The Pennsylvania State University
The Graduate School
Department of Economics

ESSAYS ON INTERNATIONAL TRADE AND MULTINATIONAL PRODUCTION

A Dissertation in
Economics
by
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Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Doctor of Philosophy

August 2016

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Abstract

This dissertation includes two chapters on international trade and multinational production. My research focuses on estimating the frictions that impede commodity trades and knowledge transfers across countries, and quantifying the consequences of policies that aim to lower these frictions. In both chapters, I build and structurally estimate multi-country general equilibrium models, conducting policy experiments based on these models. However, they emphasize different economic forces that affect the implications of trade and multinational production liberalization.

Chapter 1: Headquarters Gravity

Multinational firms play a crucial role in international trade and production. I develop a new general equilibrium model that characterizes multinational firms' export behaviors and quantify their implications for trade and welfare. The unique feature of this model is that it allows a multinational affiliate's export cost to each market to depend on how close this market is to its production location (gravity) and to its headquarters (headquarters gravity). I show analytically that in existence of headquarters gravity the standard gravity equation is not enough to characterize trade flows across countries. The model delivers structural gravity equations that allow me to estimate headquarters gravity from Chinese firm data. The estimates suggest that multinational affiliates face much lower export costs to markets closer to their headquarters. I then calibrate the general equilibrium model to the world of 2001 with 28 major economies. The model fits the multinational firms' exports well both in firm-level and aggregate data. Counterfactual experiments show that if foreign affiliates in China have the same export costs as Chinese firms, Chinese manufacturing exports in 2001 would decrease by about a quarter. Furthermore, I show that ignoring headquarters gravity would substantially bias the estimates of welfare gains from multinational production. Finally, I demonstrate the usefulness of my model in quantifying the impacts of regional trade and investment agreements and the spillover effects of domestic policies.

Chapter 2: Multinational Production and External Economies of Scale

I introduce locally external economies of scale in production into a standard multi-country general equilibrium model with trade and multinational production (MP). I provide sufficient conditions for the existence and uniqueness of equilibrium. The model shows that both the elasticity of trade flows with respect to trade costs and the external economies of scale in production are crucial for the welfare implications of trade and MP liberalization. Via the lens of my model, I separate the external economies of scale from comparative advantage using the event of China joining WTO as an instrument. Counterfactual analysis shows that with stronger external economies of scale in production developing countries specalized in production gain more from MP liberalization.

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Acknowledgments

I am deeply indebted to my advisor Stephen Yeaple, who led me into the fantastic research field of multinational production, shared his knowledge and experience, and always encouraged me towards better research.

I would also like to express my appreciation to Jonathan Eaton. His comments always pushed me to clarify my thoughts and organize my dissertation in a more transparent way.

Thanks also to Felix Tintelnot, who offered invaluable comments to the preliminary version of Chapter 1.

My research has greatly benefited from discussions with James Tybout, Kala Krishna, Paul Grieco, Marc Henry, and Vijay Krishna. Helpful comments have also come from Pol Antras, Treb Allen, Dan Lu, Melanie Morten, Fernando Parro, Ferdinando Monte, Eduardo Morales, Alan Deardorff, Jing Zhang, and Michael Peters. I thank my classmates Jianpeng Deng, Kai Li, Hongsong Zhang, Yanping Liu for countless discussions. I also thank the best staff Krista Winkelblech, whose support is critical for the accomplishment of my dissertation.

Dedication

To my parents, my wife Peipei, and my son Steve.

Chapter 1

Headquarters Gravity

1.1 Introduction

Export-led growth has dominated development strategies in recent decades. However, this strategy faces challenge of getting access to foreign markets. Local firms lack the knowledge of foreign markets and the expertise in international transaction. Also, their brand names are hardly known by foreign consumers. In contrast, multinational firms[1] excel in these dimensions by their very nature. Indeed, in recent success stories such as China and Ireland, their exports have primarily been driven by foreign multinationals.[2]

This paper investigates the exporting behaviors of multinational firms. I start with assembling a new Chinese firm database with information on the nationalities of foreign affiliates in China and their exports by destination. I find that not only do foreign affiliates in China export more than Chinese firms, but they also export more to markets closer to their headquarters. I define this dependence of destination market access on headquarters locations as *headquarters gravity*.

Headquarters gravity is consistent with the idea long noticed by the marketing literature that firms can hardly make large sales in markets far away from their

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[1] A multinational firm is an enterprise that controls and manages production establishments in at least two countries. Parents are entities located in headquarters, while affiliates are establishments located outside headquarters countries that are owned by parents.

[2] In 2001, according to OECD data 91% of Irish manufacturing exports were carried out by foreign affiliates in Ireland. And according to Chinese customs records, in 2001 68% of Chinese manufacturing exports were carried out by foreign affiliates in China.

headquarters,[3] which can be attributed to several issues. For example, A firm may own better-known brand names in markets closer to their headquarters. It may know more about the consumers' tastes in these markets. And it is more likely to establish marketing and distribution networks there. However, these factors have not been incorporated into quantitative frameworks for multinational production (MP). Previous studies assume that multinational affiliates face the same export costs with local firms, which as I will show below is inconsistent with the micro data.[4]

This paper aims to identify headquarters gravity from micro data and quantify its implications for trade and welfare consequences of MP liberalization. To achieve this, I develop and estimate a multi-country general equilibrium model of trade and MP. Following Melitz (2003), firms are heterogeneous in productivity and incur both iceberg[5] and fixed costs to export. I depart from the Melitz model by assuming that (i) firms can produce outside their home countries at the expense of efficiency losses and fixed costs, and (ii) an affiliate's export cost to each market depends on how close this market is to its production location (*gravity*) and to its headquarters (*headquarters gravity*).[6] The firm decides the locations of its plants and the global sales of each plant simultaneously based on its productivity, headquarters gravity, and the trade and MP frictions emphasized in the literature.[7] This paper is the first attempt to incorporate headquarters gravity into a general equilibrium framework, providing a natural workhorse to evaluate the implications of globalization.

My model provides a unified framework that can consistently estimate headquarters gravity along with other trade and MP frictions. I estimate my model in a two-tiered empirical framework. First, I estimate headquarters gravity in Chinese firm data. The major empirical challenge is that both productivities and headquar-

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[3] For example, Bronnenberg, Dhar, and Dube (2009) finds that a brand's market shares are systematically higher in markets closer to its city of origin.

[4] See for example Tintelnot (2014), Arkolakis et al. (2015), Irarrazabal, Moxnes, and Opromolla (2013), and Ramondo and Rodriguez-Clare (2013).

[5] The iceberg cost is a cost of transferring a good or an idea that uses up only some fraction of the good or idea itself. For example, a 10 percent iceberg cost means that to transfer a unit of goods or idea to destination, we need to send 1.1 unit from the source. We often measure iceberg costs by the units of goods sent from source to deliver a unit to destination. An iceberg cost of 1.5 is 25 percent higher than an iceberg cost of 1.2.

[6] As common in the trade literature, I assume that preferences are of constant elasticity of substitution (CES). Under CES preferernces, it is isomorphic to model market access in terms of export costs and in terms of market-specific demand.

[7] These frictions include iceberg and fixed costs of producing in foreign countries, and iceberg and fixed export costs that depend on the distance between the destination and production location.

ters gravity affect affiliate exports. The identification of headquarters gravity comes from the fact that the productivity affects firm sales in all markets but headquarters gravity affect firm sales in certain export markets. I control firms productivities by their sales in China and uncover headquarters gravity from the remaining variation of exports with respect to the distance between the destination and the headquarters.

The structural estimates suggest that headquarters gravity is substantial. The iceberg export cost of a foreign affiliate in China to its headquarters country is, *ceteris paribus*, 32 percent lower than to any other country, while the fixed export cost is 80 percent lower. Doubling the distance between headquarters and destination will increase an affiliate's iceberg export cost by 5 percent, and fixed export cost by 10 percent. On average, the iceberg export cost of foreign affiliates in China is 28 percent lower than that of Chinese firms, while the fixed export cost is 82 percent lower.

In the second tier, I embed the estimated headquarters gravity into the general equilibrium model and calibrate the full set of trade and MP frictions across countries by fitting equilibrium outcomes to aggregate bilateral trade and MP data. To highlight the importance of headquarters gravity, I also calibrate a model without headquarters gravity by letting all multinational affiliates have the same export costs as local firms and fitting equilibrium outcomes to aggregate data. The results suggest that comparing to the model without headquarters gravity, my baseline model fits multinationals' exports better in both Chinese firm data and aggregate OCED data.

With the calibrated model, I quantify the impacts of headquarters gravity on trade and welfare by counterfactual experiments. If foreign affiliates in China have the same export costs as Chinese firms, Chinese manufacturing exports in 2001 would decrease by about a quarter. Furthermore, if we shut down all foreign affiliates in China, Chinese manufacturing exports would decrease by about a half. Consequently, both multinationals' productivities and headquarters gravity are quantitatively important for Chinese export-led growth. This result relates to the hot debate in rich countries on the increasing import competition from China. It suggests that a large fraction of import competition from China can be attributed to foreign affiliates in China, in particular to their connections with the markets close to their headquarters.

It is essential to incorporate headquarters gravity into a general equilibrium model because it can affect our estimates on welfare gains from MP. In my baseline model, shutting down all foreign affiliates in China would decrease Chinese real income by 10 percent. In the model without headquarters gravity, shutting down foreign affiliates in China would decrease Chinese real income by 13 percent. This is because multinationals' productivities and headquarters gravity have different welfare implications. Higher productivities can lower multinationals' unit costs in serving Chinese markets, while lower export costs cannot. Without headquarters gravity, we will attribute the multinational affiliates' sales solely to their productivities, which makes us overestimate Chinese welfare gains from multinational production. The opposite happens in the U.S. With headquarters gravity, the U.S. multinational firms can exploit Chinese cheap labors to serve the U.S. market with low costs, which is very much beneficial to the U.S. So in order to understand the welfare consequences of MP liberalization, we need to understand the structure of multinational firms' export costs, which have been carefully estimated in this paper.

This paper is related to several strands of the literature. First, it contributes to a growing literature about the multinationals' home market advantage. Head and Mayer (2015) find that in the auto industry, it is more difficult to make sales in markets farther away from the brand's headquarters. This paper departs from their study by focusing on aggregate trade patterns instead of on one industry. Moreover, my model endogenizes the choices on production locations and export destinations, whereas in Head and Mayer (2015) these decisions are taken as a given. These margins are shown to be important for trade and welfare. Cosar et al. (2015) emphasize firms' disadvantage in selling outside of their home countries. This paper complements their study by emphasizing that the multinationals' advantage in the home markets can be transferred to their affiliates.

Second, this paper builds on, and contributes to, quantitative studies of trade and multinational production. Tintelnot (2014) allows firms to build export platforms at the expense of fixed costs. Irarrazabal, Moxnes, and Opromolla (2013), Ramondo and Rodriguez-Clare (2013) and Arkolakis et al. (2015) aim to quantify the gains from openness in a world with both trade and multinational production. All of these papers assume that foreign affiliates face the same export costs as local firms. So they cannot capture the advantage of multinational affiliates in serving markets close to their headquarters.

Third, this paper contributes to the literature on informational and marketing frictions in international trade. Unlike most firms whose production sites and headquarters are in the same country, multinational firms produce outside home countries, enabling us to disentangle the standard gravity that depends on the proximity between production locations and destination markets, and the headquarters gravity. This paper explores the roles of informational and marketing costs represented by headquarters gravity, complementing the findings in Arkolakis (2010) and Allen (2014).

Fourth, this paper contributes to studies about across-border knowledge transfer driven by multinational production. Previous papers focus on multinationals transferring productive knowledge to their affiliates (MacGrattan and Prescott, 2009; Burstein and Monge-Naranjo, 2009). This paper complements these papers by emphasizing that the parents transfer to their affiliates not only productive knowledge, but also access to international markets.

The rest of the paper is organized as follows. In Section 1.2, I describe the data I use and document facts about exports by foreign affiliates in China. In Section 1.3, I introduce my model, define the equilibrium, and deliver structural equations for estimation. In Section 1.4, I identify and estimate the headquarters gravity from Chinese firm data. Section 1.5 calibrates the general equilibrium model. Section 1.6 presents comparative statics. Section 1.7 concludes.

1.2 Data and stylized facts

1.2.1 Data description

The cross-sectional data of essentially all manufacturing firms located in China in 2001 is created by merging the balance sheet data and trade data for all manufacturers and the registration information of foreign manufacturers in China.

The balance sheets come from the Annual Survey of Chinese Manufacturing (ASCM)[8] which contains the firms' total sales, employment, and capital stocks. The firm exports come from the Chinese Customs Records (CCR) which contains the export value of each firm by destination[9]. The registration information of foreign

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[8] ASCM contains all state-owned manufacturing firms and other manufacturing firms whose annual sales exceed 5 million RMB (about 0.6 million dollars). The omitted firms are small and unlikely to be engaged with international trade.

[9] The original data contains the value, the destination, the 8-digit HS category, and the mode of trade for each export transaction. Because I am interested in the overall export performance of

manufacturers in China comes from Foreign-Invested Enterprise Survey in China (FIESC) which contains the nationality of a firm's primary foreign investor. The details on data construction are presented in the appendix.

Table 1.1 depicts the importance of foreign affiliate in Chinese manufacturing sectors. In 2001, they account for about 10 percent of Chinese manufacturing plants and 13 percent manufacturing employment, but for nearly 30 percent of manufacturing sales and 70 percent of manufacturing exports. Table 1.1 confirms that Chinese export-led growth was primarily driven by foreign affiliates in China.

Enterprises	Employment	Sales	Exports
11	13.1	27	68

Table 1.1: Foreign Affiliates in Chinese Manufacturing Sectors in 2001

(Note: Percentage shares of foreign affiliates in Chinese manufacturing sectors are shown. Affiliates from Hong Kong and Macau are excluded.)

