for any particular year, which may in turn be attributed to climatic variations. Thus, our relatively low interest rates may be consistent with the prevailing idea that "agricultural risk" is high because, in fact, these are two different concepts. Agricultural risk typically refers to the risk of the failure of the harvest, not the risk of asset movements once the harvest has arrived.

Our analysis captures the average riskiness of the grain asset, and this risk is relatively low not only because the market is quite thick—and buyers and sellers are relatively easy to find—but also because the risk of holding grain is low given it can be consumed. In comparison, the risk of a Canton trading company is likely to be substantially higher[28] . Higher risk will be naturally compensated for by a higher rate of interest.

The second issue is selection. Our analysis is based on market prices for grain in a given region, implying that the grain interest rates reflect the activity of all farmers, merchants, government officials, and others that were buying and selling grain in a given prefecture and year. While not all of China's grain supply entered the market (perhaps a quarter of the total), enough of it did that not a single seller or buyer, including the government, could monopolize the market. Grain

[28] The enforcement (credit) risk could also be different.

interest rates reflect activities from a far larger set of the population than most other interest rates that we know of. To the extent that our rates differ from historically available rates, and tend to be lower than memorialized interest rates, this is not surprising. Interest rates charged by pawnshops such as those noted by Li and van Zanden (2013) were, given the low credit rating of the borrower, notoriously high, and officially memorialized interest rates would be selected because a high rate would have a higher chance to be memorialized in the first place.

Third, while it is useful to compare the grain interest rates to other rates, our primary goal is to compare capital markets in China and Britain. So far we have shown that based on the same methods and assets, Britain had interest rates that were 30 to 40 percent lower than China's. While one might consider this figure to be too small (or too large) we believe that this evidence is important as it can be argued that a reliable set of comparable interest rates did not exist in this setting. At the same time, our goal is to compare capital market performance by studying market integration. The reason for this as noted above is that interest rates can differ across regions even with virtually perfect markets, while factors determining interest rate differentials often do not affect the extent of market integration.

3.4.2 Comparison of capital market performance in Britain and China

This section presents our analysis of capital market performance in Britain and China by comparing the extent of regional market integration in the two countries. We begin by contrasting capital markets in Britain with those of China overall before narrowing the analysis down to China's Yangzi Delta, one of China's most developed regions. We then turn to the question of timing by asking whether capital market development was already different by the late 18th century, or only later. The section concludes with examining the influence of a number of factors such as temporal changes (e.g., the British Corn Laws), region size, as well as other issues for our results.

We compare the capital market performance in Britain and China in terms of bilateral correlations between regional interest rates over time. A high level of bilateral correlation indicates that the forces that integrate capital markets in the two regions are strong[29] . Furthermore, because early capital market participants typically had to meet in person to trade, given some cost of moving in geographic space, bilateral correlations will tend to fall with distance.

Bilateral interest rate correlations for each pair of regions in a given country are computed over all years (1770 to 1860) based on the grain interest rates derived above (Table 3.2, column 4). The degree of capital market integration in the two countries is summarized in Figure 3.3. There are six distance bins in steps of one hundred kilometers, from 0-100 kilometers to 500-600 kilometers[30] . For each country and each distance bracket, Figure 3.3 shows the average bilateral interest rate correlation based on both filtered and unfiltered price series.

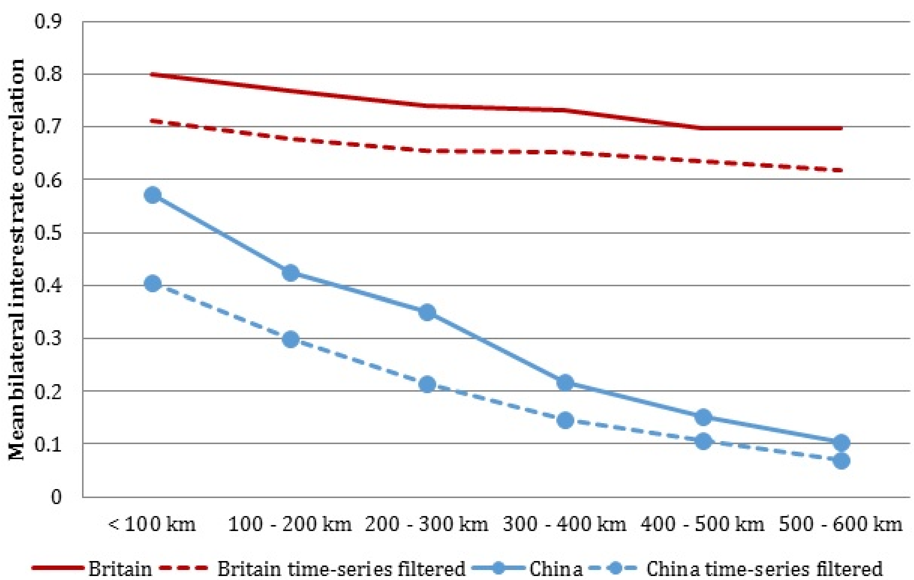


Figure 3.3: Capital market integration in Britain and China, 1770-1860

Notice that the lines for Britain lie well above those for China in Figure 3.3. In particular, the bilateral correlations based on raw (unfiltered) grain prices for distances below 100 kilometers are typically around 0.8 while in China they are less than 0.6. Even more striking is the difference

[29] Instead of bilateral correlations, more sophisticated techniques can be employed to study market integration (see, e.g., Shiue and Keller 2004, Mitchener and Ohnuki 2007). Doing so here does not change our main findings.

[30] The maximum distance between any two British county capitals in our sample is 638 kilometers.

in the decline of capital market integration with distance. In Britain, an increase in distance from 100 to 600 kilometers is associated with a fall in the average bilateral correlation from 0.8 to 0.7; in China over the same distances, the fall is quite a bit larger, from 0.6 to 0.1.

We find somewhat lower correlations when interest rates are based on the filtered grain prices, in line with the idea that filtering removes common shocks. Nonetheless, the comparison between Britain and China yields a very similar finding: bilateral correlations are higher in Britain than in China, especially at greater distances.

A more detailed picture can be drawn with interest correlations based on different types of grain for China (see Tables 3.3 and 3.4). We see that irrespective of the type of grain underlying the interest rate, bilateral correlations fall with distance, which is what we would expect. Distinguishing among the different grains is also informative because millet is grown mostly in Northern China and rice mostly in Central and Southern China, implying that these results shed light on within-China heterogeneity. The results turn out to be not too different across grains. For example, Table 3.4 reports correlations for 300-400 kilometers ranging from 0.12 (millet) to 0.17 (second-grade rice). With a value of 0.13, interest rate correlations based on wheat at this geographic distance are in between these two values. In contrast, wheat interest rate correlations in Britain are around 0.65 for distances between 300 and 400 kilometers (Table 3.4, first column). The highest average interest rate correlation in China is found for distances below 100 kilometers based on first-grade rice, with a value of 0.65 (Table 3.3). This type of rice in our sample is grown mostly in the relatively urban and commercialized central-southern areas of China, where one would expect capital market integration to be relatively high.

In sum, comparing the average interest rate correlations at a given geographic distance provides evidence that Britain's capital market integration was considerably higher than China's at this time. To be sure, the degree of variation in interest rate correlations at a given distance is substantial, as the standard deviations show. While it is possible to observe comparable levels of capital market integration in Britain and China, typical levels are always lower in China than in Britain as a cell-by-cell comparison of the means in Tables 3.3 and 3.4 shows.

Table 3.3: Capital market integration in comparison

Based on log grain price data

	Britain	China			
	Wheat	Wheat	Rice 1st quality	Rice 2nd quality	Millet
0-100km	0.80	0.53	0.65	0.56	0.54
	(0.16)	(0.38)	(1.18)	(0.62)	(0.36)
	[n = 350]	[n = 186]	[n=196]	[n=202]	[n=152]
100-200km	0.77	0.41	0.45	0.40	0.44
	(0.16)	(0.55)	(1.37)	(0.69)	(0.38)
	[n = 788]	[n = 566]	[n=602]	[n=628]	[n=484]
200-300km	0.74	0.30	0.39	0.36	0.35
	(0.17)	(0.43)	(1.43)	(0.72)	(0.45)
	[n = 720]	[n=730]	[n=758]	[n=840]	[n=616]
300-400km	0.73	0.21	0.20	0.22	0.25
	(0.18)	(0.39)	(0.80)	(1.01)	(0.43)
	[n = 476]	[n=786]	[n=802]	[n=902]	[n=684]
400-500km	0.70	0.11	0.20	0.14	0.17
	(0.18)	(0.49)	(2.07)	(0.88)	(0.38)
	[n = 246]	[n = 886]	[n=908]	[n=1,108]	[n=568]
500-600km	0.70	0.07	0.11	0.11	0.12
	(0.19)	(0.48)	(2.04)	(1.22]	(0.27)
	[n = 64]	[n=1,002]	[n=1,018]	(n=1,184)	[n=548]

Notes: Entries are average correlations over period 1770 to 1860. Interest rates as underlying Table 3.2, Panel A, column 4. Standard deviations in parentheses.

There may be no better way of making this comparison than by visually examining the entire distributions of bilateral interest rate correlations. In Figure 3.4 we show those distributions plotted against bilateral geographic distance based on the filtered interest rates. The circles are bilateral interest rate correlations in Britain, while the crosses are observations for China. The British circles fill up the upper part of the figure, indicating high levels of capital market integration for a given distance. The figure also shows the smoothed mean correlation for China (dashed line). The observations for Britain are positioned almost entirely above the dashed line for China. The evidence in Figure 3.4 strongly supports the hypothesis that the degree of integration in British capital markets exceeded that of Chinese capital markets over 1770-1860.