TTable 1.2 summarizes the sales distribution of manufacturing firms in China that come from four major sources: China, Europe, Japan and Korea, and the U.S. These four regions happen to be four largest export destinations for Chinese manufacturing goods. It turns out that firms sell disproportionately to their home markets, which as I will show below cannot hold in the model without headquarters gravity.

	Source				
Destination	China	Europe	J&K	USA	Total
China	96.3	84.0	45.6	76.1	91.3
Europe	1.1	8.7	8.2	6.7	2.3
J&K	1.4	3.4	36.0	4.0	4.0
USA	1.2	3.9	10.2	13.2	2.4
Total	100	100	100	100	100

Table 1.2: Sales distribution of Manufacturing firms in China (2001)
(Unit: percentage)

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individual firms, I aggregate the export value in firm-destination level

1.2.2 Empirical Regularities

I now turn to describe empirical regularities for multinational affiliates' exports.

Fact 1: Controlling for firm characteristics, foreign multinational affiliates in China are more likely to export and export more than Chinese domestic firms.

I estimate the extensive and intensive margins of firm exports controlling for observed firm characteristics such as industry, value-added, employment, and capital.

$$\mathbf{1}\{exp(\nu) > 0\} = \mathbf{1}\{\beta_0 + \beta_1 foreign(\nu) + \mathbf{Z}(\nu)\beta_2 + u(\nu) \geq 0\}, \tag{1.1}$$

where $exp(\nu)$ is total export sales of firm ν, $foreign(\nu)$ is the dummy for foreign firm, control $\mathbf{Z}$ includes industry, value-added, employment, and capital, and $u(\nu)$ is normally distributed.

Intensive margin is estimated by

$$\log(exp(\nu)) = \beta_0 + \beta_1 foreign(\nu) + Z(\nu)\beta_2 + u(\nu). \tag{1.2}$$

	$\mathbf{1}\{exp(\nu) > 0\}$	$\log(exp(\nu))$
$foreign$	1.357***	1.231***
	(0.011)	(0.025)
Value-added (in log)	0.0444***	0.610***
	(0.0040)	(0.0081)
Employment (in log)	0.209***	0.225***
	(0.0054)	(0.013)
Capital (in log)	0.101***	-0.0865***
	(0.0038)	(0.0097)
Industry Dummy	Yes	Yes
R-square		.30
N. of Obs.	120715	34738

Table 1.3: The export advantage of foreign affiliates: Extensive and Intensive Margins

Fact 1 confirms that the multinational affiliates' export advantage cannot be fully explained by their size, labor productivity, and capital intensity. In other words, foreign ownership should be considered as a separate determinant for firms' exports.

Fact 2: Controlling for the firm characteristics, the destination market size, and the destination distance from China, foreign affiliates in China are more likely to export and export more to the markets closer to their headquarters.

Following Morales et al. (2015), I measure the distance between headquarters country i and destination d a vector D_{di} which consists of their geographic distance, $\log(dist_{di})$, a dummy for common language, $lang_{di}$, a dummy for similar GDP per capita $sgdp_{di}$, and a dummy for $i = d$, $self_{di}$. Let $x_{dni}(\nu)$ be the sales of affiliate ν who produce in country n (here n is China) and whose headquarters is located in country i to destination market d. Then the export entry is estimated by

$$\mathbf{1}\{x_{dni}(\nu) > 0\} = \mathbf{1}\{fe_d + fe(\nu) + \beta_3 D_{di} + u_d(\nu) \geq 0\}, \quad d \neq n = CHN, \tag{1.3}$$

where fe_d is the destination fixed effect and $fe(\nu)$ is the affiliate fixed effect.

The export sales to destination d is estimated by

$$\log(x_{dni}(\nu)) = fe_d + fe(\nu) + \beta_3 D_{di} + u_d(\nu), \quad d \neq n = CHN. \tag{1.4}$$

The reduced-form results are presented in table 1.4. They suggest that the location of headquarters does matter for affiliates' exports. Controlling for the standard gravity, multinational affiliates export disproportionately more to their headquarters countries. The affiliates' exports would decrease by 4% if the geographic distance between headquarters and destination doubles. Furthermore, the shared language and similar GDP per capita between the headquarters and the destination matter for affiliates' exports.

This regularity is robust in more disaggregated data and different specifications. Interestingly, I find that the home market advantage is stronger for differentiated goods than for homogeneous goods, which is consistent with the idea that the market access is more important in the exports of differentiated goods. Other robustness exercises are presented in the appendix.

1.3 The Model

I present a general equilibrium model with trade and MP. The model consists of two parts. The first part characterizes the affiliates' export entry and sales given their production locations. This part is set to capture key features in micro trade data. The second part characterizes firms' choices of production locations. This part is introduced to close the model and provide general equilibrium implications. I start

	$\mathbf{1}\{x_{dni}(\nu) > 0\}$	$\log(x_{dni}(\nu))$	$\mathbf{1}\{x_{dni}(\nu) > 0\}$	
			Homo.	Diff.
$\log(dist_{di})$	-.023**	-.026	0.0218	-0.0344***
	(.01)	(.02)	(0.016)	(0.0087)
$self_{di}$	.60***	1.36***	0.656***	0.650***
	(.08)	(.12)	(0.088)	(0.056)
$lang_{di}$	.055**	.18***	0.0684*	0.0885***
	(.022)	(.04)	(0.035)	(0.020)
$sgdp_{di}$	.22***	.07	0.0693	0.195***
	(.026)	(.06)	(0.045)	(0.023)
Destination FE	Yes	Yes	Yes	Yes
Affiliate FE	Yes	Yes	Yes	Yes
R-square		.46		
N. of Obs.	116071	43860	56048	170885

Table 1.4: Extensive and Intensive Margins of Headquarters Gravity

(Note: Country i is the headquarter country. Country n is the production country, which is China in my micro data. Country d is the destination market. $\mathbf{1}\{x_{dni}(\nu) > 0\}$ indicates whether an affiliate from i and located in n exports to market d. $x_{dni}(\nu)$ is the exports conditional on entry. $dist_{di}$ is the distance between i and d. $self_{di}$ is the dummy for $i = d$. $lang_{di}$ is the dummy for i and d speak the same language. $sgdp_{di}$ is the dummy for i and d have similar GDP per capita. The sample excludes affiliates from China, Hong Kong, Taiwan and Macau. The extensive margin is estimated by Probit model, while the intensive margin is estimated by OLS. The estimation controlling for firm fixed effects excludes all firms with less than 15 export destinations.)

with the description of the demand and then turn to the firm's problem.

I consider a world with $i = 1, \ldots, N$ countries, one primary factor of production, labor L_i, and a continuum of horizontally differentiated varieties of goods. In each country the representative consumer has a Constant Elasticity of Substitution (CES) preference over a continuum of goods varieties:

$$U_i = [\int_{\omega \in \Omega_i} q_i(\omega)^{\frac{\sigma-1}{\sigma}} d\omega]^{\frac{\sigma}{\sigma-1}}, \tag{1.5}$$

where the elasticity of substitution $\sigma > 1$, $q_i(\omega)$ is the quantity of variety ω consumed in country i, and Ω_i is the set of varieties sold in country i.

1.3.1 The Firm's Problem

Each variety is produced by a firm under monopolistic competition. Firm ν originated from country i draws a productivity $\varphi_i(\nu)$. The measure of firms with

$\varphi_i \geq \varphi$ is exogenously given by

$$F_i(\varphi) = T_i\varphi^{-\theta}, \quad \varphi > 0, \quad T_i > 0, \quad \theta > \sigma - 1. \tag{1.6}$$

After drawing productivity, a firm can replicate its technology in multiple production sites by building affiliates. Without loss of generality I assume that each firm can at most build one affiliate in each country.[10] To ensure model identifiability in the data, I make the following assumption:

Assumption 1 *Each affiliate produces a distinctive variety ω, i.e. an affiliate's pricing does not affect the demand faced by other affiliates within firm boundary.*

Assumption 1 implies that, for example, consumers regard Toyato cars produced in Japan and in the U.S. as two different goods. This "Armington" assumption has to be enforced due to data limitation. Note that Chinese firm data contains the nationalities of foreign affiliates in China and their exports to each market from China. But I do not observe the MP sales of these multinationals in other countries. Assumption 1 makes my model identifiable in Chinese firm data by separating the affiliate's export decision from the firm's MP decision.

In the rest of this subsection I will introduce geographic frictions that affect the firm's multinational production and sales and then solve the firm's problem.

1.3.1.1 Frictions Shaping Multinational Sales

There are three types of frictions impeding the multinational activities. First, transferring technologies from headquarters to affiliates incurs iceberg efficiency losses and fixed costs for creating affiliates. Second, transferring products from production sites to destination markets incurs iceberg and fixed shipping costs. The iceberg shipping costs can be freight costs or tariffs while the fixed shipping costs, for example, can be the costs of creating distribution networks. These two types of frictions have been well-documented in the literature.

This paper introduces a new type of frictions: for each of its affiliates to serve a destination market, a multinational firm incurs fixed and iceberg marketing costs. This new type of frictions represents all advantages an affiliate has in serving markets

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[10] I refer to an affiliate by its parent firm ν and its location country n. In the case without confusion, I also use ν to represent an affiliate.

close to its headquarters. An example of the fixed marketing costs is the cost of building destination-specific marketing networks. It would cost less for a multinational to build marketing networks for its affiliates in markets closer to its headquarters, because it has more experience in serving these markets. An example of the iceberg marketing costs is the cost of hiring salespeople. A multinational has to hire more salespeople in a market if its affiliates wants to sell more there. Fewer salespeople are required for making certain amount of sales in markets closer to its headquarters, because its brand names are better-known there. In sum, for its affiliates to serve a market farther away from its headquarters, a multinational firm faces higher fixed and iceberg marketing costs. This new type of frictions highlights the role of headquarters in affiliate sales and thus characterizes headquarters gravity in my model.

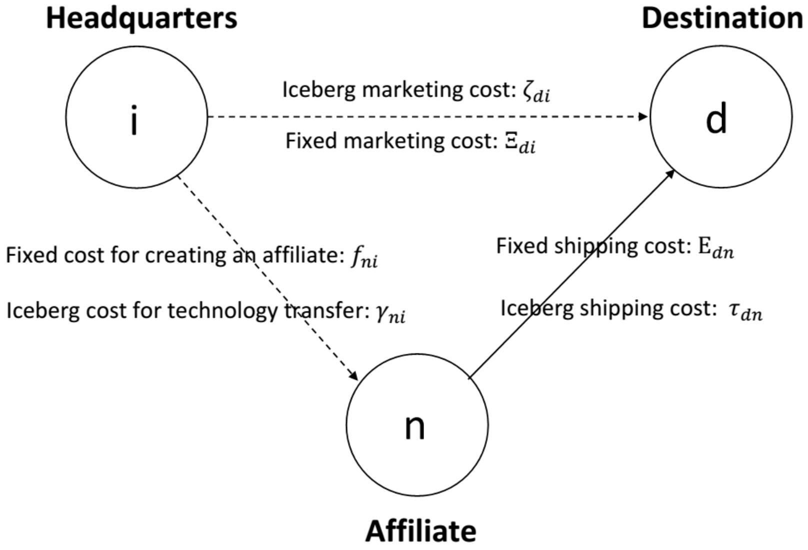

Figure 1.1: Spatial Frictions Shaping Multinational Sales

(Note: the solid arrow represents goods transfer and the dash arrows represent knowledge transfer.)

These frictions are illustrated in Figure 1.1. The spatial structure of frictions illustrated by Figure 1.1 is related to the one in Head and Mayer (2015). My work departs from their in two key aspects. First, they do not allow firms to choose their production sites. So they do not incorporate MP fixed costs. Second, they do not allow fixed trade costs. As I show below, both differences are important for welfare evaluation.

To build an affiliate in country n, firm ν from country i has to pay a fixed MP cost $f_{ni} > 0$ in terms of n's labor. MP also incurs iceberg efficiency losses. The unit cost for firm ν to produce in country n is

$$c_{ni}(\nu) = \gamma_{ni} w_n^{\beta} P_n^{1-\beta} / \varphi_i(\nu), \tag{1.7}$$

where γ_{ni} is the iceberg efficiency loss for MP from country i to n, w_n is the wage in country n, P_n is the price index for the composite final good consumed in country n, and $\beta \in (0, 1]$ is the value-added share.

Firm ν's affiliate in country n incurs standard iceberg shipping cost τ_{dn} and fixed shipping cost E_{dn} (in terms of labor in country d) to serve market d. It also faces iceberg marketing cost ζ_{di} and fixed marketing cost Ξ_{di} (in terms of labor in country d) that depend on the proximity between its headquarters country i and destination d. I assume that the total fixed cost for an affiliate from country i and located in country n to serve market is $E_{dn}\Xi_{di}$. The unit cost for an affiliate from country i and located in country n to serve market d is

$$c_{dni}(\nu) = \tau_{dn}\zeta_{di} c_{ni}(\nu) = \frac{\gamma_{ni}\tau_{dn}\zeta_{di} w_n^{\beta} P_n^{1-\beta}}{\varphi_i(\nu)}. \tag{1.8}$$

Monopolistic competition implies that the price of an affiliate from country i located in country n to serve market d is

$$p_{dni}(\nu) = \bar{m} c_{dni}(\nu) = \bar{m}\frac{\gamma_{ni}\tau_{dn}\zeta_{di} w_n^{\beta} P_n^{1-\beta}}{\varphi_i(\nu)}, \quad \bar{m} = \frac{\sigma}{\sigma - 1}. \tag{1.9}$$

To rationalize the micro trade pattern, I introduce affiliate-destination-specific shocks as in Eaton, Kortum, Kramarz (2011). Firm ν's affiliate in country n incurs a fixed cost $\varepsilon_{dn}(\nu) E_{dn}\Xi_{di}$ to serve market d. $\varepsilon_{dn}(\nu)$ is an affiliate-destination-specific idiosyncratic fixed-cost shock. Furthermore, an affiliate in country n faces an affiliate-destination-specific demand shock $\xi_{dn}(\nu)$ to serve market d.