Capital market integration in China's Yangzi delta in comparison

Table 3.4: Capital market integration in comparison II

Based on filtered price data

	Britain	China			
	Wheat	Wheat	Rice 1st quality	Rice 2nd quality	Millet
0-100km	0.71	0.35	0.44	0.51	0.29
	(0.17)	(0.28)	(0.50)	(0.46)	(0.34)
	[n = 350]	[n = 138]	[n=166]	[n=158]	[n=134]
100-200km	0.68	0.26	0.34	0.35	0.24
	(0.18)	(0.30)	(0.56)	(0.54)	(0.35)
	[n = 788]	[n = 424]	[n=500]	[n=494]	[n=390]
200-300km	0.66	0.21	0.23	0.25	0.16
	(0.17)	(0.33)	(0.62)	(0.58)	(0.35)
	[n = 720]	[n=556]	[n=620]	[n=612]	[n=482]
300-400km	0.65	0.13	0.16	0.17	0.12
	(0.16)	(0.31)	(0.73)	(0.56)	(0.34)
	[n = 476]	[n=560]	[n=628]	[n=660]	[n=514]
400-500km	0.63	0.10	0.15	0.10	0.07
	(0.19)	(0.34)	(0.78)	(0.55)	(0.33)
	[n = 246]	[n = 630]	[n=658]	[n=804]	[n=398]
500-600km	0.62	0.07	0.07	0.08	0.03
	(0.23)	(0.34)	(0.75)	(0.62]	(0.29)
	[n = 64]	[n=706]	[n=682]	(n=802)	[n=374]

Notes: Entries are average correlations over period 1770 to 1860. Interest rates as underlying Table 3.2, Panel B, column 4. Standard deviations in parentheses.

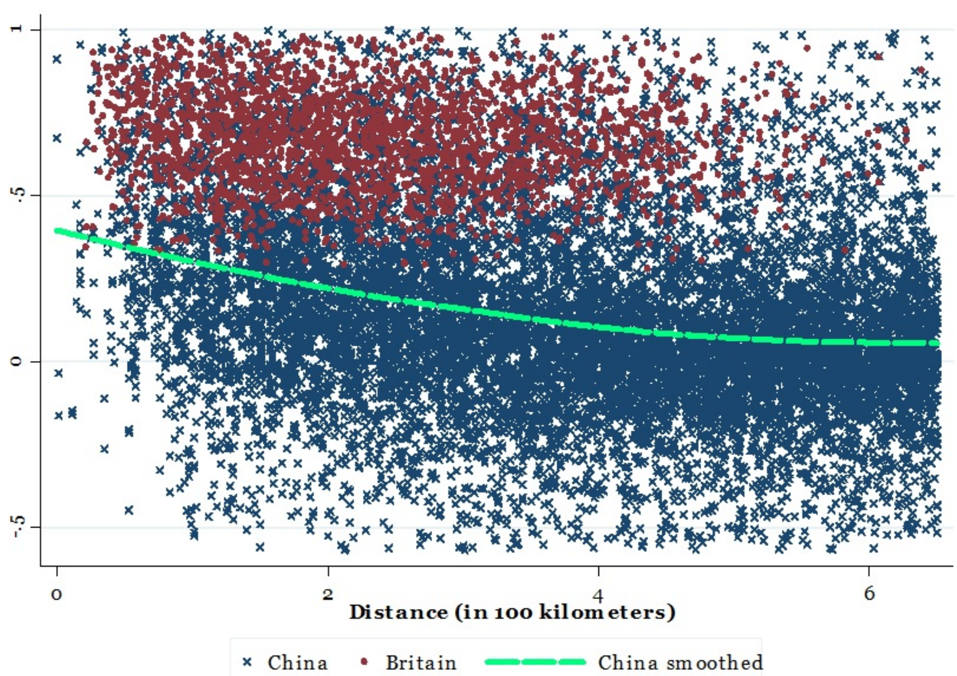


Figure 3.4: Bilateral interest rate correlations versus distance, 1770-1860

Pomeranz (2000) emphasized that a comparison of other parts of the world with China should account for China's large size. To be specific, in the present analysis we do not want to make the mistake of comparing capital markets in the relatively underdeveloped regions of China's south-western Yunnan province with capital markets in Lancashire, where the world's first factory-based textile industry emerged.

In this section we focus on China's Yangzi Delta as an example of a relatively highly developed area[31] . Results are shown in Table 3.5. We find an average interest rate correlation for all grains in China's Yangzi Delta of 0.47 at distances below 100 kilometers, which is higher than at these distances outside of the Delta (0.42, last row). There is also evidence for relatively high capital market integration in the Delta at distances above 100 kilometers (column 2 and 3). Our analysis yields results in line with other evidence that the Yangzi Delta was more developed than other parts of China.

Table 3.5: Capital market performance: the Yangzi Delta and beyond

		Distance		
		0-100km	100-200km	200-300km
Britain	Mean	0.621	0.592	0.552
	n	350	788	720
Yangzi Delta Rice	Mean	0.598	0.618	0.300
	n	36	28	20
Yangzi Delta, All Grains	Mean	0.468	0.242	0.115
	n	66	68	36
China outside Yangzi Delta,	Mean	0.416	0.238	0.086
All Grains	n	704	2,364	3,194

Notes: Interest rates based on time-series filtered data (Table 3.2, Panel B, column 5). "Yangzi Delta" prefectures are particular prefectures that are listed in Table B.3. "Rice" is first(grade and second(grade rice. "All Grains" here is rice plus wheat.

Next, we focus on capital market integration based on rice prices, because rice was the Yangzi Delta's most important grain and rice quotations might be more reliable than those for other grains. Bilateral correlations with rice-based interest rates show figures of around 0.6 for distances below 200 kilometers (row 2). Note that a correlation of around 0.6 is also obtained at these distances

[31] The seven Yangzi Delta prefectures in our data set are marked in Table B.3.

for Britain (range from 0.59 to 0.62, see row 1). Beyond 200 kilometers, however, correlations in Britain are almost twice as high as in the Yangzi Delta (0.55 versus 0.30).

Together with the previous results indicating grain type does not give rise to very different estimates within regions, we conclude that while the Yangzi Delta's capital market integration over short distances was high by most standards, the Delta's capital market integration above 200 kilometers was considerably lower than in Britain[32] . In sum, capital market integration in Britain exceeded the integration of capital markets even of China's most developed areas.

The timing of capital market development and industrialization

An important question on which we can provide insight is whether our findings hold already for the late 18th century, or only for the entire sample period of 1770 to 1860. This speaks to simultaneity and reverse causation concerns. Regarding the latter, if capital market development is an outcome of industrialization, it should not come as a surprise that Britain was ahead of China in the 19th century, because after all, Britain industrialized first. As for simultaneity, it would still be impossible to establish a causal effect from capital market development on modern economic growth using only data for the 19th century if capital market development and the take-off into modern economic growth went hand in hand.

In order to shed some light on this question we compare capital market integration in China and Britain in the late 18th century. Figure 3.5 shows the entire distribution of bilateral interest rate correlations in China and Britain for the years 1770 to 1794. Figure 3.5 can be compared with Figure 3.4, which shows the correlations for the entire sample period of 1770 to 1860. While the advantage of Britain grew somewhat over time, the most striking finding from comparing Figures 3.4 and 3.5 is how large Britain's advantage over China already was by the late 18th century. If we were to follow convention and use 1770 as the start date of British industrialization, the findings are consistent with capital market development being an important factor in explaining why Britain industrialized first. Britain had an advantage in terms of capital markets not only in comparison to China during the sample period, but given the stark difference shown in Figure 3.5, we can conclude

[32] Larger geographic distance is an important margin of market integration (Keller and Shiue 2007).

that a large gap existed well before the onset of Britain's own higher rate of technological change.

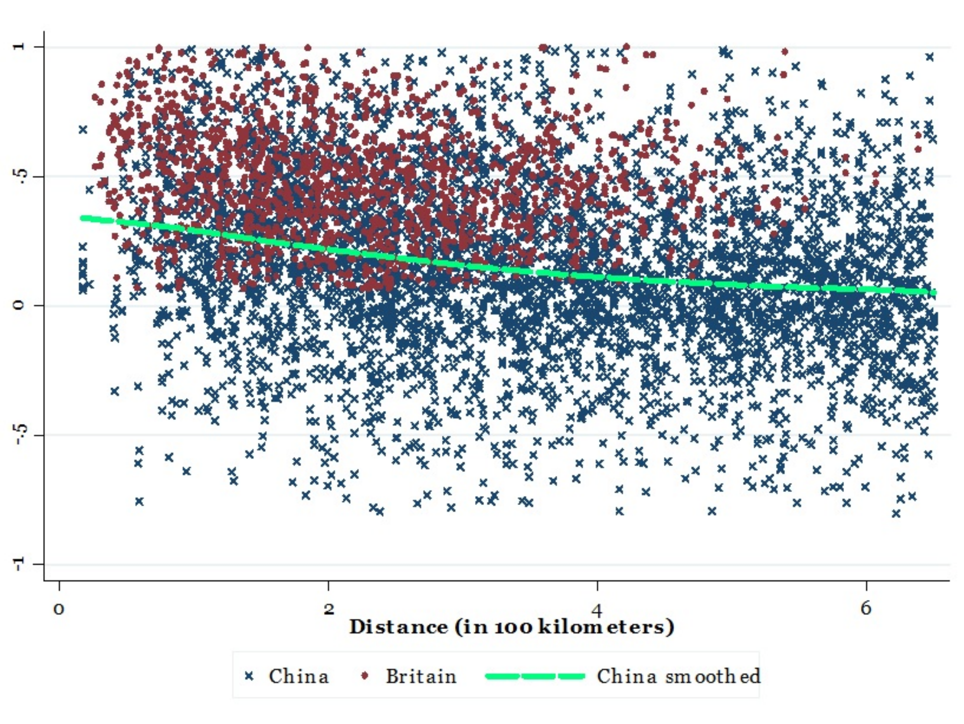


Figure 3.5: Bilateral interest rate correlations, 1770-1794

3.4.3 Robustness analysis

3.4.3.1 Region size and the role of spatial aggregation

Chinese prefectures are on average roughly twice as large as British counties. To see the implications of this for our study of capital market performance, we have paired up the 52 British counties into 26 regions of roughly similar size. Taking the same steps as before for these larger British regions, we compare bilateral interest rate correlations resulting from this set of 26 regions with the results from before based on the 52 counties. In Table B.6, the latter are denoted by "Baseline" (left two columns) while the former are denoted by "Aggregated".

We see that for both interest rates based on the filtered and on the unfiltered data series, aggregation increases the correlations somewhat. Furthermore, it does so for all geographic distance categories. This implies that our findings are not driven by the relatively small size of the regions in Britain. If anything, the difference in average region size has put Britain at a disadvantage relative to China.