The timing of the firm's decisions is as follows. First, firm ν draws its productivity $\varphi_i(\nu)$. Second, firm ν decides where to build its affiliates. Third, the idiosyncratic entry and demand shocks are realized. Finally, firm ν decides the export destinations and export sales for each of its affiliate.

1.3.1.2 Export Entry and Sales

I solve the firm's decision by reverse order. I start with the scenario in which firm ν from country i has created an affiliate in country n. Monopolistic competition implies that the potential sales of an affiliate from country i located in country n to destination market d is given by

$$x_{dni}(\nu) = \xi_{dn}(\nu) p_{dni}(\nu)^{1-\sigma} P_d^{\sigma-1} X_d, \tag{1.10}$$

where $p_{dni}(\nu)$ is its individual price derived in Equation (1.9), P_d is the price index of destination market d, X_d is the total absorption of destination market d, and $\xi_{dn}(\nu)$ is the affiliate-destination-specific idiosyncratic demand shock.

The potential sales in Equation (1.10) will be realized if and only if the profit from this sales exceeds the fixed export cost $w_d \varepsilon_{dn}(\nu) E_{dn} \Xi_{di}$. Monopolistic competition implies that the profit has a share of $\frac{1}{\sigma}$ in sales. So the affiliate will serve market d if and only if

$$\frac{1}{\sigma} x_{dni}(\nu) \geq w_d \varepsilon_{dn}(\nu) E_{dn} \Xi_{di}. \tag{1.11}$$

Export entry and sales are driven by the unit cos $c_{dni}(\nu)$, and the idiosyncratic demand shock $\xi_{dn}(\nu)$ and fixed-cost shock $\varepsilon_{dn}(\nu)$. Combining Equation (1.11) with Equation (1.10) and (1.9), an affiliate from country i located in country n will serve market d if and only if

$$c_{dni}(\nu) \leq \bar{c}_{dni}(\eta_{dn}(\nu)), \tag{1.12}$$

where

$$\bar{c}_{dni}(\eta_{dn}(\nu)) := (\eta_{dn}(\nu) \frac{X_d}{\sigma w_d E_{dn} \Xi_{di}})^{\frac{1}{\sigma-1}} \frac{P_d}{\bar{m}}, \tag{1.13}$$

and

$$\eta_{dn}(\nu) = \frac{\xi_{dn}(\nu)}{\varepsilon_{dn}(\nu)} \tag{1.14}$$

is the idiosyncratic entry shock given by the ratio of the demand shock to the fixed-cost shock.

Conditional on $c_{dni}(\nu) \leq \bar{c}_{dni}(\eta_{dn}(\nu))$, the sales in Equation (1.10) is given by

$$x_{dni}(\nu) = \frac{\xi_{dn}(\nu)}{\eta_{dn}(\nu)} [\frac{c_{dni}(\nu)}{\bar{c}_{dni}(\eta_{dn}(\nu))}]^{-(\sigma-1)} \sigma w_d E_{dn} \Xi_{di}. \tag{1.15}$$

I assume that the demand shock $\xi_{dn}(\nu)$ and the entry shock $\eta_{dn}(\nu)$ are realizations of affiliate-destination-specific shocks drawn from a joint c.d.f. $G(\xi, \eta)$ that is identical and independent across affiliates and destinations. I further assume that $G(\xi, \eta)$ is a bivariate lognormal distribution:

$$(\log(\xi), \log(\eta)) \sim_{IID} N(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma_\xi^2 & \rho_{\xi\eta}\sigma_\xi\sigma_\eta \\ \rho_{\xi\eta}\sigma_\xi\sigma_\eta & \sigma_\eta^2 \end{pmatrix}), \tag{1.16}$$

where σ_ξ is the standard deviation for $\log\xi$, σ_η is the standard deviation for $\log\eta$, and $\rho_{\xi\eta} \in [-1, 1]$ is the correlation between $\log\xi$ and $\log\eta$.

To save notations, I denote $\xi_{dn} = \xi$ and $\eta_{dn} = \eta$ for all d and n. Moreover, I denote the vectors of demand and entry shocks an affiliate face in destination markets as, respectively, $\tilde{\xi} := (\xi_{1n}(\nu), \ldots, \xi_{Nn}(\nu))'$ and $\tilde{\eta} := (\eta_{1n}(\nu), \ldots, \eta_{Nn}(\nu))'$. The joint c.d.f. of $(\tilde{\xi}, \tilde{\eta})$ is denoted as $\tilde{G}(\tilde{\xi}, \tilde{\eta})$.

Equation (1.12) and (1.15) characterize, respectively, the export entry condition and the export sales. These two equations, after transformation, will be used to estimate the parameters of headquarters gravity, ζ_{di} and Ξ_{di}, from Chinese firm data.

1.3.1.3 Production Sites

Since a firm chooses its production sites before the realization of idiosyncratic shocks, it will build an affiliate in country n if its expected operating profit in country n exceeds its fixed MP cost. By Equation (1.15) and (1.12), the operating profit of an affiliate from country i located in country n is its profits from exporting to all destinations net of fixed export costs:[11]

$$\pi_{ni}(\tilde{\xi}, \tilde{\eta}, c_{ni}) = \sum_{d \in \Lambda(\tilde{\xi}, \tilde{\eta}, c_{ni})} [\frac{1}{\sigma}\xi[\bar{m}\tau_{dn}\zeta_{di}c_{ni}]^{1-\sigma} P_d^{\sigma-1} X_d - \frac{\xi}{\eta} w_d E_{dn} \Xi_{di}], \tag{1.17}$$

where the set of export destinations is derived by Equation (1.12) as

$$\Lambda(\tilde{\xi}, \tilde{\eta}, c_{ni}) = \{d : c_{dni} \leq \bar{c}_{dni}(\eta)\}. \tag{1.18}$$

Firm ν will establish an affiliate in country n if and only if its expected operating

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[11] To save notations I omit the firm index ν.

profit (with respect to $(\tilde{\xi}, \tilde{\eta})$) exceeds MP fixed cost. By Equation (1.17), firm ν will create an affiliate in country n if and only if

$$c_{ni} \leq \hat{c}_{ni}, \tag{1.19}$$

where $\hat{c}_{ni}$ is the solution to

$$\bar{\pi}(c_{ni}) := \int_{\tilde{\xi}} \int_{\tilde{\eta}} \pi_{ni}(\tilde{\xi}, \tilde{\eta}, c_{ni}) d\tilde{G}(\tilde{\xi}, \tilde{\eta}) = w_n f_{ni}. \tag{1.20}$$

1.3.2 Aggregation

In this section I will add up firms' trade and MP decisions into aggregate trade and MP flows. In my model the firm heterogeneity comes from heterogeneity in productivity as well as the idiosyncratic demand shocks ξ and entry shocks η. Aggregation is done by summing firms over these three dimensions. Note that if the fixed MP cost $f_{ni} = 0$, my model is isomorphic to Eaton, Kortum, and Kramarz (2011). The introduction of the fixed MP costs complicates aggregation.

Note that for each affiliate it draws a demand shock ξ and an entry shock η in each destination market from a joint c.d.f. $G(\xi, \eta)$. I denote the vectors of demand and entry shocks faced by each affiliate in all destination markets as $(\tilde{\xi}, \tilde{\eta})$. The joint c.d.f. for $(\tilde{\xi}, \tilde{\eta})$ is denoted as $\tilde{G}(\tilde{\xi}, \tilde{\eta})$.

By Equation (1.6) and (1.7), the measure of affiliates from country i in country n with the unit cost in $c_{ni} \leq c$ is given by

$$\tilde{\mu}_{ni}(c) = T_i [\frac{\gamma_{ni} w_n^{\beta} P_n^{1-\beta}}{c}]^{-\theta}. \tag{1.21}$$

By Equation (1.6) and (1.8), the measure of firms from country i serving market d by affiliates in country n with the unit cost $c_{dni} \leq c$ is given by

$$\mu_{dni}(c) = T_i [\frac{\gamma_{ni} \tau_{dn} \zeta_{di} w_n^{\beta} P_n^{1-\beta}}{c}]^{-\theta}. \tag{1.22}$$

I derive the measure of firms from country i building affiliates in country n. It depends on the distribution of unit costs in Equation (1.21) and the MP entry condition in Equation (1.19):

$$J_{ni} = \int_0^{\hat{c}_{ni}} d\tilde{\mu}_{ni}(c). \tag{1.23}$$

Then I derive the price index in country d. It depends on individual prices of all varieties served in country d. Note that if a firm from country i wants to serve market d from its affiliate in country n, it must be profitable for this firm to build an affiliate in country n and for its affiliate in country n to export to country d. By Equation (1.12) and (1.19), the firm has to satisfy

$$c_{dni} \leq \min\{\bar{c}_{dni}(\eta), \tau_{dn}\zeta_{di}\hat{c}_{ni}\}. \tag{1.24}$$

By preference in Equation (1.5) and entry condition in Equation (1.24), the price index in country d can be given by

$$P_d = \{\int_{\tilde{\xi}}\int_{\tilde{\eta}}\sum_{n=1}^{N}\sum_{i=1}^{N}[\int_0^{\min\{\bar{c}_{dni}(\eta),\tau_{dn}\zeta_{di}\hat{c}_{ni}\}} \xi(\bar{m}c)^{\frac{\sigma-1}{\sigma}} d\mu_{dni}(c)]d\tilde{G}(\tilde{\xi},\tilde{\eta})\}^{\frac{\sigma}{\sigma-1}}. \tag{1.25}$$

By firm sales in Equation (1.15), the aggregate exports by affiliates from country i and located in country n to market d is given by

$$X_{dni} = \int_{\xi}\int_{\eta}\int_0^{\min\{\bar{c}_{dni}(\eta),\tau_{dn}\zeta_{di}\hat{c}_{ni}\}} \frac{\xi}{\eta}[\frac{c}{\bar{c}_{dni}(\eta)}]^{-(\sigma-1)}\sigma w_d E_{dn}\Xi_{di}d\mu_{dni}(c)dG(\xi,\eta) \tag{1.26}$$

By export entry conditions in Equation (1.22), the measure of affiliates from country i, located in country n, and serving market d is given by

$$J_{dni} = \int_{\xi}\int_{\eta}\int_0^{\min\{\bar{c}_{dni}(\eta),\tau_{dn}\zeta_{di}\hat{c}_{ni}\}} d\mu_{dni}(c)dG(\xi,\eta). \tag{1.27}$$

By definition the aggregate fixed export costs paid by affiliates from country i and located in country n to serve market d is given by

$$M_{dni} = w_d E_{dn}\Xi_{di}\int_{\xi}\int_{\eta}\int_0^{\min\{\bar{c}_{dni}(\eta),\tau_{dn}\zeta_{di}\hat{c}_{ni}\}} \frac{\xi}{\eta}d\mu_{dni}(c)dG(\xi,\eta). \tag{1.28}$$

The net profit earned by firms in country i is their operating profits net of fixed trade and MP costs:

$$\Pi_i = \sum_{d=1}^{N}\sum_{n=1}^{N}(\frac{1}{\sigma}X_{dni} - M_{dni}) - \sum_{n=1}^{N} w_n f_{ni} J_{ni}. \tag{1.29}$$

Now I get all income flows in this economy. The total labor income in country i is the sum of wage incomes of production workers, the wages for workers as fixed trade costs, and the wages for workers as fixed MP costs:

$$w_i L_i = \underbrace{(1-\frac{1}{\sigma})\beta\sum_{d=1}^{N}\sum_{k=1}^{N}X_{dik}}_{\text{Wage Income of Production Workers}} + \underbrace{\sum_{n=1}^{N}\sum_{k=1}^{N}M_{ink}}_{\text{Fixed Trade Costs}} + \underbrace{\sum_{k=1}^{N}w_i f_{ik} J_{ik}}_{\text{Fixed MP Costs}}. \tag{1.30}$$

Finally, the total absorption of country i is the sum of labor income, the firms' net profit, and the expenditure on the intermediates.

$$X_i = \underbrace{w_i L_i}_{\text{Wage Income}} + \underbrace{\Pi_i}_{\text{Profit}} + \underbrace{(1-\frac{1}{\sigma})(1-\beta)\sum_{d,k}X_{dik}}_{\text{Expenditures on Intermediates}}. \tag{1.31}$$

1.3.3 Equilibrium

Definition 2 *Given* $(L_i, f_{ni}, \gamma_{ni}, \tau_{dn}, \zeta_{di}, E_{dn}, \Xi_{di})$*,* $F_i(.)$ *and* $G(.,.)$*, the equilibrium is* $(w_i, X_i, P_i)_{i=1}^{N}$ *such that (i)* $\bar{c}_{dni}$ *is defined by Equation (1.12) and* $\hat{c}_{ni}$ *is defined by Equation (1.19), (ii) the sales of affiliates in* n *from* i *to* d *is given by Equation (1.26), (iii) the current account balance conditions, Equation (1.30) and (1.31), hold, and (iv) the aggregate price index satisfies Equation (1.25).*

The equilibrium outcomes $(w_i, X_i, P_i)_{i=1}^{N}$ can be computed by solving equation (1.25), (1.30), and (1.31). I develop the an iterative algorithm to compute the equilibrium outcomes. The details of this algorithm are presented in the appendix.