3.4.3.2 The role of the choice of storage months

Recall that interest rates are estimated to be lower if we were to include the less steep parts of the price curve over the harvest cycle in the analysis (Table 2, column 5). To see the influence of this for our comparison of capital market integration, Figure B.3 shows results on bilateral correlations based on filtered grain prices, where the solid lines are based on our preferred interest rates while the dashed lines are for the broader interest rates. Generally, the broader interest rates imply a relatively low degree of capital market integration. For China, the difference between the preferred and the broader definition is increasing in distance. The results suggest that including additional storage months makes the grain interest rate a relatively noisy measure. At the same time, irrespective of whether we adopt the preferred or the broader storage month criterion, we find evidence that the integration of capital markets in Britain was higher than in China.

3.4.3.3 Convenience yields, volatility, and inventories

This section examines the possible influence of convenience yields on our capital market performance analysis. Since the convenience yield is unobserved we employ price information to predict periods of high inventory, exploiting the well-established negative relationship between inventories and convenience yields. Table B.7 provides results for three alternative criteria that yield periods of low convenience yields, based on current and past price levels as well as price volatility. These criteria are detailed in the notes to Table B.7.

Each of these criteria is applied in the same way to both Chinese and British regions, and Table B.7 reports average bilateral interest rate correlations across distance bins based on the subsamples that satisfy the particular low convenience yield criteria. We see throughout that the result of the main analysis that capital market integration in Britain was higher than in China is upheld. Based on these results, it is very unlikely that variation in convenience yields over time and across regions is important for explaining the finding that Britain's capital markets performed better than China's during the sample period.

3.4.3.4 Sample composition before and after the year 1820

There are on average more than 170 Chinese prefectures in the sample for a given year, with just under 150 from 1770 to 1820, after which the number jumps to around 215 prefectures. The increase in the number of regions is due to the publication of a reprint of these price data that starts in the year 1820. In Britain, the number of counties in the sample is on average 45. There is information for almost all counties between 1790 and 1820, while during the 1820s the number of counties is only around 35. The change in regional coverage in Britain reflects in part in the influence of certain groups upon British legislation (see Brunt and Cannon 2013).

Because such changes might affect our comparison of capital market performance, we have conducted the analysis of capital market integration for the period before and after 1820 separately. Results are shown in Table B.8. Even though the change in the number of regions from one period to the other is at times substantial, we do not see evidence that this systematically affects the results for Britain. For China, there is some evidence for lower levels of integration after the year 1820 for short distances. This finding, however, is to some extent reversed at higher distances. Overall, we do not find evidence that changes in the sample composition have a major impact on our results.

3.4.3.5 Capital market integration and time series length

A related concern is that we calculate the bilateral correlations for interest rates that are based on different numbers of annual observations. For some pairs we have interest rates over the entire sample period 1770 to 1860, while for others only for a subset of years. Because the degree of bilateral correlation might be affected by the time series length, if there were differences between China and Britain this could affect our results. We analyze this issue by contrasting the results when using all region pairs with results that employ data for 50 to 70 years.

The results in Table B.9 show that the time series length has some effects on the estimates of capital market integration. In particular, when focusing on pairs with data for 50 to 70 years, the average interest rate correlations for China increase. For example, at distances between 200 and 300 kilometers, the mean correlation increases from 0.25 to 0.36. Based on these figures, China's capital market integration appears to have been not far behind Britain's at distances below 100 kilometers (mean correlation of 0.61 versus 0.68, respectively). At distances above 300 kilometers, however, interest rate correlations between British regions are typically still at least twice as high as those in China.

Overall, the shorter average time series length together with the larger regional units in China does not clearly raise or lower the rates estimated. Taken together, there is no evidence that would overturn our finding of a British lead in capital market performance over China.

3.5 Conclusion

The problem of the role of financial development for growth in China is not that researchers have been unaware of deficiencies in China's capital markets. Rather, it has never been quite clear what these deficiencies were, and why they could possibly have been so critical to China's long-run development relative to Britain and other countries of Northwestern Europe. To some extent this has been due to scarce information on early capital markets. Avoiding the potential biases inherent in the scattered existing information, our analysis is based on a large new set of interest rates not only for China but also for Britain. To be sure, our grain price approach to capital markets has its own limitations; at the same time, the method is based on an externally validated approach using U.S. data. We provide a new empirical grounding for future research—a consistent set of annual and regional interest rates for most of the geographical area of Britain and China over a critical century in world history.

We estimate interest rates that average between 7.5 and 9% for China, and somewhat lower in China's most-developed areas. These rates are higher than our estimate for Britain of about 5.5%. While it is possible to develop a threshold model of development in which the difference between

5.5% and 7.5% interest is crucial, we think the difference is relatively small and that surplus as such was probably not the main constraint in China.

Rather, our finding that capital market integration in China was relatively low points to questions of the allocation of capital. Markets generally facilitate the division of labor, allowing gains from specialization to be reaped. We know that commodity markets in China worked quite well in the 18th century—and were not much less integrated than British markets (Shiue and Keller, 2007); however, in terms of capital market integration, China was further behind Britain. Why does this matter?

Commodity markets match buyers and sellers, as in an endowment economy model in which lychees and apples fall from trees and are traded for other consumption goods. In contrast, capital markets channel resources from individuals willing to postpone consumption to others with productivity-enhancing projects that pay off only in the future. The finding of low regional capital market integration provides evidence that the search for good matches between savers and investors in China was mostly a local process, thereby reducing the allocative efficiency of capital.

Further research is needed to determine what explains the lower regional capital market integration in China compared to Britain. Some accounts suggest that the wealthy in China in the 18th and 19th centuries did not conduct much capital accumulation. The salt merchants of Yangzhou, for example, the wealthiest merchants of this time, saw their wealth dissipate in a few generations (Ho, 1954). Investments flowed into political connections or for the grooming of sons to enter the civil service examinations and a career in officialdom, rather than towards the preservation or expansion of family wealth. While this might lead to low levels of capital market integration, much work remains to be done on the returns to different investments in China to substantiate these accounts[33] .

Another possible explanation is that the Chinese empire, up until the Taiping Rebellion of the 19th century, was a balanced budget state, meaning that it never borrowed, and therefore had no experience with bonds and other financial instruments. The first stock market in China

[33] For an analysis of the changing returns to human capital accumulation in China, see Shiue (2016).

was introduced by foreigners (Goetzmann et al. 2007). In England, by contrast, it was not only the state but also state-backed ventures such as the East India Company that created wealth for nationals, giving investors new opportunities and investment strategies with financial innovations such as limited liability joint stock companies. There is probably some truth to this state finance hypothesis, although very little is known at this point on its quantitative importance.

Further on the role of the state, our finding of low capital market integration over long distances in China is consistent with the hypothesis that borrowing and lending is segmented geographically because of the importance of local lineages (common descent groups). Along these lines, China's relatively low capital market integration would reflect the delayed transition in China from kinship-based financial transactions to impersonal transactions, especially those involving banks.

In sum, we have shown that Britain had a lead in capital market development not only in comparison to most areas of China, but also at a date well before the onset of technological change in Britain (ca. 1770). While this is consistent with accounts that have emphasized capital market development as an important factor in explaining income divergence in these parts of the world, future research is needed to address a number of important remaining questions.

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Appendix A

Derivations for Chapter 1

A.1 Solve the model

A.1.1 Firm's problem in the manufacturing sector

Equation (1.1) implies that $y_{ij} = \tau_{ij}^{-\frac{\rho}{1-\rho}} y_{ii} (\frac{Y_i}{Y_j})^{-\frac{\rho-\alpha}{1-\rho}}$, given $p_{ij} = \tau_{ij} p_{ii}$. Therefore, the general form of total revenues of a firm with productivity θ reads

$$R_i(\theta) = \theta^{\rho} h_i(\theta)^{\rho} \big[Y_i^{-\frac{(\rho-\alpha)}{1-\rho}} + \sum_{j \neq i} I_{ij}(\theta) \tau_{ij}^{-\frac{\rho}{1-\rho}} Y_j^{-\frac{(\rho-\alpha)}{1-\rho}} \big]^{1-\rho} \tag{A.1}$$

Following Felbermayr et al. (2011), the first condition of dynamic problem in equation (1.7) leads to

$$\frac{\partial R_i(l;\theta)}{\partial l} = \frac{c}{q(\varphi_i)} \frac{r+\psi}{1-\delta} + w_i(l:\theta) + \frac{\partial w_i(l;\theta)}{\partial l} l \tag{A.2}$$

Therefore,

$$\frac{\partial J_i(l;\theta)}{\partial l} = \frac{1}{\psi + r} [\frac{\partial R_i(l;\theta)}{\partial l} - w_i(l:\theta) - \frac{\partial w_i(l;\theta)}{\partial l} l] \tag{A.3}$$

Additionally, solving the problem in (1.5) yields

$$(1-\beta)[E_i(l:\theta) - U_i] = \beta \frac{\partial J_i(l;\theta)}{\partial l} \tag{A.4}$$

while in steady state the equations in (1.6) can be written as

$$rE_i(l:\theta) = w_i(l;\theta) - \psi[E_i(l:\theta) - U_i]$$

$$rU_i = \varphi_i q(\varphi_i)[E_i(l:\theta) - U_i] \tag{A.5}$$

Combining equation (A.4) with (A.5) leads to

$$\frac{\partial J_i(l;\theta)}{\partial l} = \frac{1-\beta}{\beta}\frac{1}{r+\psi}(w_i(l;\theta) - rU_i)$$

Substituting this expression into the left hand side of equation (A.3) and solving the the differentiate equation, $w_i(l;\theta)$ can be written as

$$w_i = (1-\beta)rU_i + \beta\frac{\sigma}{\sigma-\beta}\frac{\partial R_i(l;\theta)}{\partial l} \tag{A.6}$$

Take derivative of equation (A.6) with respect to l, we obtain

$$\frac{\partial w_i(l;\theta)}{\partial l}l = \beta\frac{\sigma}{\sigma-\beta}(-\frac{1}{\sigma})\frac{\partial R_i(l;\theta)}{\partial l}$$

Reinserting it into equation (A.2) gives

$$w_i(l;\theta) = \frac{\sigma}{\sigma-\beta}\frac{\partial R_i(l;\theta)}{\partial l} - (\frac{r+\psi}{1-\delta})\frac{c}{q(\varphi_i)} \tag{A.7}$$

Combined with equation (A.6), the above equation yields the expression of wage

$$w_i(l;\theta) = rU_i + \frac{\beta}{1-\beta}\frac{r+\psi}{1-\delta}\frac{c}{q(\varphi_i)}$$

which is equation (1.9) in the main text.

A.1.2 Solve for goods market equilibrium

With the wage curve in equation (1.9) and the relation between $R_i(l:\theta)$ and w as shown in equation (A.7), we have

$$a(\varphi_i) = \frac{\beta}{1-\beta}\frac{1}{1-\delta}\frac{\sigma-\beta}{\sigma}[\varphi_i c + \frac{r+\psi}{\beta}\frac{c}{q(\varphi_i)}]$$

Let $l_{ii}(\theta)$ and $l_{ij}(\theta)$ denote the employment for domestic and export sales to market j respectively. With the expression of $R_i(l:\theta)$ in equation (A.1) and the optimal allocation rule between the employment for domestic sale and export sales, we can solve for

$$l_{ii} = \rho^{\frac{1}{1-\rho}} Y_i^{-\frac{\rho-\alpha}{1-\rho}} \theta_i^{\frac{\rho}{1-\rho}} a(\varphi_i)^{-\frac{1}{1-\rho}}$$

$$l_{ij} = \tau_{ij}^{-\frac{\rho}{1-\rho}} \rho^{\frac{1}{1-\rho}} Y_j^{-\frac{\rho-\alpha}{1-\rho}} \theta_i^{\frac{\rho}{1-\rho}} a(\varphi_i)^{-\frac{1}{1-\rho}} \tag{A.8}$$

Next solve the zero profit cutoff conditions. Since firms pay fixed cost and vacancy posting cost first and start production in the next period, the profits earned in market j in each period $\pi_{ij}(\theta)$ satisfies

$$\frac{1}{1+r}\sum_{t=0}^{\infty}(\frac{1-\delta}{1+r})^t \pi_{ij}(\theta) \equiv \sum_{t=1}^{\infty}(\frac{1-\delta}{1+r})^t([R_{ij}(l:\theta) - w_{Mi}(l;\theta)l_{ij} - cv_i - f_{ij}] - \frac{c}{q_i(\varphi)} l_{ij} - f_{ij} \tag{A.9}$$

where $R_{ij}(l:\theta)$ represents the total revenue from the sales to market j from location i, l_{ij} is the employment for the sales to market j. Therefore, the productivity threshold θ^*_{ij} satisfies

$$\sum_{t=1}^{\infty}(\frac{1-\delta}{1+r})^t([R_{ij}(l:\theta^*_{ij}) - w_{Mi}(l;\theta^*_{ij})l_{ij} - cv_i - f_{ij}] = \frac{c}{q_i(\varphi)} l_{ij} - f_{ij}$$

Combining this equation with equation (A.7) leads to

$$R_{ij}(\theta^*_{ij}) = \frac{1+r}{1-\delta}\frac{\sigma-\beta}{1-\beta} f_{ij} \tag{A.10}$$

We can obtain the expression of productivity threshold (1.11) in the main text using the expression of R_{ij}, equation (A.8) and condition (A.10).

Next solve the free entry condition. For any two firms with productivity θ_1 and θ_2, we have $\frac{R_{ij}(\theta_1)}{R_{ij}(\theta_2)} = (\frac{\theta_1}{\theta_2})^{\frac{\rho}{1-\rho}}$. Combined with equation (A.10), this condition implies

$$R_{ij}(\theta) = (\frac{\theta}{\theta^*_{ij}})^{\frac{\rho}{1-\rho}}(\frac{1+r}{1-\delta}\frac{\sigma-\beta}{1-\beta}) f_{ij}$$

Hence, the free entry condition can be simplified as

$$\sum_j f[(\frac{\tilde{\theta}_{ij}}{\theta^*_{ij}})^{\frac{\rho}{1-\rho}} - 1] = \frac{(r+\delta)}{(1+r)}\frac{f_e}{1-G(\theta^*_{ii})}$$

A.2 Proof of lemma 1 and lemma 2

In the model with symmetric regions, equation (1.14) can be reduced to

$$\frac{\theta^*_d}{\theta^*_x} = (\frac{f_d}{f_x})^{\frac{\rho}{1-\rho}} \tau^{-1}$$

Therefore, the impact of variable trade cost τ on cutoffs satisfies

$$\hat{\theta}_x^* = \tau + \hat{\theta}_d^*$$

In addition, differentiating the free-entry condition leads to

$$\sum_j \{ \frac{f_{ij}}{\theta_{ij}^*} \int_{\theta_{ij}^*.}^{\infty} \theta^{\sigma-1} dG(\theta) \hat{\theta}_{ij}^* \} = 0$$

Combining the above two equations yields the expression of changes in productivity thresholds (1.18) in the main text. Lemma 1 follows the sign of coefficients in equation (1.18).

To see why lemma 2 holds, total differentiating equation (1.15) yields

$$\frac{dN_M}{d\varphi} = \frac{\beta}{1-\beta}\frac{1}{1-\delta} c w_A'^{-1}(N_M) > 0 \tag{A.11}$$

Additionally, substituting (1.14) into (1.17) and total differentiating the equation yield:

$$\frac{dN_M}{d\varphi} = -\frac{x'(\varphi)/[x(\varphi)+\psi]^2 \psi N_M + [\alpha\rho/(\rho-\alpha)+1] a^{-2}(\varphi) a'(\varphi) \rho Y^\alpha}{x(\varphi)/(x(\varphi)+\psi)} < 0 \tag{A.12}$$

The above results imply that the wage curve in equation (1.15) and labor flow function (1.17) are monotonic and intersect with each other at a unique point. Therefore, given the value of productivity threshold, there exists an unique solution of N_M and φ. In addition, combining equation (A.11) and (A.12) yields the relation between φ and θ_d^* as: $\hat{\varphi} = \phi \hat{\theta}_d^*$, where $\phi = \frac{\rho}{a(\varphi)} Y^\alpha \frac{\alpha\rho}{\rho-\alpha} / \{ \varphi \{ \frac{x'(\varphi)\psi N_M}{(x(\varphi)+\psi)^2} + (\frac{\alpha\rho}{\rho-\alpha} + 1) a^{-2}(\varphi) a'(\varphi) \rho Y^\alpha + \frac{x(\varphi)}{x(\varphi)+\psi} w_A'^{-1}(N_M) \frac{\beta}{1-\beta}\frac{1}{1-\delta} c \} \} > 0$. Therefore, reduction in trade cost increases φ by raising the value of θ_d^*.

A.3 The planner's problem

The planner's problem is to maximize total net revenue by choosing the appropriate number of vacancy posted by firms in the manufacturing sector and allocating workers across firms and sectors. The corresponding Bellman equation is

$$V(L,D) = \max_{l(\theta), \varphi, N_A} \frac{1}{1+r} \left[\int_{\theta_d^*}^{\infty} R(\theta, l) dG(\theta) + F(N_A) - c\varphi D + V(L'; D') \right]$$

$$\text{s.t.} \quad \int_{\theta_d^*}^{\infty} l(\theta) dG(\theta) = L$$

$$L' = (1-\psi)L + x(\varphi)D$$

$$D = \psi(\bar{N} - N_A - D) + (1 - x(\varphi))D$$

where L is the total employment in the manufacturing sector and D is the total unemployment. The first order conditions leads to equal marginal product across firms and the two equations in (1.19).

A.4 Procedures to compute the measure of TFP

To get the firm level TFP, equation (1.25) is estimated with the augmented semi-parametric "Olley-Pakes" method following Pavcnik (2002). Specifically, I first get $\hat{\beta}_1$and $\hat{\beta}_2$in equation (1.25) by estimating

$$\ln y_{it} = \beta_0 + \beta_1 \ln w_{it} + \beta_2 \ln m_{it} + \lambda(\ln k_{it}, I_{it}, EX_{it}, SOE_{it}) + \epsilon_{it} \tag{A.13}$$

where $\lambda$is a third order polynomial series expansion in capital, investment, firm's export dummy EX and state owned dummy SOE. I then estimate the coefficient for capital with the following equation

$$R_{it} = \beta_3 \ln k_{it} + \phi(\hat{\lambda}_{i,t-1} - \beta_3 k_{i,t-1}, \hat{P}_{i,t-1}) + \epsilon_{it} \tag{A.14}$$

where R_{it} is the residual in equation (A.13) and it's calculated as

$$R_{it} = \ln y_{it} - \hat{\beta}_1 \ln w_{it} - \hat{\beta}_2 \ln m_{it}$$

$\hat{P}$ is fitted value of the probability at which a firm will stay in the market in the next period. I estimate this survival probability with a third order polynomial in capital and investment and use a third order polynomial series expansion in $\hat{P}$ and $\hat{\lambda}_{i,t-1} - \beta_3 k_{i,t-1}$ to approximate ϕ. Equation (A.14) is estimated with non-linear least squares since the coefficient of capital in the first term and second term are the same.

Data used to estimate TFP comes from the Annual Survey of Industrial Production (1998-2007). The panel of firms and variables for estimation are constructed following the approach in the online appendix of Brandt et al. (2012).

Appendix B

Data, Tables, and Figures for Chapter 3

B.1 Grain price data

China

The price reports are originally from the Gongzhong zhupi zouzhe, nongye lei, liangjia qingdan [Grain Price Lists in the Agricultural Section of the Vermilion Rescripts in the Palace Archives; Chinese Academy of Social Sciences (2009)], which records prices for each lunar month during the sample period of 1770 to 1860. These data exist on microfilm (Yishiguan 1990) and in published volumes from the Daoguang reign onwards (after the year 1820; Chinese Academy of Social Sciences 2009). The price quotes are for each prefecture, a unit that is one level below the province.

The sources give the prefectural high price, which is for the market with the highest price in the prefecture, as well as the prefectural low price, which is for the market with the lowest price in the prefecture. The analysis uses the mid-point price, defined as the average of the high price and low price of the prefecture, which is mapped to the location of the prefectural capital. Quantity units are in units of shi, where 1 shi = 103 liters. The original monetary units are in liang, or the Chinese silver tael. We focus on the four most prevalent grains as reported in the sources, wheat, millet, and 1st and 2nd quality rice. As a consequence, we do not cover some areas where particular grains were grown, perhaps most importantly Zhejiang province where particular types of rice were grown. We have confirmed that this does not drive the main findings of the analysis.