1.3.4 Beyond Gravity Equation

The aim of this paper is to quantify the implications of headquarters gravity for trade and welfare. Since this model is in the class of gravity trade model, its trade and welfare implications rely on the model-based gravity equation. Unfortunately, my model does not deliver a closed-form gravity equation in the general case. In this subsection, I consider a special case in which $f_{ni} = 0$ for all n and i. In this special case, "trilateral" trade flows, $\{X_{dni}\}$, can be characterized by a closed-form gravity equation which has straightforward economic interpretations. Based on this new gravity equation, I will show analytically why in existence of headquarters gravity the standard gravity equation is not enough to characterize bilateral trade flows.

Proposition 3 *Suppose that $f_{ni} = 0$ for all n and i. Then*

$$\frac{X_{dni}}{X_d} = \frac{\psi_{dni}(E_{dn}\Xi_{di})^{-\frac{\theta-(\sigma-1)}{\sigma-1}}}{\Psi_d}, \tag{1.32}$$

where

$$\psi_{dni} = T_i(\tau_{dn}\gamma_{ni}\zeta_{di}w_n^{\beta}P_n^{1-\beta})^{-\theta}, \tag{1.33}$$

and

$$\Psi_d = \sum_{i=1}^{N}\sum_{n=1}^{N}\psi_{dni}(E_{dn}\Xi_{di})^{-\frac{\theta-(\sigma-1)}{\sigma-1}}. \tag{1.34}$$

Proposition 3 is derived directly from the equilibrium conditions. There are few points worth noting. First the elasticity of trade flows with respect to variable trade costs is $-\theta$ while the elasticity of trade flows with respect to fixed trade costs is $-\frac{\theta-(\sigma-1)}{\sigma-1}$. This result is a direct extension of Eaton, Kortum, and Kramarz (2011). Second the gravity equation in Proposition 3 is isomorphic to the gravity equation in Arkolakis et al. (2015) if in their model the productivities of affiliates within a firm are uncorrelated. This implies that although proximity-concentration trade-off is abstracted away from my model, my model shares the similar general equilibrium properties with the models which considers proximity-concentration trade-off explicitly.

The following result shows the importance of headquarters gravity in shaping bilateral trade flows.

Corollary 4 *Suppose that $f_{ni} = 0$ for all n and i. Then the bilateral trade flows,*

$X_{dn} = \sum_{i=1}^{N} X_{dni}$, *can be given by*

$$X_{dn} = \underbrace{\tau_{dn}^{-\theta} E_{dn}^{-\frac{\theta-(\sigma-1)}{\sigma-1}}}_{\textit{Bilateral Trade Barriers}} \quad \underbrace{(\frac{X_d}{\Psi_d})}_{\textit{Importer Fixed Effect}} \quad \underbrace{(w_n^{\beta} P_n^{1-\beta})^{-\theta}}_{\textit{Exporter Fixed Effect}} \quad \underbrace{[\sum_{i=1}^{N} T_i \gamma_{ni}^{-\theta} \zeta_{di}^{-\theta} \Xi_{di}^{-\frac{\theta-(\sigma-1)}{\sigma-1}}]}_{\textit{Multi-country Resistance from HG}} \ . \tag{1.35}$$

The standard gravity characterizes bilateral trade flows by the importer's fixed effect, the exporter's fixed effect, and their bilateral trade barriers. Corollary 4 shows that this is not enough in existence of multinational production and headquarters gravity. Third-country terms can affect bilateral trade flows directly. For example, Chinese exports to Canada is affected by the U.S. affiliates in China and their market access to Canada. This new effect is captured by the last term in Corollary 4. Note that if $\zeta_{di} = 1$ and $\Xi_{di} = 1$, then this new multi-country resistance term will be absorbed by the exporter's fixed effect.

Before moving to the structural estimation, I explore the welfare implications of this special case.

Corollary 5 *Suppose the welfare* $W_d := \frac{w_i L_i + \Pi_i}{P_i}$. *Let* $\hat{Z} = \frac{Z'}{Z}$ *where* Z *is the benchmark value of variable* Z *and* Z' *is the value of variable* Z *after shocks. Let* $\lambda_{dni} := \frac{X_{dni}}{X_d}$ *and* $Y_d^m := \sum_{k=1}^{N} \sum_{i=1}^{N} X_{kdi}$. *Then the changes in* W_d *can be expressed as*

$$\hat{W}_d = \hat{\lambda}_{ddd}^{-\frac{1}{\theta\beta}} \hat{X}_d^{\frac{\theta-(\sigma-1)}{\sigma-1}\frac{1}{\theta\beta}} \{ \frac{\frac{\theta-(\sigma-1)}{\sigma-1} X_d + (1-\frac{1}{\sigma})\beta Y_d^m}{X_d - (1-\frac{1}{\sigma})(1-\beta) Y_d^m} \frac{X_d \hat{X}_d - (1-\frac{1}{\sigma})(1-\beta) Y_d^m \hat{Y}_d^m}{\frac{\theta-(\sigma-1)}{\sigma-1} X_d \hat{X}_d + (1-\frac{1}{\sigma})\beta Y_d^m \hat{Y}_d^m} \}. \tag{1.36}$$

The expression of welfare changes in Corollary 5 is isomorphic with the one in Arkolakis, Costinot, and Rodriguez-Clare (2010) with two extensions. First in existence of multinational production the welfare changes do not only need to consider the production location but also headquarters location. Second the welfare changes need to adjust for the profit flows of multinational production. Note that λ_{dni} is not observable. We have to infer these shares through the lens of structural models. I will show in the empirical part that the multinational firms' trade costs are crucial for estimating the welfare gains from multinational production.

1.4 Estimating Headquarters Gravity

The parameters in my general equilibrium model are summarized in Table 1.5. I take two parameters from the literature: the elasticity of substitution $\sigma = 4$ from Arkolakis et al. (2015) and the value-added share $\beta = 0.35$ from Johnson and Moxnes (2013).

Outside the Model

Parameter	Definition	Target/Source
σ	Elasticity of Substituion	Arkolakis et al. (2015)
β	Value-added Share	Johnson and Moxnes (2013)
θ	Dispersion of Firm Productivity	Dispersion of firm sales
L_i	Manufacturing Labor	ILO (2001)

Headquarters Gravity Parameters

Parameter	Definition	Target/Source
ζ_{di}	Iceberg marketing cost	Exports given sales in China
Ξ_{di}	Fixed marketing cost	Export entry and exports

Shock Parameters

Parameter	Definition	Target/Source
σ_ξ	Standard error for demand shock	Relation b/w sales in China and exports
σ_η	Standard error for demand/entry shock	Relation b/w Sales in China and export entry
$\rho_{\xi\eta}$	Correlation between ξ and η	Relation b/w export entry and exports

Standard Gravity and Technology

Parameter	Definition	Target/Source
E_{dn}	Fixed shipping cost	Export entry and exports
τ_{dn}	Iceberg shipping costs	Export as a share of production
γ_{ni}	Iceberg MP costs	Inward MP as a share of production
f_{ni}	Fixed MP costs	MP affiliates as a share of total firms
T_i	Level of productivity	Wage from ILO (2001)

Table 1.5: Structural Parameters in the General Equilibrium Model

My empirical implementation consists of two parts. In this section I estimate headquarters gravity and shock parameters from Chinese firm data. In the next section I calibrate the remaining parameters in aggregate data.

The main objective of this section is to estimate the headquarters gravity parameters ζ_{di} and Ξ_{di} in Chinese firm data. To achieve this, I follow the Heckman two-step approach developed by Irarrazabal, Moxnes, and Opromolla (2013). This approach controls for the firms' productivities by their sales in China. The identification for $\{\zeta_{di}, \Xi_{di}\}$ comes from the fact that firm export entry depends on both iceberg and fixed trade costs while firm export sales (conditional on entry) depends only on the iceberg trade cost.

1.4.1 Export Entry

In the first step I deliver and estimate the condition for an affiliate in China to enter certain export market. The model implies that an affiliate will export to certain market if its operating profit of doing that exceeds the fixed export cost. Hence affiliate ν's export entry in Equation (1.11) can be re-expressed as

$$\frac{1}{\sigma}\eta_{dn}(\nu)\bar{m}^{1-\sigma}[\frac{\gamma_{ni}\tau_{dn}\zeta_{di}w_n^{\beta}P_n^{1-\beta}}{\varphi_i(\nu)}]^{1-\sigma}X_dP_d^{\sigma-1} \geq w_dE_{dn}\Xi_{di}. \tag{1.37}$$

The productivity $\varphi_i(\nu)$ in Equation (1.37) is unobserved. But it can be expressed as a function of sales in China, $x_{nni}(\nu)$. Substituting $\varphi_i(\nu)$ by $x_{nni}(\nu)$, Equation (1.37) can be rewritten as

$$\log(x_{nni}(\nu)) + \log(\eta^*_{dn}(\nu)) \geq H_{dni}, \quad d \neq n = CHN, \tag{1.38}$$

where

$$\begin{aligned} H_{dni} = &\log\sigma + \underbrace{\log(w_dE_{dn}\Xi_{di})}_{\text{Fixed Export Cost}} + \underbrace{(\sigma-1)\log(\zeta_{di}) - (\sigma-1)\log(\zeta_{ni})}_{\text{Iceberg Headquarters Gravity}} \\ &- \underbrace{[\log(X_dP_d^{\sigma-1}/X_nP_n^{\sigma-1}) - (\sigma-1)\log(\tau_{dn})]}_{\text{Export Sales Potential}}, \end{aligned} \tag{1.39}$$

and $\eta^*_{dn}(\nu) = \eta_{dn}(\nu)/\xi_{nn}(\nu)$ is a compound entry shock.

Equation (1.38) means that an affiliate in China from country i will serve market d if its sales in China plus an affiliate-destination specific shock exceed an entry hurdle H_{dni}. Therefore, the entry hurdle H_{dni} characterizes how likely an affiliate will export to a market, given its sales in China.

H_{dni} consists of three parts. First it increases with respect to the fixed trade cost $w_dE_{dn}\Xi_{di}$. Second it increases with respect to the distance between ζ_{di} (relative to ζ_{ni}). Third it decreases with respect to the export sales potential which depends on the destination market size, the destination price level, and the distance between the destination and China.

By construction $\log(\eta^*_{dn}(\nu))$ is drawn from a normal distribution with mean 0 and standard deviation $\sigma_{\eta^*} = \sqrt{\sigma_\eta^2 + \sigma_\xi^2}$. Therefore, $\Theta_1 = \{H_{dni}, \sigma_{\eta^*}\}$ can be estimated by a ML estimator with the following likelihood function:

$$l_1(\Theta_1) = \sum_{d \neq n} \sum_{i} \sum_{\nu} [1 - y_{dni}(\nu)] \log\{\Phi[\frac{H_{dni} - \log x_{nni}(\nu)}{\sigma_{\eta^*}}]\} + y_{dni}(\nu) \log\{1 - \Phi[\frac{H_{dni} - \log x_{nni}(\nu)}{\sigma_{\eta^*}}]\}, \tag{1.40}$$

where $y_{dni}(\nu) = 1$ indicates that affiliate ν enters market d and $\Phi[.]$ is the c.d.f. of the standard normal distribution.

The entry hurdle H_{dni} is estimated as a headquarters-destination fixed effect in Probit Equation (1.40). The entry hurdle H_{dni} is identified by the mean sales in China for those firms from country i who serve market d. With a higher entry hurdle H_{dni}, firms from country i have to be more productive to serve market d. This in turn raises the mean sales in China for those entrants.

The standard deviation of the compound entry shock, σ_{η^*}, is recovered from the coefficient of the sales in China in Probit Equation (1.40). The model implies that the firm with larger sales in China are more likely to export to all destination countries. However, this firm size effect is disturbed by compound entry shocks. With $\sigma_{\eta^*} = 0$, the export entry is entirely decided by the sales in China.

To estimate Equation (1.40), I restrict the sample by requiring that $x_{nni}(\nu) > 0$ and for each headquarters-destination pair (d, i) there are at least 20 entrants and 20 non-entrants. The sample details are presented in the appendix.

The estimation on Probit Equation (1.40) shows that the coefficient of $\log(x_{nni})$ is 0.203 with with standard error 0.0033. This implies that the standard deviation of the compound entry shock η^* is $\sigma_{\eta^*} = 4.93$.

Figure 1.2 reports the estimated entry hurdle, $H_{d,CHN,n}$, with respect to the distance between the headquarters country and the destination. It shows that foreign affiliates in China must be larger in terms of their sales in China to serve markets farther away from their headquarters. Note that H_{dni} is the headquarters-destination fixed effect in Probit Equation (1.40). The patterns in Figure 1.2 are entirely data-driven since I do not impose any geographic structure on H_{dni}.

Figure 1.3 shows cultural and economic distances between the headquarters and destination countries matter to export entry as well. The foreign affiliates in China have better access to markets using the same language or with similar income level with their headquarters countries. In particular, the foreign affiliates in China face substantially lower export entry hurdles to their headquarters countries.