Britain

Wheat prices for British counties for our sample period come from the British government's

Corn Returns, which were published weekly in the London Gazette (a newspaper). Before 1820 there is information on the weighted average of the grain price in the county, while after October 1820, prices and quantities for all market towns within each county are available (Adrian 1977). We construct the weighted monthly price at the level of the county for the period 1770 to 1860 as our British grain data. The difference between the mid-point price (for China) and the weighted average price (for Britain) does not drive our main findings. Thanks to Edmund Cannon who provided to us the data for 1770 to 1820, see Brunt and Cannon (2013). Data for the later years were obtained from www.cornreturnsonline.org

B.2 Weather data

China

The Chinese rainfall data comes from the compilation published by the State Meteorological Administration (1981) from a variety of historical sources, including local histories and gazetteers. A ranking of one to five is used to summarize the "wetness and dryness" of weather for each year during the sample period at 120 "stations", a regional designation that serves one or two prefectures, throughout the sample area. The weather categories are defined as follows:

- Level 1 represents years in which there has been exceptional rainfall, leading to major floods, typhoons, water-related disasters, and the destruction of all crops.
- Level 2 encompasses cases where there is heavy rainfall, but limited in scope and/or resulting in only minor flooding.
- Level 3 should be interpreted as normal weather, neither very wet nor very dry, and therefore the most favorable weather for that locality.
- Level 4 indicates minor droughts of limited consequences.
- Level 5 denotes the years of greatest drought, lasting two or more seasons of the year, and leading to major harvest failures.

Over all years and all regions considered, the five categories are classified by the authors such that years and regions ranking level 1 and 5 in severity each appear with a frequency of 10 percent, ranks of level 2 and 4 each appears with a frequency between 20-30 percent, and the rank of level 3 accounts for 30-40 percent of the total distribution. In particular, the scale of rainfall is classified as follows:

Level 1: $R_i > (\overline{R} + 1.17\tilde{\sigma})$

Level 2: $(\overline{R} + 0.33\tilde{\sigma}) < R_i \leq (\overline{R} + 1.17\tilde{\sigma})$

Level 3: $(\overline{R} - 0.33\tilde{\sigma}) < R_i \leq (\overline{R} + 0.33\tilde{\sigma})$

Level 4: $(\overline{R} - 1.17\tilde{\sigma}) < R_i \leq (\overline{R} - 0.33\tilde{\sigma})$

Level 5: $R_i \leq (\overline{R} - 1.17\tilde{\sigma})$

where,

R_i= relative wetness of year i, between the months of May and September.

$\overline{R}$= average wetness between the months May and September over all years.

$\tilde{\sigma}$= standard deviation.

The weather for each prefecture in the sample is determined by the weather at the weather station that is closest in terms of geographic distance to the prefectural capital. To adjust carry costs for weather effects and storage cost differences, we include indicator variables for each of the five wetness levels to determine the weather during which carry costs were on average lowest during the sample period; this wetness level is defined as the best possible weather in the sense that it is associated with the on average lowest carry costs. We adjust the carry costs using the difference of the OLS estimates for the best possible and the actual climate in each region and year in our interest rate calculation.

Britain

We use the precipitation reconstructions from Pauling et al. (2006) as our rainfall data to adjust the British carry costs for weather and storage effects. Pauling et al. (2006) present seasonal precipitation reconstructions for European land areas on a 0.5 by 0.5 degree grid for each year of our sample period. We aggregate the seasonal data to obtain total seasonal precipitation. The weather in a given county and year is the geographically closest data point from Pauling et al. (2006). We normalize the British weather data according to the methodology for China from above to the same 1 to 5 scale and the same aggregate frequencies that are in the Chinese data.

B.3 Other data

Location of regions and geographic distance

The latitude and longitude measurements of the prefectural cities in China come from Playfair (1965), which are based on their historical locations. The data for Britain is based on the maps with historical information at http://www.cornreturnsonline.org/analysis/map-of-grain-markets together with distances between counties calculated using http://www.distancesfrom.com/Latitude-Longitude.aspx .

Inter-regional trade and waterways

We construct indicator variables for the location of a region on a major waterway, accounting for

- Rivers: Yangzi and Pearl rivers in China, and the Thames, Trent, Severn, and Lea in Britain. C
- Canals: Grand Canal in China and the Bridgewater Canal in Britain.
- Coastal location: In China we employ three indicator variables, for North and South of the Yangzi Delta, as well as the Yangzi Delta itself.
- The selection of these waterways is based on Watson (1972), Paget-Tomlinson (1993), and the sources given in Shiue and Keller (2007).

Differences in harvest patterns

In creating the indicator for particular harvest patterns we focus on the possibility that in certain parts of Southern China it was possible to harvest rice twice in a given year (Chuan and Kraus 1975, LeClerc 1927). Perkins (1969) reports that double-cropping in certain areas with wheat and barley in the winter, followed by millet and rice in the summer of China was also significant (1969, p. 46). There is little data on the extent of this double-cropping during the years 1770 to 1860, though we know it became more important over time; by the 1930s the increase in output due to double-cropped wheat and barley was about 14 million tons, compared to a total output of about 33 million tons of wheat and barley (Perkins 1969, p.47, Table D.5, Table D.7). During our sample period double-cropped wheat is unlikely to account for more than one third of all of wheat production. Based on the relatively small effect of double-cropping on our rice interest rates, and the fact that we find similar grain interest rates across grain types, accounting for double-cropping in millet, wheat, and barley is very unlikely to affect our main findings.

Table B.1: United States Regional Interest Rates, 1815-1859

Year	New York City	Philadelphia	Richmond	New Orleans	Indianapolis
1815		4.62			
1816		5.7			
1817		3.69			
1818		5.55			
1819		3.84			
1820		5.6			
1821		4.78			
1822		5.65	4.08		
1823		3.42	3.81		
1824		5.21	4.14		
1825		4.24	4.61		
1826		5.86	3.97		
1827		4.95	4.97		
1828		5.82	3.97		
1829		4.58	4.23		
1830		4.97	4.45		
1831		5.15	4.84		
1832		4.48	6.28		
1833	5.03	6.54	8.02		
1834	5.69	3.41	3.75	6.82	
1835	5.11	6.12	4.43	7.54	7.97
1836	6.82	5.74	7.22	7.16	7.6
1837	5.91	4.75	5.7	11.28	8.5
1838	5.33	5.47	4.41	7.68	8.35

Table B.1 – United States Regional Interest Rates, 1815-1859(continued)

Year	New York City	Philadelphia	Richmond	New Orleans	Indianapolis
1839	4.24	3.44	6.78	10.15	
1840	5.57	5.73	5.43	9.01	
1841	5.27	4.41	4.21	8.86	7.65
1842	3.95	2.5	4.2	8.85	5.05
1843	5.37	3.72	4.12		2.85
1844	5.8	5.18	4.15		5.74
1845	5.21	4.2	5.1		7.86
1846	4.69	6.39	3.95		
1847	5.04	5.21	4.99		6.32
1848	5.32	4.83	4.43	7.73	8.36
1849	7.17	6.35	4.19	4.84	7.77
1850	5.62	6.47	4.53	7.42	9.45
1851	6.32	4.69	4.72	7.79	5.95
1852	7.23	5.56	5.53	7.91	6.81
1853	4.99	5.1	4.46	7.38	6.37
1854	4.98	5.31	5.04	8.5	7.7
1855	5.87	5.7	5.18	12.81	10.89
1856	6.09	4.45	4.29		9.25
1857	5.45	3.16	3.88		
1858	4.95	6.46	2.92		
1859	4.62	4.32	5.96		

Source: Bodenhorn and Rokoff (1992). “Richmond” rates are for Virginia, “Indianapolis” rates are for Indiana.

Table B.2: British regions

Region No.	County name	Region No.	County name
1	Anglesey	27	Lancashire
2	Bedfordshire	28	Leicestershire
3	Berkshire	29	Lincolnshire
4	Brecknockshire	30	Merionethshire
5	Buckinghamshire	31	Middlesex
9	Caernarfonshire	32	Monmouthshire
6	Cambridgeshire	33	Montgomeryshire
7	Cardiganshire	34	Norfolk
8	Carmarthenshire	35	Northamptonshire
10	Cheshire	36	Northumberland
11	Cornwall	37	Nottinghamshire
12	Cumberland	38	Oxfordshire
13	Denbighshire	39	Pembrokeshire
14	Derbyshire	40	Radnorshire
15	Devon	41	Rutland
16	Dorset	42	Shropshire
17	Durham	43	Somerset
18	Essex	44	Staffordshire
19	Flintshire	45	Suffolk
20	Glamorgan	46	Surrey
21	Gloucestershire	47	Sussex
22	Hampshire	48	Warwickshire
23	Herefordshire	49	Westmorland
24	Hertfordshire	50	Wiltshire
25	Huntingdonshire	51	Worcestershire
26	Kent	52	Yorkshire

Table B.3: Chinese regions

Region No.	Name	Prefecture name in pinyin	Province	Province in pinyin	Yangzi Delta	Region No.	Name	Prefecture name in pinyin	Province	Province in pinyin	Yangzi Delta
1	奉天府	Fengtian Fu	奉天	Fengtian		46	绛州	Jiangzhou Zhilizhou	山西	Shanxi	
2	錦州府	Jingzhou Fu	奉天	Fengtian		47	隰州直隶州	Xizhou Zhilizhou	山西	Shanxi	
3	承德府	Chengde Fu	热河	Rehe		48	朔平府	Shuoping Fu	山西	Shanxi	
4	济南府	Jinan Fu	山东	Shandong		49	宁武府	Ningwu Fu	山西	Shanxi	
5	兖州府	Yanzhou Fu	山东	Shandong		50	霍州直隶州	Huozhou Zhilizhou	山西	Shanxi	
6	东昌府	Dongchang Fu	山东	Shandong		51	归绥道	Guisui Dao	山西	Shanxi	
7	青州府	Qingzhou Fu	山东	Shandong		52	开封府	Kaifeng Fu	河南	Henan	
8	登州府	Dengzhou Fu	山东	Shandong		53	归德府	Guide Fu	河南	Henan	
9	莱州府	Laizhou Fu	山东	Shandong		54	彰德府	Zhangde Fu	河南	Henan	
10	泰安府	Taian Fu	山东	Shandong		55	卫辉府	Weihui Fu	河南	Henan	
11	武定府	Wuding Fu	山东	Shandong		56	怀庆府	Huaiqing Fu	河南	Henan	
12	曹州府	Caozhou Fu	山东	Shandong		57	河南府	Henan Fu	河南	Henan	
13	济宁直隶州	Jining Zhilizhou	山东	Shandong		58	南阳府	Nanyang Fu	河南	Henan	
14	沂州府	Yizhou Fu	山东	Shandong		59	汝宁府	Runing Fu	河南	Henan	

Table B.3 – Chinese regions(continued)

Region No.	Name	Prefecture name in pinyin	Province	Province in pinyin	Yangzi Delta	Region No.	Name	Prefecture name in pinyin	Province	Province in pinyin	Yangzi Delta
15	临清直隶州	Linqing Zhilizhou	山东	Shandong		60	汝州	Ruzhou Zhilizhou	河南	Henan	
16	顺天府	Shuntian Fu	直隶	Zhili		61	陈州府	Chenzhou Fu	河南	Henan	
17	保定府	Baoding Fu	直隶	Zhili		62	许州直隶州	Xuzhou Zhilizhou	河南	Henan	
18	永平府	Yongping Fu	直隶	Zhili		63	陕州直隶州	Shaanzhou Zhilizhou	河南	Henan	
19	河间府	Hejian Fu	直隶	Zhili		64	光州直隶州	Guangzhou Zhilizhou	河南	Henan	
20	正定府	Zhengding Fu	直隶	Zhili		65	西安府	Xi'an Fu	陕西	Shaanxi	
21	顺德府	Shunde Fu	直隶	Zhili		66	延安府	Yan'an Fu	陕西	Shaanxi	
22	广平府	Guangping Fu	直隶	Zhili		67	凤翔府	Fengxiang Fu	陕西	Shaanxi	
23	大名府	Daming Fu	直隶	Zhili		68	汉中府	Hanzhong Fu	陕西	Shaanxi	
24	冀州直隶州	Jizhou Zhilizhou	直隶	Zhili		69	兴安府	Xing'an Fu	陕西	Shaanxi	
25	赵州直隶州	Zhaozhou Zhilizhou	直隶	Zhili		70	商州	Shangzhou Zhilizhou	陕西	Shaanxi	
26	深州直隶州	Shenzhou Zhilizhou	直隶	Zhili		71	同州府	Tongzhou Fu	陕西	Shaanxi	
27	定州直隶州	Dingzhou Zhilizhou	直隶	Zhili		72	乾州厅	Qianzhou Zhilizhou	陕西	Shaanxi	
28	天津府	Tianjin Fu	直隶	Zhili		73	邠州	Binzhou Zhilizhou	陕西	Shaanxi	
29	易州直隶州	Yizhou Zhilizhou	直隶	Zhili		74	鄜州	Fuzhou Zhilizhou	陕西	Shaanxi	

Table B.3 – Chinese regions(continued)

Region No.	Name	Prefecture name in pinyin	Province	Province in pinyin	Yangzi Delta	Region No.	Name	Prefecture name in pinyin	Province	Province in pinyin	Yangzi Delta
30	遵化直隶州	Zunhua Zhilizhou	直隶	Zhili		75	绥德州	Suide Zhilizhou	陕西	Shaanxi	
31	宣化府	Xuanhua Fu	直隶	Zhili		76	榆林府	Yulin Fu	陕西	Shaanxi	
32	太原府	Taiyuan Fu	山西	Shanxi		77	兰州府	Lanzhou Fu	甘肃	Gansu	
33	平阳府	Pingyang Fu	山西	Shanxi		78	平凉府	Pingliang Fu	甘肃	Gansu	
34	大同府	Datong Fu	山西	Shanxi		79	巩昌府	Gongchang Fu	甘肃	Gansu	
35	潞安府	Luan Fu	山西	Shanxi		80	庆阳府	Qingyang Fu	甘肃	Gansu	
36	汾州府	Fenzhou Fu	山西	Shanxi		81	宁夏府	Ningxia Fu	甘肃	Gansu	
37	辽州直隶州	Liaozhou Zhilizhou	山西	Shanxi		82	西宁府	Xining Fu	甘肃	Gansu	
38	沁州直隶州	Qinzhou Zhilizhou	山西	Shanxi		83	安西直隶州	Anxi Zhilizhou	甘肃	Gansu	
39	泽州府	Zezhou Fu	山西	Shanxi		84	凉州府	Liangzhou Fu	甘肃	Gansu	
40	平定州	Pingding Zhilizhou	山西	Shanxi		85	甘州府	Ganzhou Fu	甘肃	Gansu	
41	忻州直隶州	Xinzhou Zhilizhou	山西	Shanxi		86	秦州直隶州	Qinzhou Zhilizhou	甘肃	Gansu	
42	代州直隶州	Daizhou Zhilizhou	山西	Shanxi		87	阶州直隶州	Jiezhou Zhilizhou	甘肃	Gansu	
43	保德州	Baode Zhilizhou	山西	Shanxi		88	肃州直隶州	Suzhou Zhilizhou	甘肃	Gansu	
44	蒲州府	Puzhou Fu	山西	Shanxi		89	泾州直隶州	Jingzhou Zhilizhou	甘肃	Gansu	

Table B.3 – Chinese regions(continued)

Region No.	Name	Prefecture name in pinyin	Province	Province in pinyin	Yangzi Delta	Region No.	Name	Prefecture name in pinyin	Province	Province in pinyin	Yangzi Delta
45	解州	Jiezhou Zhilizhou	山西	Shanxi		90	江宁府	Jiangning Fu	江苏	Jiangsu	1
91	苏州府	Suzhou Fu	江苏	Jiangsu	1	136	福宁府	Funing Fu	福建	Fujian	
92	松江府	Songjiang Fu	江苏	Jiangsu	1	137	永春州	Yongchun Zhilizhou	福建	Fujian	
93	常州府	Changzhou Fu	江苏	Jiangsu	1	138	龙岩州	Longyan Zhilizhou	福建	Fujian	
94	镇江府	Zhenjiang Fu	江苏	Jiangsu	1	139	台湾府	Taiwan Fu	福建	Fujian	
95	淮安府	Huaian Fu	江苏	Jiangsu		140	武昌府	Wuchang Fu	湖北	Hubei	
96	扬州府	Yangzhou Fu	江苏	Jiangsu		141	汉阳府	Hanyang Fu	湖北	Hubei	
97	徐州府	Xuzhou Fu	江苏	Jiangsu		142	安陆府	Anlu Fu	湖北	Hubei	
98	太仓直隶州	Taicang Zhilizhou	江苏	Jiangsu	1	143	襄阳府	Xiangyang Fu	湖北	Hubei	
99	海州直隶州	Haizhou Zhilizhou	江苏	Jiangsu		144	郧阳府	Yunyang Fu	湖北	Hubei	
100	通州直隶州	Tongzhou Zhilizhou	江苏	Jiangsu	1	145	德安府	De'an Fu	湖北	Hubei	
101	安庆府	Anqing Fu	安徽	Anhui		146	黄州府	Huangzhou Fu	湖北	Hubei	
102	徽州府	Huizhou Fu	安徽	Anhui		147	荆州府	Jingzhou Fu	湖北	Hubei	
103	宁国府	Ningguo Fu	安徽	Anhui		148	宜昌府	Yichang Fu	湖北	Hubei	
104	池州府	Chizhou Fu	安徽	Anhui		149	施南府	Shinan Fu	湖北	Hubei	

Table B.3 – Chinese regions(continued)

Region No.	Name	Prefecture name in pinyin	Province	Province in pinyin	Yangzi Delta	Region No.	Name	Prefecture name in pinyin	Province	Province in pinyin	Yangzi Delta
105	太平府	Taiping Fu	安徽	Anhui		150	荆门直隶州	Jingmen Zhilizhou	湖北	Hubei	
106	庐州府	Luzhou Fu	安徽	Anhui		151	长沙府	Changsha Fu	湖南	Hunan	
107	凤阳府	Fengyang Fu	安徽	Anhui		152	岳州府	Yuezhou Fu	湖南	Hunan	
108	广德直隶州	Guangde Zhilizhou	安徽	Anhui		153	宝庆府	Baoqing Fu	湖南	Hunan	
109	和州直隶州	Hezhou Zhilizhou	安徽	Anhui		154	衡州府	Hengzhou Fu	湖南	Hunan	
110	滁州直隶州	Chuzhou Zhilizhou	安徽	Anhui		155	常德府	Changde Fu	湖南	Hunan	
111	六安直隶州	Liu'an Zhilizhou	安徽	Anhui		156	辰州府	Chenzhou Fu	湖南	Hunan	
112	泗州直隶州	Sizhou Zhilizhou	安徽	Anhui		157	永州府	Yongzhou Fu	湖南	Hunan	
113	颍州府	Yingzhou Fu	安徽	Anhui		158	靖州	Jingzhou Zhilizhou	湖南	Hunan	
114	南昌府	Nanchang Fu	江西	Jiangxi		159	郴州直隶州	Chenzhou Zhilizhou	湖南	Hunan	
115	饶州府	Raozhou Fu	江西	Jiangxi		160	永顺府	Yongshun Fu	湖南	Hunan	
116	广信府	Guangxin Fu	江西	Jiangxi		161	澧州直隶州	Lizhou Zhilizhou	湖南	Hunan	
117	南康府	Nankang Fu	江西	Jiangxi		162	沅州府	Yuanzhou Fu	湖南	Hunan	
118	九江府	Jiujiang Fu	江西	Jiangxi		163	桂阳州	Guiyang Zhilizhou	湖南	Hunan	
119	建昌府	Jianchang Fu	江西	Jiangxi		164	广州府	Guangzhou Fu	广东	Guangdong	

Table B.3 – Chinese regions(continued)