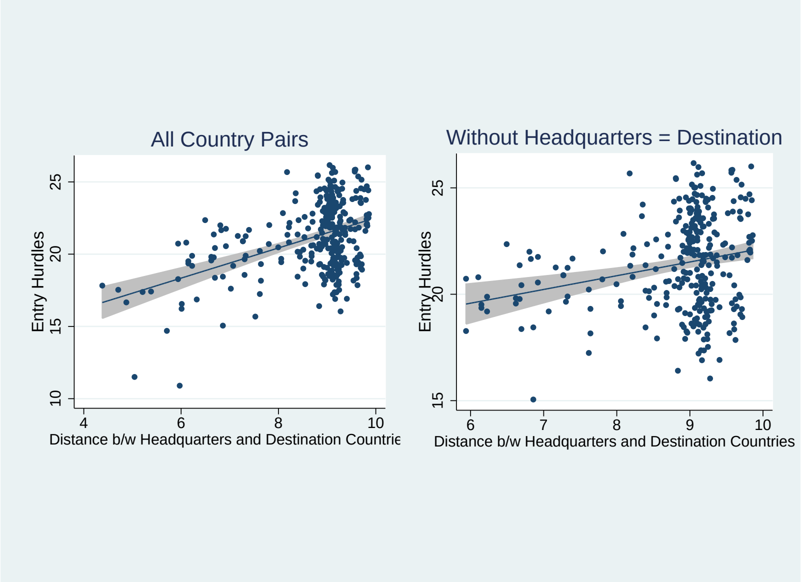

Figure 1.2: Entry Hurdles with the Distance between Headquarters and Destination

(Note: Entry hurdle $H_{d,CHN,i}$ is defined in Equation (1.38) as a cutoff of the sales in China above which an affiliate from country i and located in China would export to market d. The higher $H_{d,CHN,i}$ means that an affiliate from country i and located in China has to be larger in terms of its sales in China to export to market d. The gray area is the 95 percent confident interval.)

1.4.2 Export Sales conditional on Entry

In the second step I estimate ζ_{di} from the export sales conditional on entry. According to the previous subsection, affiliate ν from country i will serve market d if and only if $\log(x_{nni}(\nu)) + \log(\eta^*_{dn}(\nu)) \geq H_{dni}$. I then define an affiliate-specific entry hurdle as

$$\bar{H}_{dni}(\nu) = H_{dni} - \log(x_{nni}(\nu)). \tag{1.41}$$

By definition, an affiliate from country i will export to market d if and only if its compound entry shock $\eta^*_{dn}(\nu)$ is greater or equal to its affiliate-specific entry hurdle $\bar{H}_{dni}(\nu)$.

Conditional on $\eta^*_{dn}(\nu) \geq \bar{H}_{dni}(\nu)$, the export sales relative to sales in China can be given by

$$\begin{aligned}\frac{x_{dni}(\nu)}{x_{nni}(\nu)} = &- \underbrace{[(\sigma-1)\log(\zeta_{di}) - (\sigma-1)\log(\zeta_{ni})]}_{\text{Iceberg Headquarters Gravity}} \\ &+ \underbrace{[\log(X_d P_d^{\sigma-1}/X_n P_n^{\sigma-1}) - (\sigma-1)\log(\tau_{dn})]}_{\text{Export Sales Potential}} + \log(\xi^*_{dn}(\nu))\end{aligned} \tag{1.42}$$

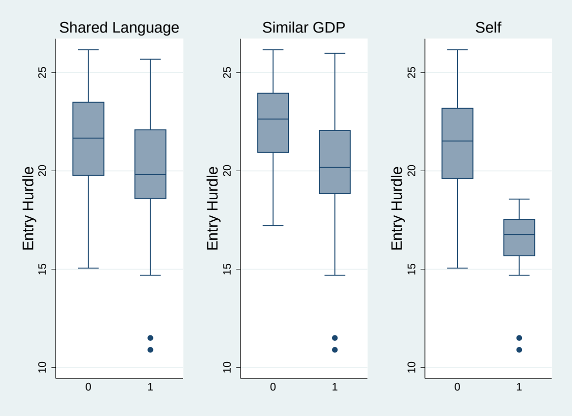

Figure 1.3: Entry Hurdles with Cultural and Economic Distances

(Note: Entry hurdle $H_{d,CHN,i}$ is defined in Equation (1.38) as a cutoff of the sales in China above which an affiliate from country i and located in China would export to market d. The higher $H_{d,CHN,i}$ means that an affiliate from country i and located in China has to be larger in terms of its sales in China to export to market d. Cultural distance is measured by whether the headquarters country and the destination use the same language. Economic distance is measured by whether the headquarters country and the destination have similar GDP per capita. "Self" is the dummy for destination being the same with headquarters country. The upper bound for the colored box is the 75 quantile while the lower bound for the colored box is the 25 quantile.)

where $\xi^*_{dn}(\nu) = \xi_{dn}(\nu)/\xi_{nn}(\nu)$ is a compound demand shock.

I parametrize ζ_{di} as a function of observed gravity variables:

$$\log(\zeta_{di}) = \rho_{\zeta,1}\log(dist_{di}) + \rho_{\zeta,2}lang_{di} + \rho_{\zeta,3}sgdp_{di} + \rho_{\zeta,4}self_{di} := \rho_\zeta D_{di}, \qquad (1.43)$$

where $dist_{di}$ is the distance between d and i, $lang_{di}$ is a dummy for d and i speaking the same language, $sgdp_{di}$ is a dummy for d and i having similar GDP per capita, $self_{di}$ is a dummy for $d = i$, $\rho_\zeta = (\rho_{\zeta,1}, \rho_{\zeta,2}, \rho_{\zeta,3}, \rho_{\zeta,4})$ and $D_{di} = (\log(dist_{di}), lang_{di}, sgdp_{di}, self_{di})'$.

Equation (1.42) can be rewritten as

$$\frac{x_{dni}(\nu)}{x_{nni}(\nu)} = -(\sigma-1)\rho_\zeta D_{di} + \iota_{ni} + \kappa_{dn} + \log(\xi^*_{dn}(\nu)), \qquad (1.44)$$

where $\iota_{ni} = (\sigma-1)\log(\zeta_{ni})$ and $\kappa_{dn} = \log(X_d P_d^{\sigma-1}/X_n P_n^{\sigma-1}) - (\sigma-1)\log(\tau_{dn})$.

Note that Equation (1.44) only holds for affiliates with $\eta^*_{dn}(\nu) \geq \bar{H}_{dni}(\nu)$. Therefore if $cov(\eta^*, \xi^*) \neq 0$, then the OLS estimator of ρ_ζ from Equation (1.44) will be biased. It is straightforward to show that if $cov(\eta^*, \xi^*) > 0$ then the OLS estimator of ρ_ζ will be biased towards 0. I leave the details of this proof in the appendix.

To correct the selection bias, I insert the estimated affiliate-specific entry hurdle into Equation (1.44) with a general functional form:

$$\log(\frac{x_{dni}(\nu)}{x_{nni}(\nu)}) = -(\sigma-1)\rho_\zeta D_{di} + \iota_{ni} + \kappa_{dn} + m(\bar{H}_{dni}(\nu)) + u_{dni}(\nu), \tag{1.45}$$

where $m(.)$ is a general-form function and $u_{dni}(\nu)$ is a measurement error. Then I use Robinson (1988) semiparametric estimator to estimate Equation (1.45). The details of this estimator are presented in the appendix.

	Dependent Variable: $(\log(x_{dni}(\nu)) - \log(x_{nni}(\nu)))$	
	Semi-parametric	OLS
$(\sigma-1)\rho_{\zeta,1}$: $\log(dist_{di})$	.13***	.033*
	(.019)	(.02)
$(\sigma-1)\rho_{\zeta,2}$: $lang_{di}$	-.1**	-.07**
	(.04)	(.04)
$(\sigma-1)\rho_{\zeta,3}$: $sgdp_{di}$	-.4***	.005
	(.15)	(.16)
$(\sigma-1)\rho_{\zeta,4}$: $self_{di}$	-1.2***	-.56***
	(.1)	(.08)
# obs.	17814	17814
R-sq	.2	.08

Table 1.6: The Estimates on ζ_{di}: Semi-parametric vs OLS

(Note: Semiparametric results are based on Robinson (1988) double residual estimator for Equation (1.45). Fixed effects are not reported. Note that I calibrate $\sigma - 1 = 3$.)

The left column of table 1.6 presents the results of semiparametric estimator. ρ_ζ is statistically significant and with expected signs. The estimates suggest that the multinational affiliates have advantage in serving markets closer to their headquarters: the iceberg export cost of a foreign affiliate in China to its headquarters country is, ceteris paribus, 32% lower than to any other country. If the distance between the headquarters and destination countries doubles, the affiliate's export cost would increase by 4.4%. The shared language between the headquarters and destination countries would decrease the affiliate's export cost by 3.4%. And the similar income level between the headquarters and destination countries would decrease the affiliate's export cost by 15%.

To show the importance of controlling entry selection, I also estimate Equation (1.45) by OLS estimator without controlling for $\bar{H}_{dni}(\nu)$. The result is presented on the right column of Table 1.6. The OLS estimator without controlling entry hurdles biases the estimates of ρ_ζ towards 0, which implies $cov(\eta^*, \xi^*) > 0$.

1.4.3 Fixed Shipping and Marketing Costs

With the estimated entry hurdle H_{dni} and iceberg headquarters gravity term ζ_{di}, I can compute the fixed export cost $E_{dn}\Xi_{di}$ directly by

$$\log(E_{dn}\Xi_{di}) = H_{dni} - (\sigma - 1)\log(\zeta_{di}) + \iota_{ni} + \kappa_{dn} - \log\sigma - \log w_d, \tag{1.46}$$

where the wage w_d is approximated by GDP per capita in 2001 from Penn World Table.

However, these estimates give me only $E_{dn}\Xi_{di}$ for $n = CHN$. To impute $E_{dn}\Xi_{di}$ for all (d, n, i) triples, I parameterize $E_{dn}\Xi_{di}$ as

$$\log(E_{dn}\Xi_{di}) = \rho_{E,1}\log(D_{di}) + \rho_{E,2}\log(D_{dn}) + v_{dni}, \quad d \neq n, n = CHN, \tag{1.47}$$

where v_{dni} is an exogenous measurement error and D_{dn} are distance measures described in previous sections. Then by construction $E_{dn} = \rho_{\hat{E,2}}\log(D_{dn})$ and $\Xi_{di} = \rho_{\hat{E,1}}\log(D_{di})$ where $\rho_{\hat{E,2}}$ and $\rho_{\hat{E,1}}$ are the estimated values.

I estimate Equation (1.47) by OLS estimator. The result is presented in Table 1.7. Similar to ζ_{di}, the estimates on Ξ_{di} suggest headquarters gravity being substantial. The fixed export cost of an affiliate to its headquarters country is, ceteris paribus, 80% lower than to any other country. Doubling the distance between the headquarters and the destination will increase the fixed export cost by 10%.

Dependent Variable: $\log(E_{dn}\Xi_{di})$								
$\log(dist_{di})$	$lang_{di}$	$sgdp_{di}$	$self_{di}$	$\log(dist_{dn})$	$lang_{dn}$	$sgdp_{dn}$	R-sq.	N. of Obs
.1*	-.4	-.95***	-1.6***	-.18	-.88***	.25	.47	311
(.065)	(.12)	(.15)	(.44)	(.11)	(.20)	(1.1)		

Table 1.7: Imputing Fixed Marketing and Shipping Costs

(Note: $E_{dn}\Xi_{di}$ is computed by Equation (1.47). Country i is the headquarter country. Country n is the production country, which is China in my micro data. Country d is the destination market.)

1.4.3.1 Shock Parameters

The observed export sales (relative to sales in China) are drawn from a truncated lognormal distribution which depends on shock parameters $\{\sigma_\xi, \sigma_\eta, \rho_{\xi\eta}\}$. I utilize this truncated lognormal distribution to back out shock parameters. The parameters for demand and entry shocks can be estimated by the following constrained ML estimator:

$$l_2(\Theta_2) = \sum_{d\neq n}\sum_i\sum_\nu y_{dni}(\nu)\log\{\frac{1}{\sigma_{\xi^*}(\nu)}\phi[\frac{\log(x_{dni}(\nu)) - \log(x_{nni}(\nu)) - \rho_\zeta D_{di} + \iota_{ni} + \kappa_{dn} - \mu_{\xi^*}(\nu)}{\sigma_{\xi^*}(\nu)}]\}, \tag{1.48}$$

where

$$\begin{aligned}
\mu_{\xi^*}(\nu) &= \frac{\sigma_\xi^2 + \rho_{\xi\eta}\sigma_\xi\sigma_\eta}{\sigma_{\eta^*}}\lambda_{dni}(\nu),\\
\sigma^2_{\xi^*}(\nu) &= (\frac{\sigma_\xi^2 + \rho_{\xi\eta}\sigma_\xi\sigma_\eta}{\sigma_{\eta^*}})^2[\frac{H_{dni} - \log(x_{nni}(\nu))}{\sigma_{\eta^*}}\lambda_{dni}(\nu) - \lambda^2_{dni}(\nu)] + 2\sigma_\xi^2,\\
\lambda_{dni}(\nu) &= \frac{\phi[(H_{dni} - \log(x_{nni}(\nu)))/\sigma_{\eta^*}]}{1 - \Phi[(H_{dni} - \log(x_{nni}(\nu)))/\sigma_{\eta^*}]},\\
\sigma^2_{\eta^*} &= \sigma^2_\eta + \sigma^2_\xi,
\end{aligned} \tag{1.49}$$

and $\Theta_2 = \{\sigma_\xi, \sigma_\eta, \rho_{\xi\eta}\}$. Note that $(H_{dni}, \rho_\zeta, \sigma_{\eta^*}, \iota_{ni}, \kappa_{dn})$ are from the estimates in previous subsections.

The variance of demand shock σ_ξ^2 is identified by the variance of firms' export sales that cannot be explained by firms' sales in China. Given the firm's sales in China, the firm's export sales would be more dispersed if σ_ξ is larger (see Equation (1.49)). Note this effect exists even without selection. In contrast, the correlation between demand and entry shock, $\rho_{\xi\eta}$, affects the mean of export sales through selection. Conditional on entry, the mean of export sales would increase with respect to $\rho_{\xi\eta}$ (see Equation (1.49)). This conditional mean identifies the correlation term $\rho_{\xi\eta}$.