Region No.	Name	Prefecture name in pinyin	Province	Province in pinyin	Yangzi Delta	Region No.	Name	Prefecture name in pinyin	Province	Province in pinyin	Yangzi Delta
120	抚州府	Fuzhou Fu	江西	Jiangxi		165	韶州府	Shaozhou Fu	广东	Guangdong	
121	临江府	Linjiang Fu	江西	Jiangxi		166	南雄直隶州	Nanxiong Zhilizhou	广东	Guangdong	
122	吉安府	Ji'an Fu	江西	Jiangxi		167	惠州府	Huizhou Fu	广东	Guangdong	
123	瑞州府	Ruizhou Fu	江西	Jiangxi		168	潮州府	Chaozhou Fu	广东	Guangdong	
124	袁州府	Yuanzhou Fu	江西	Jiangxi		169	肇庆府	Zhaoqing Fu	广东	Guangdong	
125	赣州府	Ganzhou Fu	江西	Jiangxi		170	高州府	Gaozhou Fu	广东	Guangdong	
126	南安府	Nan'an Fu	江西	Jiangxi		171	廉州府	Lianzhou Fu	广东	Guangdong	
127	宁都直隶州	Ningdu Zhilizhou	江西	Jiangxi		172	雷州府	Leizhou Fu	广东	Guangdong	
128	福州府	Fuzhou Fu	福建	Fujian		173	琼州府	Qiongzhou Fu	广东	Guangdong	
129	泉州府	Quanzhou Fu	福建	Fujian		174	罗定直隶州	Luoding Zhilizhou	广东	Guangdong	
130	建宁府	Jianning Fu	福建	Fujian		175	连州直隶州	Lianzhou Zhilizhou	广东	Guangdong	
131	延平府	Yanping Fu	福建	Fujian		176	嘉应直隶州	Jiaying Zhilizhou	广东	Guangdong	
132	汀州府	Tingzhou Fu	福建	Fujian		177	佛冈直隶厅	Fogang Zhiliting	广东	Guangdong	
133	兴化府	Xinghua Fu	福建	Fujian		178	连山直隶厅	Lianshan Zhiliting	广东	Guangdong	
134	邵武府	Shaowu Fu	福建	Fujian		179	桂林府	Guilin Fu	广西	Guangxi	

Table B.3 – Chinese regions(continued)

Region No.	Name	Prefecture name in pinyin	Province	Province in pinyin	Yangzi Delta	Region No.	Name	Prefecture name in pinyin	Province	Province in pinyin	Yangzi Delta
135	漳州府	Zhangzhou Fu	福建	Fujian		180	柳州府	Liuzhou Fu	广西	Guangxi	
182	思恩府	Si'en Fu	广西	Guangxi		218	楚雄府	Chuxiong Fu	云南	Yunan	
183	平乐府	Pingle Fu	广西	Guangxi		219	澂江府	Chengjiang Fu	云南	Yunan	
184	梧州府	Wuzhou Fu	广西	Guangxi		220	广西直隶州	Guangxi Zhilizhou	云南	Yunan	
185	浔州府	Xunzhou Fu	广西	Guangxi		221	顺宁府	Shunning Fu	云南	Yunan	
186	南宁府	Nanning Fu	广西	Guangxi		222	曲靖府	Qujing Fu	云南	Yunan	
187	太平府	Taiping Fu	广西	Guangxi		223	武定直隶州	Wuding Zhilizhou	云南	Yunan	
188	郁林直隶州	Yulin Zhilizhou	广西	Guangxi		224	永昌府	Yongchang Fu	云南	Yunan	
189	泗城府	Sicheng Fu	广西	Guangxi		225	永北直隶厅	Yongbei Zhiliting	云南	Yunan	
190	镇安府	Zhenan Fu	广西	Guangxi		226	元江直隶州	Yuanjiang Zhilizhou	云南	Yunan	
191	成都府	Chengdu Fu	四川	Sichuan		227	广南府	Guangnan Fu	云南	Yunan	
192	保宁府	Baoning Fu	四川	Sichuan		228	蒙化直隶厅	Menghua Zhiliting	云南	Yunan	
193	顺庆府	Shunqing Fu	四川	Sichuan		229	景东直隶厅	Jingdong Zhiliting	云南	Yunan	
194	叙州府	Xuzhou Fu	四川	Sichuan		230	开化府	Kaihua Fu	云南	Yunan	
195	重庆府	Zhongqing Fu	四川	Sichuan		231	丽江府	Lijiang Fu	云南	Yunan	

Table B.3 – Chinese regions(continued)

Region No.	Name	Prefecture name in pinyin	Province	Province in pinyin	Yangzi Delta	Region No.	Name	Prefecture name in pinyin	Province	Province in pinyin	Yangzi Delta
196	夔州府	Kuizhou Fu	四川	Sichuan		232	东川府	Dongchuan Fu	云南	Yunan	
197	龙安府	Longan Fu	四川	Sichuan		233	镇沅直隶州	Zhenyuan Zhiliting	云南	Yunan	
198	潼川府	Tongchuan Fu	四川	Sichuan		234	昭通府	Zhaotong Fu	云南	Yunan	
199	嘉定府	Jiading Fu	四川	Sichuan		235	普洱府	Puer Fu	云南	Yunan	
200	雅州府	Yazhou Fu	四川	Sichuan		236	镇雄直隶州	Zhenxiong Zhilizhou	云南	Yunan	
201	眉州	Meizhou Zhilizhou	四川	Sichuan		237	贵阳府	Guiyang Fu	贵州	Guizhou	
202	邛州	Qiongzhou Zhilizhou	四川	Sichuan		238	思州府	Sizhou Fu	贵州	Guizhou	
203	泸州直隶州	Luzhou Zhilizhou	四川	Sichuan		239	思南府	Sinan Fu	贵州	Guizhou	
204	资州	Zizhou Zhilizhou	四川	Sichuan		240	镇远府	Zhenyuan Fu	贵州	Guizhou	
205	绵州	Mianzhou Zhilizhou	四川	Sichuan		241	石阡府	Shiqian Fu	贵州	Guizhou	
206	茂州	Maozhou Zhilizhou	四川	Sichuan		242	铜仁府	Tongren Fu	贵州	Guizhou	
207	叙永厅	Xuyong Zhilizhou	四川	Sichuan		243	黎平府	Liping Fu	贵州	Guizhou	
208	绥定府	Suiding Fu	四川	Sichuan		244	安顺府	Anshun Fu	贵州	Guizhou	
209	宁远府	Ningyuan Fu	四川	Sichuan		245	都匀府	Duyun Fu	贵州	Guizhou	
210	酉阳州	Youyang Zhilizhou	四川	Sichuan		246	平越直隶州	Pingyue Zhilizhou	贵州	Guizhou	

Table B.3 – Chinese regions(continued)

Region No.	Name	Prefecture name in pinyin	Province	Province in pinyin	Yangzi Delta	Region No.	Name	Prefecture name in pinyin	Province	Province in pinyin	Yangzi Delta
211	忠州	Zhongzhou Zhilizhou	四川	Sichuan		247	大定府	Dading Fu	贵州	Guizhou	
212	松潘厅	Songpan Zhiliting	四川	Sichuan		248	兴义府	Xingyi Fu	贵州	Guizhou	
213	石砫厅	Shizhu Zhiliting	四川	Sichuan		249	遵义府	Zunyi Fu	贵州	Guizhou	
214	太平厅	Taiping Zhiliting	四川	Sichuan		250	仁怀直隶厅	Renhuai Zhiliting	贵州	Guizhou	
215	云南府	Yunnan Fu	云南	Yunan		251	松桃直隶厅	Songtao Zhiliting	贵州	Guizhou	
216	大理府	Dali Fu	云南	Yunan		252	普安直隶厅	Pu'an Zhiliting	贵州	Guizhou	
217	临安府	Lin'an Fu	云南	Yunan							

Table B.4: Summary statistics for grain prices

	n	Mean	Std. Dev.	Coeff. Var.	One-month Δnon-zero Mean
Britain					
Wheat	48,314	7.732	2.696	0.349	0.994
Bandpass filtered					
Wheat	48,314	1.001	0.049	0.048	0.994
China					
Wheat	107,069	1.466	0.521	0.355	0.344
Millet	52,947	1.601	0.558	0.348	0.456
Rice 1st quality	74,282	1.798	0.603	0.336	0.517
Rice 2nd quality	84,458	1.694	0.572	0.338	0.464
Bandpass filtered					
Wheat	107,069	1.000	0.02	0.02	0.344
Millet	52,947	1.000	0.022	0.022	0.456
Rice 1st quality	74,231	1.000	0.018	0.018	0.517
Rice 2nd quality	84,374	1.000	0.02	0.02	0.464

Notes: Source of data, see text. Last column gives the fraction of one-month price changes that is non-zero in the original data source.

Table B.5: Carry costs of grain, 1770 to 1860

			Monthly rate		Annualized
		n	Mean (%)	Std. dev.	(%)
Britain	Wheat	4,074	0.854	2.577	10.248
China	All grains	15,152	1.144	2.446	13.732
China	Wheat	4,930	1.124	2.577	13.488
	Millet	3,973	1.02	2.598	12.242
	Rice 1st quality	5,135	1.071	1.978	12.854
	Rice 2nd quality	5,384	1.074	2.133	12.883
Bandpass filtered					
Britain	Wheat	4,102	0.684	2.239	8.209
China	All grains	13,403	0.801	2.172	9.612
China	Wheat	4,221	0.774	1.886	9.284
	Millet	3,314	0.684	2	8.21
	Rice 1st quality	4,366	0.761	2.048	9.131
	Rice 2nd quality	4,794	0.781	2.054	9.376

Notes: Means are weighted by the fraction of month-to-month prices changes that are non-zero as shown in Table B.4. Annual rates are computed as 12 times the monthly rate.

Table B.6: Spatial Aggregation and capital market integration

	Baseline		Aggregated	
	Unfiltered	Filtered	Unfiltered	Filtered
0-100 km	0.8	0.71	0.85	0.81
	(0.16)	(0.17)	(0.1)	(0.11)
	[n = 350]	[n = 350]	[n = 42]	[n = 42]
100-200km	0.77	0.68	0.82	0.74
	(0.16)	(0.18)	(0.13)	(0.13)
	[n = 788]	[n = 788]	[n = 162]	[n = 162]
200-300km	0.74	0.66	0.81	0.71
	(0.17)	(0.17)	(0.12)	(0.11)
	[n = 720]	[n = 720]	[n = 170]	[n = 170]
300-400km	0.73	0.65	0.8	0.7
	(0.18)	(0.16)	(0.12)	(0.11)
	[n = 476]	[n = 476]	[n = 132]	[n = 132]
400-500km	0.7	0.63	0.78	0.69
	(0.18)	(0.19)	(0.13)	(0.11)
	[n = 246]	[n = 246]	[n = 74]	[n = 74]
500-600km	0.7	0.62	0.79	0.67
	(0.19)	(0.23)	(0.19)	(0.15)
	[n = 64]	[n = 64]	[n = 20]	[n = 20]

Notes: All results are for Britain. Shown in the Baseline columns are results for 52 counties. In the Aggregated columns, the 52 counties are aggregated to 26 regions that on average closely resemble the size of a Chinese prefecture.