The approach in Irarrazabal, Moxnes, and Opromolla (2013) estimates ρ_ζ and $(\sigma_\xi, \sigma_\eta, \rho_{\xi\eta})$ simultaneously by ML estimator in Equation (1.48). My approach departs from theirs by first estimating ρ_ζ by semiparametric regression and then estimating shock parameters by a ML estimator. The advantage of my approach is that the key parameter ρ_ζ is not affected by the estimates of shock parameters. In fact, to estimate ρ_ζ consistently I only need the compound entry shock η^* to be i.i.d. and log-normally distributed. Therefore, my approach is more robust to model specification errors.

The estimation results are shown in Table 1.8. It confirms that $cov(\eta^*, \xi^*) = \sigma_\xi^2 + \rho_{\xi\eta}\sigma_\xi\sigma_\eta > 0$.

ML Estimators for Shock Parameters		
σ_ξ	σ_η	$\rho_{\xi\eta}$
3.55***	3.42***	.94**
(.019)	(.0002)	(.37)

Table 1.8: The Estimates on Shock Parameters

(Note: σ_ξ is the standard deviation of the affiliate-destination-specific demand shock. σ_η is the standard deviation of the affiliate-destination-specific entry shock defined in Equation (1.14). $\rho_{\xi\eta}$ is the correlation coefficient between these two shocks.)

Note that ξ is an idiosyncratic demand shock and η is the ratio of ξ to an idiosyncratic fixed export cost shock ε. The correlation between $\log(\eta)$ and $\log(\xi)$ is close to 1, which implies that the variation of idiosyncratic demand shocks is much higher than the variation of fixed export cost shock. The Chinese firm data implies that we can almost regard the idiosyncratic fixed export cost shock ε as a constant and the variation of export entry across firms is primarily driven by the demand shock. The shock variation estimated from Chinese firm data is much larger than the estimates in Eaton, Kortum, and Kramarz (2011) from French firm data but similar to the estimates of Irarrazabal, Moxnes, and Opromolla (2013) from Norwegian firm data.

1.4.4 Model fit for Micro Data

In this section I test the fit of my model for micro data patterns. To generate model predictions, I take the sales of each foreign affiliate in China as given and simulate (ξ, η) for all affiliate-destination pairs. Then the export entry and sales can be derived from equation (1.38) and (1.42).

Figure 1.4 presents the model fit for the number of exporters and export sales in Chinese data. The model fits the number of exporters by destination and the number of exporters to headquarters countries pretty well. The fits in intensive margins shown in the right column of Figure 1.4 are not as tight as those for extensive margins. But they are still reasonably good.

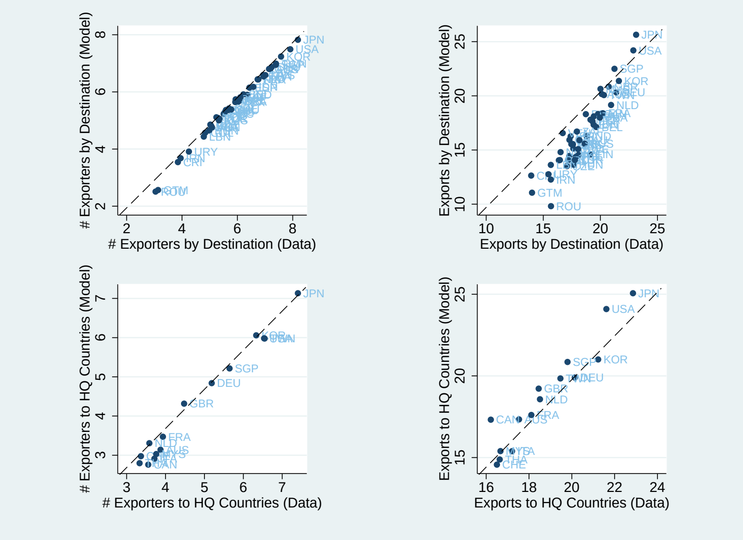

Figure 1.4: Model Predictions on Chinese Exports: Baseline Model

(Note: The model predictions are generated by simulating demand and entry shocks for all foreign affiliates in China, taking their sales in China as given. Data moments are presented in horizontal axises and model predictions are presented in vertical axises.)

To shed light on the importance of headquarters gravity for model fit, I eliminate headquarters gravity by forcing foreign affiliates in China to have the same export costs as Chinese firms. The simulation results are shown in Figure 1.5. The model without headquarters gravity severely underestimates the number of exporters and export values to headquarters countries. Therefore, headquarters gravity is the key for my model to fit patterns in micro trade data.

1.4.5 The Magnitude of Headquarters Gravity

The estimates of ζ_{di} and Ξ_{di} show how the multinational affiliates' export costs depend on their headquarters locations. In this section I illustrate the effects of headquarters locations on the export costs of multinational affiliates.

I start with computing the average differences in export costs between foreign affiliates and Chinese local firms. I compute the average iceberg headquarters gravity term weighted by export share $\log(\bar{\zeta}_{MNE}) = \sum_{d,i\neq CHN} \frac{X_{d,CHN,i}}{\sum_{l,k} X_{l,CHN,k}} \log(\zeta_{di})$. Similarly for Chinese local firm $\log(\bar{\zeta}_{CHN}) = \sum_{d} \frac{X_{d,CHN,CHN}}{\sum_{l} X_{l,CHN,CHN}} \log(\zeta_{d,CHN})$. Then I can compute the average difference by $\Delta_{\zeta} = \frac{\bar{\zeta}_{CHN}-\bar{\zeta}_{MNE}}{\bar{\zeta}_{CHN}}$. By exactly the same procedure I can get the average difference for the fixed marketing cost Δ_{Ξ}.

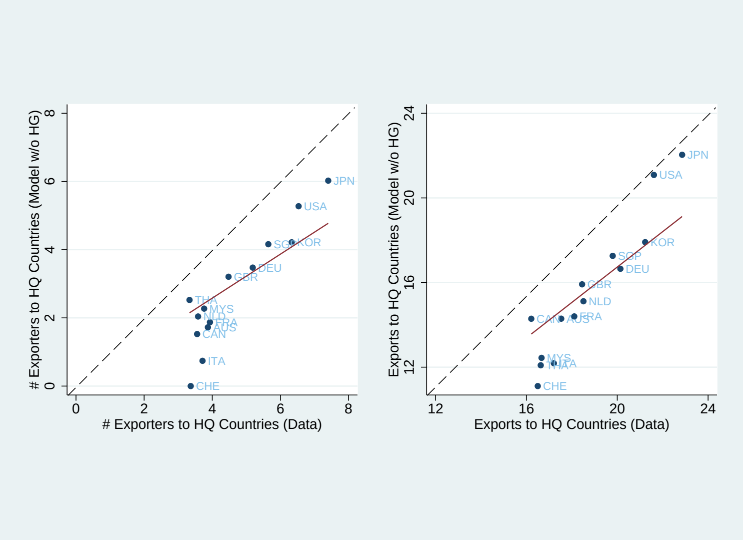

Figure 1.5: Model Predictions on Chinese Exports: the Model without Headquarters Gravity

(Note: The model without headquarters gravity comes from forcing foreign affiliates in China to have the same export costs as Chinese firms, i.e. $\zeta_{di} = \zeta_{d,CHN}$ and $\Xi_{di} = \Xi_{d,CHN}$ for all $d \neq CHN$. The model predictions are generated by simulating demand and entry shocks for foreign affiliates in China, taking their sales in China as given. Data moments are presented in horizontal axises and model predictions are presented in vertical axises.)

The results suggest the foreign affiliates' advantage in export is substantial: $\Delta_\zeta = 0.28$ and $\Delta_\Xi = 0.82$. However, this advantage in export is not distributed evenly across destinations. By the estimates of headquarters gravity, we have known that this advantage is strongly biased towards headquarters countries. I now turn to summarize the foreign affiliates' advantage in export by destination, showing the foreign affiliates' advantage in serving certain markets.

The average iceberg headquarters gravity term by destination can be computed by $\log(\bar{\zeta}_{MNE,d}) = \sum_{i \neq CHN} \frac{X_{d,CHN,i}}{\sum_k X_{d,CHN,k}} \log(\zeta_{di})$. Then $\Delta_{\zeta,d} = \frac{\zeta_{d,CHN} - \bar{\zeta}_{d,MNE}}{\zeta_{d,CHN}}$. $\Delta_{\Xi,d}$ is derived analogously. The results are illustrated by Figure 1.6. Foreign affiliates in China are shown to have strong advantage in exporting to developed countries such as Japan, Korea, Germany, and the U.S. Apparently this is due to these developed countries are Chinese major MP sources. In contrast, Chinese local firms have comparative advantage in exporting to developing countries such as India and Poland. This comparative advantage, as I elaborate below, has distributional implications for Chinese manufacturing exports.

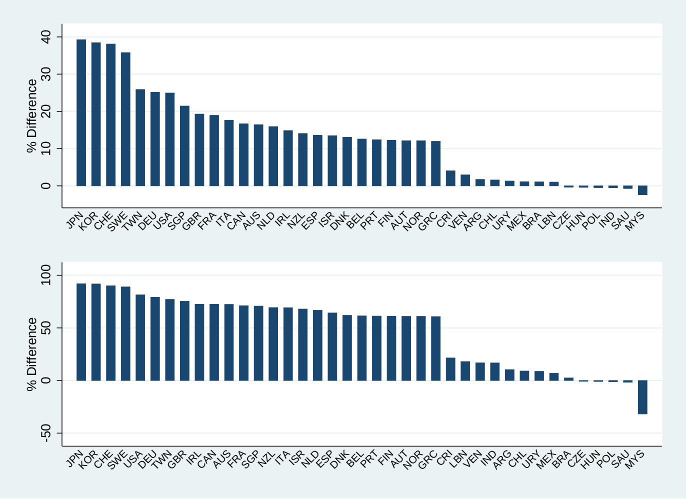

Figure 1.6: Differences in Export Costs between Foreign Affiliates and Chinese Firms

(Note: The upper panel is the percentage differences in iceberg export costs by destination, $\Delta_{\zeta,d} = \frac{\zeta_{d,CHN} - \bar{\zeta}_{d,MNE}}{\zeta_{d,CHN}}$. The lower panel is the percentage differences in fixed export cost by destination, $\Delta_{\Xi,d} = \frac{\Xi_{d,CHN} - \bar{\Xi}_{d,MNE}}{\Xi_{d,CHN}}$.)

1.5 Calibrating the general equilibrium model

In this section I calibrate the rest of the structural parameters of the general equilibrium model. This enables us to compute the general equilibrium outcomes and to conduct counterfactual analysis in next section. The world I target to consists of 28 economies in 2001.[12]

In the following subsections, I first calibrate the productivity dispersion parameter θ and country size $\{L_i\}$. Then I calibrate bilateral trade and MP frictions by matching the model-generated trade and MP flows to their data correspondents.

1.5.1 Calibrating θ and L_i

The dispersion parameter of firm productivity, θ, is calibrated from the dispersion of the domestic sales for Chinese local firms.

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[12] These economies are Australia, Austria, Brazil, Canada, Switzerland, China, Germany, Denmark, Spain, Finland, France, Britain, Indonesia, India, Ireland, Italy, Japan, Korea, Mexico, Malaysia, Netherlands, Poland, Portugal, Singapore, Sweden, Thailand, Taiwan, and the U.S.

Let $\alpha = \frac{\theta}{\sigma-1}$. The model shows that the domestic sales for Chinese local firms is

$$\log(x_{nnn}(\nu)) = \tilde{\delta}(\nu) + \log\xi(\nu) + \Psi_n, \tag{1.50}$$

where $\Psi_n = A_n \bar{m}^{1-\sigma}(w_n^{\beta} P_n^{1-\beta})^{1-\sigma}$, $\tilde{\delta}$ follows an exponential distribution with parameter α, and $\log\xi$ follows a left-truncated normal distribution.

For the domestic sales I ignore the selection of exporters, assuming $\log\xi$ is symmetrically distributed[13]. The property of exponential distribution gives that

$$mean(\log(x_{nnn})) - median(\log(x_{nnn})) = \frac{1-\log(2)}{\alpha}. \tag{1.51}$$

Therefore, $\frac{\theta}{\sigma-1} = 1.39$. Since $\sigma = 4$, $\theta = 4.17$.

L_i comes directly from ILO database for 2001. I use the variable "paid employment in manufacturing" as the measure of country size in the model. There are two reasons for me to use this measure. First it is a comparable measures for manufacturing employment in all 28 countries I am interested. Second I will use the manufacturing wage in ILO database to calibrate the technology levels. This "paid employment in manufacturing" is compatible with my wage measures.

1.5.2 Calibrating $\{\tau_{dn}, \gamma_{ni}, f_{ni}, T_i\}$

I calibrate the general equilibrium model to match aggregate bilateral trade flows and MP sales. The data moments are summarized in Table 1.9.

Moments	Definition	Data Source	Model	Identified Parameters
π_{dn}^{tr}	Export Share	UNCOMTRADE	$\sum_i X_{dni}/\sum_{d,i} X_{dni}$	Iceberg shipping cost τ_{dn}
π_{ni}^{mp}	MP Share	Ramondo et al. (2015)	$\sum_d X_{dni}/\sum_{d,i} X_{dni}$	Iceberg MP cost γ_{di}
π_{ni}^{aff}	Affiliate Share	Ramondo et al. (2015)	J_{nni}/J_{iii}	Fixed MP cost f_{ni}
w_i	manufacturing wage	ILO database	w_i	Technology T_i

Table 1.9: Data moments for calibrating the general equilibrium model

(Note: All data are for year 2001.)

The aggregate bilateral trade flows come from UNCOMTRADE database. Since this paper is about manufacturing exports, I keep trade flows with 2-digit HS code between 16 and 97 (excluding 25, 26, 27). The bilateral MP sales and numbers of

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[13] The imputed entry hurdle for local firms in the domestic market, H_{nnn}, is very low. Therefore assuming $\log\xi$ is symmetrically distributed will not change the result much.

affiliates come from Ramondo et al. (2015). The manufacturing wages come from ILO database. It will be targeted in order to back out technology level T_i.

I have normalized bilateral trade flows and MP sales as shares of the total production of the exporting countries. Moreover, the number of bilateral affiliates is normalized as a share of total firms in the source countries. Targeting on shares instead of levels prevents my calibration from dealing with current account imbalance in the data.

Given the estimated $(\theta, \sigma, \beta, \sigma_\eta, \sigma_\xi, \sigma_{\xi\eta})$ and $(\zeta_{di}, E_{dn}, \Xi_{di}, L_i)$, I calibrate $(\tau_{dn}, \gamma_{ni}, f_{ni}, T_i)$ by the following algorithm. This algorithm can be widely used in calibrating gravity models.

Guess $(\tau^0_{dn}, \gamma^0_{ni}, f^0_{ni}, T^0_i)$. Compute (w_i, X_i, P_i) using the iterative algorithm described above. Then compute the model-generated moments, $\tilde{w}_i$, $\tilde{\pi}^{tr}_{dn}$, $\tilde{\pi}^{mp}_{ni}$, and $\tilde{\pi}^{aff}_{ni}$, and their gap with the data moments. If the gap is below tolerance, stop. Otherwise increase τ_{dn} if the trade share in the model is higher than in data. Similar rules apply for γ_{ni} and f_{ni}. Increase T_i if the wage in the model is lower than in data. Stop until converge.

Figure 1.7 shows that the calibrated bilateral shipping costs are increasing with the bilateral distances between import and export countries. Moreover, the calibrated iceberg and MP costs are increasing with the distance between source and host countries. These patterns are consistent with the literature. Finally, the calibrated technology levels are in line with the TFP measures from Penn World Table for 2001.

1.5.3 Out-of-Sample Predictions

In this section I provide additional validity for my model using the data moments that my calibration never targets to. OECD database contains the foreign affiliates' export share for a number of OECD countries in 2001. I compute the equilibrium with the calibrated parameters and compare the moments generated by the model with the data.

To examine how important the headquarters gravity is for out-of-sample predictions, I re-calibrate the model ignoring headquarters gravity, i.e. $\zeta_{di} = 1$ and $\Xi_{di} = 1$ for all (d, i) and re-calibrate the model to match the bilateral trade and MP shares. By construction, the baseline model and the model ignoring headquarters gravity should generate the same production share of foreign affiliates. But their predictions

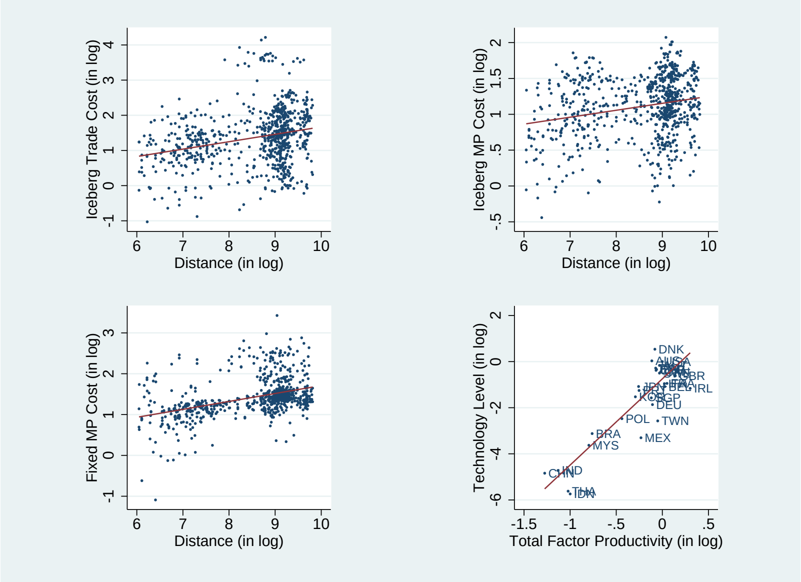

Figure 1.7: The Calibrated $\{\tau_{dn}, \gamma_{ni}, f_{ni}, T_i\}$

(The parameters are calibrated by the algorithm described above. The distance is the geographic bilateral distance between the importing and the exporting countries (compared with trade costs) and between the source and host countries (compared with MP costs). The TFP comes from Penn World Table for 2001.)

for the foreign affiliates' export shares could be different.

The out-of-sample predictions are shown in Table 1.10. The baseline model fits the foreign affiliates' export shares in several OECD countries. The model ignoring headquarters gravity tends to underestimate the foreign affiliates' export shares. Therefore, headquarters gravity is the key for my model to fit the exports of multinational affiliates.

1.6 Counterfactual Exercises

I have shown that my model is consistent with the patterns in micro data and can make fairly good out-of-sample predictions for the export share of multinational affiliates. With the calibrated general equilibrium model, I conduct counterfactual exercises in order to (1) illustrate the model implications, especially the roles of headquarters gravity in shaping international trade and cross-country income distribution, and (2) to show the usefulness of my framework in policy evaluation. In

Export Share of Foreign Affiliates in Host Countries			
	Data	Baseline model	Ignoring HG
France	40.6	46.6	26.7
Ireland	90.6	89.0	76.8
Poland	65.3	68.6	42.5
Netherlands	64.2	66.6	39.7
Sweden	45.1	48.1	28.6

Table 1.10: Model-fit for the foreign affiliates' Export Share in OCED Countries (Note: the data shown in this table come from OECD database in 2001. The model ignoring headquarters gravity comes from setting $\zeta_{di} = 1$ and $\Xi_{di} = 1$ for all (d, i) and re-calibrating the model to match the bilateral trade and MP shares that have been described in Table 1.9.)

this paper I am primarily interested in the impacts of foreign affiliates on Chinese economy. But apparently my multi-country general equilibrium model can apply for policy discussions in other countries.

1.6.1 To Promote Export, Promote Foreign Multinationals

In this subsection I examine the impacts of headquarters gravity on Chinese exports. To achieve this, I impose foreign affiliates in China to have the same export costs as Chinese firms, i.e. $\zeta_{di} = \zeta_{d,CHN}$ and $\Xi_{di} = \Xi_{d,CHN}$ for $d \neq CHN$.[14] Furthermore, I shut down foreign affiliates by letting $\gamma_{CHN,i} = \infty$. The differences between these two scenarios gauge the impacts of multinationals' productivities.

Changes in Chinese manufacturing exports from the baseline economy to counterfactual scenarios are presented in Table 1.11. According to Chinese firm data, foreign affiliates account for 68 percent of Chinese manufacturing exports in 2001. In my baseline model, shutting down foreign affiliates would decrease Chinese manufacturing exports by 49 percent. Shutting down foreign affiliates would induce the entry of Chinese firms. But these new entrants are less productive and with higher export costs than foreign affiliates. Consequently, Chinese manufacturing exports would fall dramatically if foreign affiliates exit.

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[14] Headquarters gravity implies Chinese firms having advantage in serving Chinese market. In this exercise I do not allow foreign affiliates to incur the same trade cost to China with Chinese firms. Otherwise it gives them additional advantage in serving China.

Moreover, imposing the same export costs on foreign affiliates as those faced by Chinese firms will decrease Chinese manufacturing exports by 23.3 percent. So the foreign affiliates' export costs explain as much of their export advantage in China as their productivities. In sum, both productive knowledge and connections with international markets brought by foreign affiliates are quantitatively important for Chinese exports.

The impacts of connections with international markets are not evenly distributed across destinations. Table 1.11 shows that if foreign affiliates have the same export costs as Chinese firms, Chinese manufacturing exports to OECD countries would decrease by 32 percent while Chinese manufacturing exports to non-OECD countries would increase by 27 percent. This trade switching effect is mainly due to the fact that most foreign affiliates come from rich OECD countries. In contrast, shutting down foreign affiliates would decrease Chinese exports to both OCED and non-OEDC countries. This is mainly due to the productivity effect. Unlike those productive foreign affiliates in China, Chinese firms can hardly export to developing countries which usually have high fixed export costs.

% Changes in Chinese Manufactuing Exports			
	No MP	No HG	No Iceberg HG
Total	-49.4	-23.3	-20.4
To OECD	-55.9	-31.9	-28.0
To non-OECD	-11.6	27.4	23.9

Table 1.11: The Impacts of Foreign Affiliates on Chinese Exports

(Note: No HG refers to the counterfactual scenario in which foreign affiliates in China have the same export costs as Chinese firms. No Iceberg HG refers to the counterfactual scenario in which foreign affiliates in China have the same iceberg costs as Chinese firms. No MP refers to the counterfactual scenario in which $\gamma_{CHN,i} = \infty$. %Change are percentage changes from the baseline level to the counterfactual level.)

Figure 1.8 illustrates impacts of headquarters gravity on Chinese exports by destination. If foreign affiliates have the same export costs as Chinese firms, China would lose a large fraction of its exports to developed countries such as Japan, Britain, Germany, and the U.S. Chinese exports would then switch into the developing countries such as India, Indonesia, and Thailand. In short, headquarters gravity does not only affect Chinese export scales but also shapes the geographical patterns of Chinese exports.

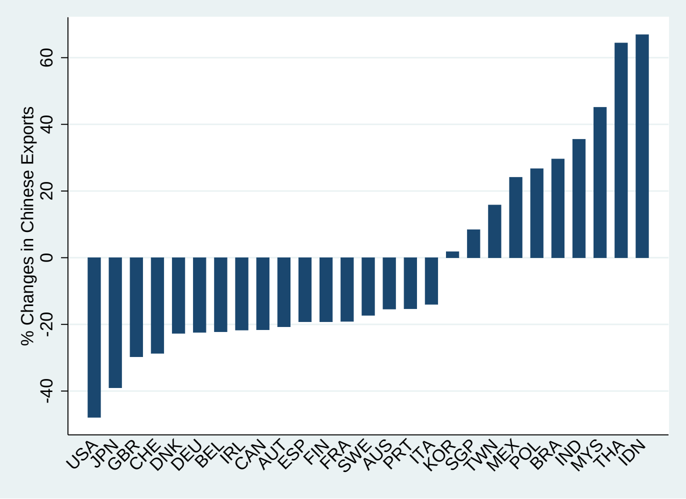

Figure 1.8: The Impacts of Headquarters Gravity on Chinese Export Destinations

(Note: %Change are percentage changes from the baseline level to the counterfactual level. Counterfactual refers to the case that foreign affiliates in China have the same export costs as Chinese firms.)

In sum, the counterfactual exercises show that foreign affiliates in China are responsible for a substantial fraction of Chinese export booms. Their productivities and export costs are both quantitatively important for Chinese exports. These results suggest that for governments that seek to promote exports, an effective policy is to attract FDI from large markets.

1.6.2 Gravity and Headquarters Gravity

Headquarters gravity implies that the standard gravity equation may not be enough for characterize international trade flows in existence of multinational firms. With headquarters gravity, bilateral trade flows do not only depend on the market sizes of two countries and trade costs between them, but are also directly related to their connections with the third country. For example, Canada is close to the U.S. and the U.S. has offshored a large fraction of its manufacturing production to China. With headquarters gravity, US-Canada and US-China connections have direct impacts on Chinese exports to Canada, which cannot be captured by the standard gravity equation.

To illustrate the impacts of headquarters gravity on bilateral trade, I conduct a counterfactual exercise by shutting down all the U.S. multinational affiliates in

China and examining how this would affect Chinese exports to all economies. As before, I conduct this exercise both in my baseline model and in the model ignoring headquarters gravity.

The results are shown in Table 1.12. Without headquarters gravity, shutting down the U.S. affiliates in China decreases Chinese exports almost uniformly to each country. In this case, multinational affiliates promote the host countries' exports by their productivity advantage. So the standard gravity is still valid in existence of multinational firms. In contrast, with headquarters gravity, shutting down the U.S. affiliates in China decreases Chinese exports disproportionately to markets close to the U.S. such as Canada and Mexico. Consequently, the bilateral trade between China and Canada does not only depend on the market sizes of China and Canada and the trade costs between these two countries, but also on the U.S. affiliates in China.

1.6.3 Welfare Consequences of Multinational Production

As I have mentioned at the beginning, multinational firms account for a large share of international trade and global production. In order to understand the welfare consequence of globalization, it is crucial to estimate the welfare implications of multinational production. The multi-country general equilibrium model in this paper provides a natural workhorse for this purpose. First, I need a welfare measure which is consistent with my model. Due to the CES preference and the exogenous country size, I can measure the welfare by real GNP:

$$W_i = \frac{w_i L_i + \Pi_i}{P_i}. \tag{1.52}$$

The GNP is determined by three factors: nominal wage, nominal profit, and price index. I assume that the firms' profits are owned by a unit measure of entrepreneurs who have the same preferences with workers. The fundamental difference between wage and profits is that the wage can only be earned in the country the labor lives in but the profits can come from multinational production.