Table B.7: Convenience yields and capital market performance

	Less than 10% above price trend		No consecutive price increases		Low volatility	
	Britain	China	Britain	China	Britain	China
0-200 km	0.776	0.438	0.782	0.441	0.732	0.388
	(1,138)	(748)	(1,128)	(738)	(1,128)	(712)
200-400 km	0.734	0.252	0.748	0.264	0.677	0.193
	(1,196)	(1,482)	(1,176)	(1,412)	(1,174)	(1,320)
400-600 km	0.722	0.124	0.727	0.145	0.631	0.086
	(310)	(1,780)	(298)	(1,626)	(298)	(1,384)

Notes: Entries give average bilateral interest rate correlation; number of observations given in parentheses. Results for three different subsamples during which convenience yields are expected to be low are shown. Less than 10% above price trend: Compute 5 period moving average trend based on annual average grain prices; identify all years in which actual price is less than 10% above this moving average trend. No consecutive price increases: Construct indicator variable equal to 1 if region has seen three or more consecutive price increases leading up to year t; results based on data for which indicator is 0. Low volatility: For year t and month m, compute price volatility as the standard deviation of prices in years t-1, t, and t+1. Take the average of these twelve month-specific standard deviations as the volatility of year t. Analysis is based on the lower 75 percent of observations in terms of volatility.

Table B.8: The role of sample composition before and after 1820

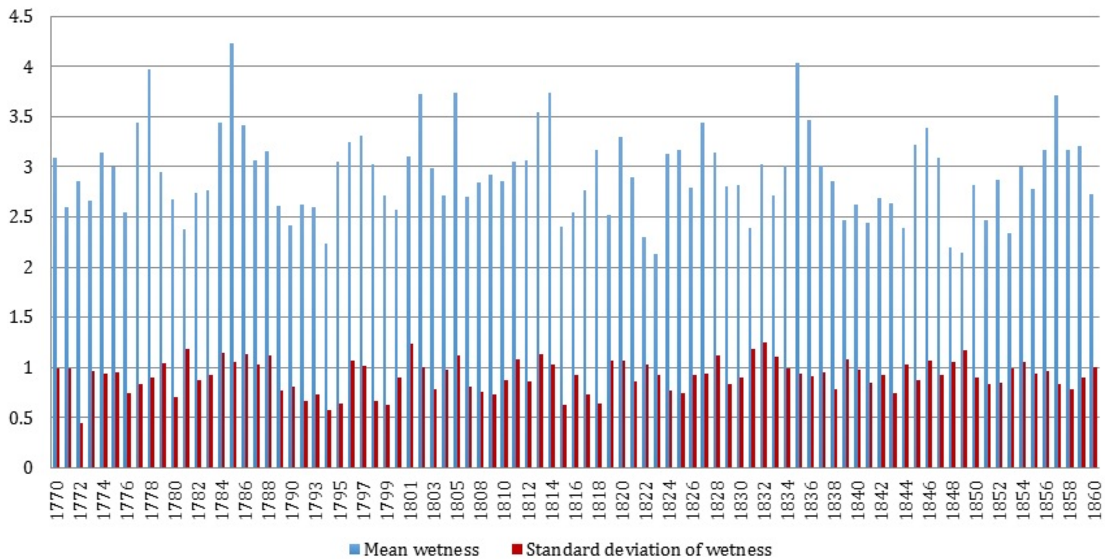
	Britain		China	
	Before 1820	After 1820	Before 1820	After 1820
0-100 km	0.73	0.72	0.38	0.29
	(0.20)	(0.23)	(0.32)	(0.32)
	[n = 350]	[n = 314]	[n = 116]	[n = 108]
100-200km	0.69	0.71	0.28	0.23
	(0.22)	(0.23)	(0.40)	(0.30)
	[n = 788]	[n = 724]	[n = 380]	[n = 274]
200-300km	0.66	0.69	0.21	0.22
	(0.21)	(0.26)	(0.42)	(0.35)
	[n = 720]	[n = 660]	[n = 472]	[n = 380]
300-400km	0.66	0.68	0.15	0.14
	(0.22)	(0.24)	(0.36)	(0.36)
	[n = 476]	[n = 430]	[n = 474]	[n = 288]
400-500km	0.64	0.66	0.10	0.09
	(0.28)	(0.21)	(0.33)	(0.43)
	[n = 246]	[n = 216]	[n = 478]	[n = 276]
500-600km	0.56	0.67	0.06	0.09
	(0.42)	(0.24)	(0.34)	(0.39)
	[n = 64]	[n = 58]	[n = 530]	[n = 278]

Notes: Results for mean bilateral correlations of interest rates based on filtered wheat prices. Standard deviation in parentheses.

Table B.9: Capital market integration and time series length

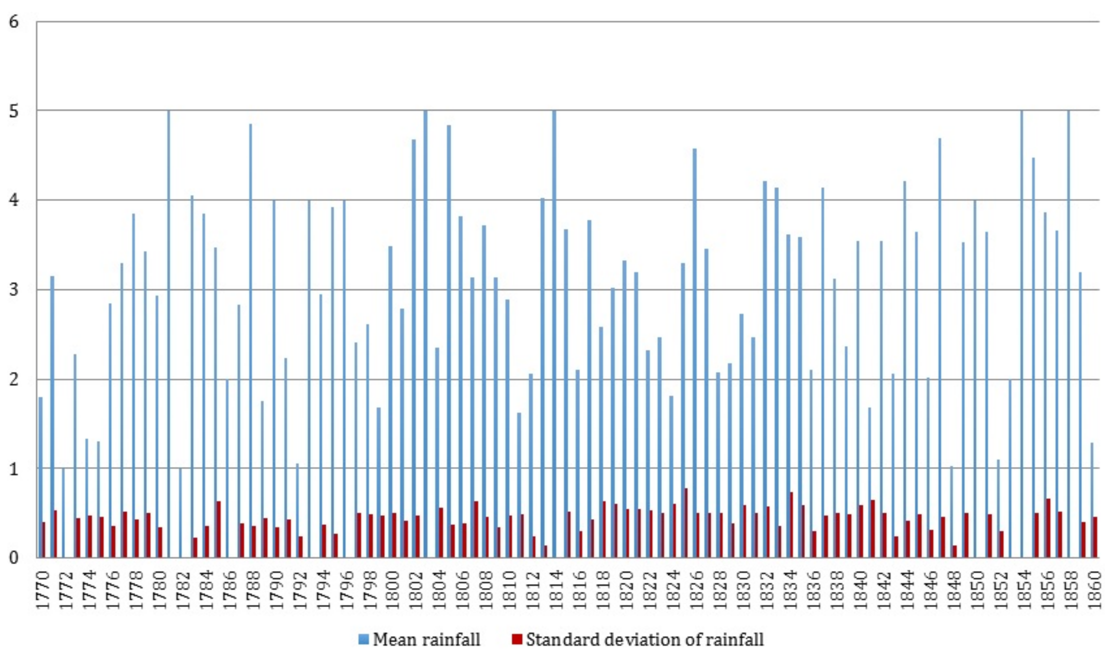
	Britain		China	
	All	50 < x < 70	All	50 < x < 70
0-100 km	0.71	0.68	0.51	0.61
	(0.17)	(0.18)	(0.46)	(0.50)
	[n = 350]	[n = 92]	[n = 158]	[n = 56]
100-200km	0.68	0.67	0.35	0.46
	(0.18)	(0.18)	(0.54)	(0.61)
	[n = 788]	[n = 222]	[n = 494]	[n = 164]
200-300km	0.66	0.67	0.25	0.36
	(0.17)	(0.16)	(0.58)	(0.49)
	[n = 720]	[n = 224]	[n = 612]	[n = 118]
300-400km	0.65	0.65	0.17	0.33
	(0.16)	(0.13)	(0.56)	(0.23)
	[n = 476]	[n = 136]	[n = 660]	[n = 66]
400-500km	0.63	0.65	0.10	0.22
	(0.19)	(0.14)	(0.55)	(0.29)
	[n = 246]	[n = 80]	[n = 804]	[n = 48]
500-600km	0.62	0.66	0.08	0.19
	(0.23)	(0.12)	(0.62)	(0.55)
	[n = 64]	[n = 28]	[n = 802]	[n = 108]

Notes: Results for mean bilateral correlations of interest rates based on filtered wheat prices for Britain and based on filtered second-grade rice prices for China. Results for columns "All" are for interest rate correlations using all data, from Table 3.4. Results for columns "50 < x < 70" are for pairs of regions with 50 to 70 years of data in the period 1770 to 1860. Standard deviation in parentheses, and number of observations in brackets.



Source: State Meteorological Society (1981)

Figure B.1: Climate in China: Annual wetness, 1770-1860



Source: Pauling, Luterbacher, Casty, and Wanner (2006)

Figure B.2: Climate in Britain: Annual rainfall, 1770-1860

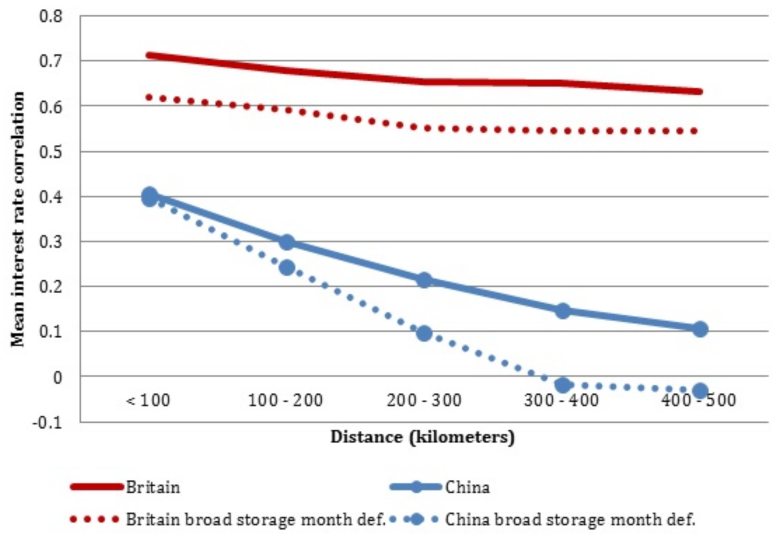


Figure B.3: Capital market integration comparison and storage months