As I mentioned at the beginning of this section, I am primarily interested in the welfare consequences of China opening to foreign multinationals. So I shut down foreign affiliates in China by letting $\gamma_{CHN,i} = \infty$ in my baseline model. To examine the role of headquarters gravity in evaluating gains from MP, I re-calibrate my model

% Changes in Imports from China		
	Baseline	Igoring HG
Australia	-6.3	-7.8
Austria	-3.4	-8.0
Netherlands	-2.8	-7.5
Brazil	-2.1	-7.3
Canada	-11.7	-7.7
Switzerland	-1.9	-8.0
Germany	-1.5	-6.8
Denmark	-3.3	-8.2
Spain	-7.7	-7.6
Finland	-3.4	-8.0
France	-3.3	-7.3
Britain	-4.2	-7.4
Indonesia	5.4	-7.0
India	-0.9	-6.9
Ireland	-8.9	-8.5
Italy	-3.9	-7.3
Japan	4.7	-6.5
Korea	-3.0	-6.8
Mexico	-9.1	-7.5
Malaysia	3.1	-7.2
Poland	0.3	-7.7
Portugal	-5.8	-8.0
Singapore	-3.6	-7.7
Sweden	-4.0	-7.9
Thailand	5.6	-6.6
Taiwan	-0.1	-6.7
United States	-49.6	-7.3

Table 1.12: Trade Effects of Shutting down the U.S. Affiliates in China

(Note: I shut down the U.S. affiliates in China by raising $\gamma_{CHN,USA}$ into infinity. The model ignoring headquarters gravity comes from setting $\zeta_{di} = 1$ and $\Xi_{di} = 1$ for all (d, i) and re-calibrating the model to match the bilateral trade and MP shares that have been described in Table 1.9. %Change are percentage changes from the baseline level to the counterfactual level.)

with $\zeta_{di} = 1$ and $\Xi_{di} = 1$ for all (d, i) to match bilateral trade and MP shares in aggregate data. Then I estimate Chinese welfare gains from opening to foreign affiliates in this new scenario by letting $\gamma_{CHN,i} = \infty$. The percentage changes of real GNP in 28 economies are presented in Table 1.13.

The results in Table 1.13 suggest that ignoring headquarters gravity will make us substantially overestimate welfare gains from MP for the host countries. Based on the model ignoring headquarters gravity, Chinese real GNP will decrease by 13 percent without foreign affiliates while based on my baseline model Chinese real

% Changes in Welfare from raising $\gamma_{CHN,i}$ into ∞ for $i \neq CHN$		
	Baseline	Igoring HG
Australia	-1.21	-.99
Austria	-.88	-.76
Netherlands	-.57	-.46
Brazil	-.08	-.18
Canada	-.60	-.48
Switzerland	-1.26	-.98
China	-9.73	-12.88
Germany	-.40	-.30
Denmark	-1.01	-.89
Spain	-.39	-.38
Finland	-1.78	-1.51
France	-.47	-.44
Britain	-.53	-.41
Indonesia	-.13	-.27
India	-.24	-.44
Ireland	-1.18	-.99
Italy	-.31	-.32
Japan	-1.09	-.78
Korea	-.61	-.47
Mexico	-.12	-.23
Malaysia	-.72	-.88
Poland	-.31	-.61
Portugal	-.78	-.82
Singapore	-1.28	-.96
Sweden	-1.05	-.88
Thailand	-.07	-.34
Taiwan	-1.52	-.78
United States	-.65	-.47

Table 1.13: Welfare Implications of China Opening to Foreign Affiliates

(Note: The model ignoring headquarters gravity comes from setting $\zeta_{di} = 1$ and $\Xi_{di} = 1$ for all (d, i) and re-calibrating the model to match the bilateral trade and MP shares that have been described in Table 1.9. %Change are percentage changes from the baseline level to the counterfactual level.)

GNP will only decrease by 9.8 percent. So ignoring headquarters gravity will make us overestimate the welfare gains from MP for the host countries.

The opposite happens in the main source countries of multinational affiliates in China such as the U.S. In the model ignoring headquarters gravity, shutting down all foreign affiliates in China will only lead 0.47% decrease of the U.S. welfare, while in the baseline model with headquarters gravity, the U.S. welfare will decrease by -0.65%.

How does the headquarters gravity affect our estimates of welfare gains from

MP? I answer this question by separating the welfare effects of headquarters gravity from multinationals' productivities. I first eliminate headquarters gravity by forcing foreign affiliates in China to have the same export costs as Chinese firms. Then I shut down foreign affiliates in China by letting $\gamma_{CHN,i} = \infty$. The differences between these two counterfactual scenarios characterize the impacts of multinationals' productivities. The results are presented in Table 1.14.

%Changes in China		
	No HG	No MP
Welfare	-.10	-9.73
Nominal Wage	-8.83	-23.9
Nominal Profit	1.39	26.9
Price	-6.22	-1.78

Table 1.14: Welfare Implications of Foreign Affiliates in China

(Note: No HG refers to the counterfactual scenario in which foreign affiliates in China have the same export costs as Chinese firms. No MP refers to the counterfactual scenario in which $\gamma_{CHN,i} = \infty$. %Change are percentage changes from the baseline level to the counterfactual level.)

The results in Table 1.14 suggest that Chinese welfare gains from multinationals' productivities are much larger than gains from headquarters gravity. Forcing foreign affiliates to have the same export costs as Chinese firms will only decrease Chinese real GNP by 0.1 percent while shutting down foreign affiliates in China will decrease Chinese real GNP by 9.73 percent. I further decompose the welfare effects into changes in nominal wage, nominal profit, and price index. The main difference between headquarters gravity and multinationals' productivities lies in their price effects. If foreign affiliates in China have the same export costs as Chinese firms, Chinese price index will decrease by 6.2 percent. This is because the low export costs of foreign affiliates do not directly lower their unit costs for serving the Chinese market, but they can drive out Chinese firms whose market is mainly domestic. In contrast, shutting down foreign affiliates in China will only decrease Chinese price index by 1.8 percent, which implies that the foreign affiliates' productivities decrease Chinese price by 4.4 percent. Therefore, the majority of Chinese welfare gains from opening to foreign affiliates come from the technologies brought by these affiliates instead of their improved access to export markets.

The decomposition presented in Table 1.14 sheds light on the welfare effects of headquarters gravity. If foreign affiliates are more export-oriented than local firms because they are more productive, they can also serve the host country with lower prices. In contrast, if foreign affiliates are more export-oriented because they have lower export costs, this does not affect their prices in the host country. Ignoring headquarters gravity, we will attribute foreign affiliates' sales solely to their productivities, which makes us overestimate the welfare gains from MP for the host country. So in order to understand the welfare consequences of MP, we need to understand the structure of multinational affiliates' export costs, which have been carefully estimated in this paper.

Finally, for the sake of general interests, I also present the welfare gains from MP for all 28 countries. In this exercise, I raise γ_{ni} into ∞ for all $n \neq i$. I conduct this counterfactual exercise both in my baseline model and in the model ignoring headquarters gravity. The results are shown in Table 1.15.

The results in Table 1.15 suggest that the welfare gains from multinational production are substantial. In small open economies such as Ireland, shutting down multinational production will decrease its GNP by a half. Furthermore, as elaborated above, ignoring headquarters gravity will make us overestimate the gains from MP for host countries, mainly developing countries like China, Brazil, Indonesia, and Thailand, but underestimate the gains from MP for source countries like the U.S., Netherlands, and Denmark.

1.6.4 Implications of China-Germany Bilateral Investment Treaty

In this section I apply my model to analyze the impacts of FDI policies in existence of headquarters gravity. In 2003 China and Germany signed a bilateral investment treaty (BIT) in order to "create favorable conditions for investment by investors of one contracting party in the territory of the other contracting party".[15] This BIT, like many others, aims to reduce the barriers of bilateral investment. However, since China and Germany are two major economies in the world, China-Germany BIT does not only affect signatory parties, but also affect other countries. Evaluating its global impacts requires a multi-country general equilibrium model.

This paper provides a suitable workhorse for this analysis. As mentioned above,

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[15] See "Agreement between the People's Republic of China and the Federal Republic of Germany on the encouragement and reciprocal protection of investments" (2003).

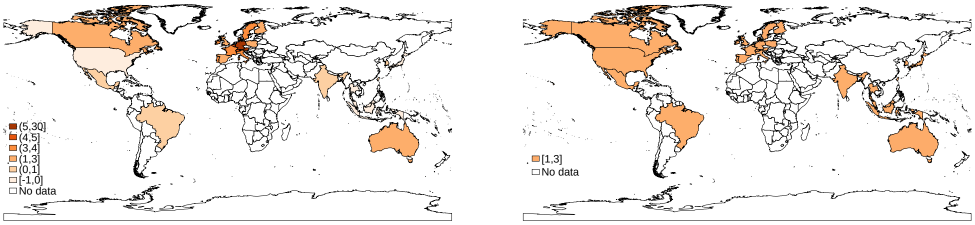
% Changes in Welfare from raising $\gamma_{n,i}$ into ∞ for all $n \neq i$		
	Baseline	Igoring HG
Australia	-23.2	-25.9
Austria	-28.0	-29.3
Netherlands	-33.2	-31.2
Brazil	-2.4	-5.5
Canada	-22.0	-22.4
Switzerland	-36.2	-34.5
China	-11.7	-14.0
Germany	-14.6	-15.0
Denmark	-28.6	-27.3
Spain	-12.6	-14.0
Finland	-32.4	-33.1
France	-16.8	-16.7
Britain	-16.9	-18.1
Indonesia	-5.9	-11.3
India	-2.5	-3.6
Ireland	-51.9	-51.5
Italy	-9.1	-9.8
Japan	-8.5	-7.0
Korea	-7.1	-7.2
Mexico	-9.5	-16.1
Malaysia	-10.6	-18.8
Poland	-6.7	-15.0
Portugal	-21.0	-26.9
Singapore	-30.2	-30.4
Sweden	-27.7	-28.6
Thailand	-5.1	-11.6
Taiwan	-9.5	-11.1
United States	-13.1	-11.8

Table 1.15: Welfare Gains from Multinational Production

(Note: The model ignoring headquarters gravity comes from setting $\zeta_{di} = 1$ and $\Xi_{di} = 1$ for all (d, i) and re-calibrating the model to match the bilateral trade and MP shares that have been described in Table 1.9. %Change are percentage changes from the baseline level to the counterfactual level.)

my model combines headquarters gravity with the standard trade and MP frictions emphasized in the literature. Multinational firms determine their global production and sales according to all trade and MP frictions. A reduction in bilateral MP costs can reallocate production between signatory countries. Since the productivities of Germany firms are much higher than those of Chinese firms, China-Germany BIT will increase MP from Germany to China. What is unique in my model is that headquarters gravity leads to a complementarity between trade and MP. As a result, China-Germany BIT will promote Chinese exports to Germany and European markets near Germany.

In practice, I assume that China-Germany BIT reduces their bilateral iceberg MP costs by 20 percent. This is not a wild guess since China maintained a number of regulations on foreign investment before signing BIT. To isolate the effects of China-Germany BIT, I keep all other parameters unchanged. I conduct counterfactual exercises in both baseline model and the model ignoring headquarters gravity.



(a) Baseline Model

(b) Model ignoring Headquarters Gravity

Figure 1.9: Percentage Changes in Imports from China after China-Germany BIT

(Note: China-Germany BIT is modeled as a 20 percent reduction on their bilateral iceberg MP costs.)

Figure 1.9 illustrates changes in imports from China after China-Germany BIT in the baseline model and in the model ignoring headquarters gravity. In the baseline model, due to headquarters gravity, China-Germany BIT promotes Chinese exports greatly to European markets such as Germany, Austria, Netherlands, Switzerland, and Denmark. In contrast, in the model ignoring headquarters gravity, China-Germany BIT promotes Chinese exports almost uniformly across destinations. Without headquarters gravity, inward MP liberalization can promote exports only due to increasing productivities.

Headquarters gravity also affects the welfare implications of China-Germany BIT. Figure 1.16 shows the welfare effects of China-Germany BIT in some countries of my sample. A few issues should be noticed. First, headquarters gravity shifts the gains from bilateral MP liberalization from China, a developing country, to Germany, a developed country. This is consistent with the welfare implication of headquarters gravity mentioned above. With headquarters gravity, German multinational firms can exploit Chinese cheap labors and serve German markets with low costs.

Second, headquarters gravity results in third-country effects of bilateral MP liberalization. With headquarters gravity, China-Germany BIT would substantially

	% Changes in Welfare	
	Baseline	Ignoring HG
Germany	.440	.298
China	.903	1.090
Austria	.005	.002
Netherlands	.015	.010
Switzerland	.001	-.001
Denmark	.001	-.003
France	.003	.000
Canada	-.002	.000
Indonesia	-.001	.005
Malaysia	-.002	.001
Singapore	.011	.018
Thailand	.002	.012
Japan	-.014	-.005
United States	-.008	.000

Table 1.16: Welfare Implications of China-Germany BIT

(Note: China-Germany BIT is modeled as a 20 percent reduction on their bilateral iceberg MP costs.)

increase Chinese exports to European countries close to Germany, bringing down their prices and raising their real income. In contrast, with headquarters gravity, China-Germany BIT would decrease the imports of European countries from other developing countries such as Indonesia, Malaysia, and Thailand, bringing down the real income in these countries. Finally, with headquarters gravity, China-Germany BIT would drive some firms from Japan and the U.S. out of China, which decrease the welfare in these countries. In sum, the third-country effects of bilateral MP liberalization under headquarters gravity depend on the trade and MP linkages across countries.

Taking China-Germany BIT as an example, I have shown that headquarters gravity has substantial impacts on the trade and production effects of bilateral MP liberalization, similar to what have been documented in Head and Mayer (2015). In addition, headquarters gravity has moderate impacts on the welfare effects of bilateral MP liberalization.

1.7 Conclusion

My paper contributes to the literature on international trade by developing a general equilibrium model that captures multinational affiliates' advantage in serving markets closer to their headquarters. In particular, my model allows an affiliate's export costs to depend on the proximity between its headquarters and destination markets (headquarters gravity). This new feature helps my model to characterize multinationals' exports better than previous trade models.

My structural estimates in Chinese firm data suggests that headquarters gravity is quantitatively important for multinational affiliates' exports. If foreign affiliates in China have the same export costs as Chinese firms, Chinese manufacturing exports would decrease by about a quarters in 2001. Moreover, I show that headquarters gravity explains as much of the export advantage of foreign affiliates in China as their productivities.

It is essential to incorporate headquarters gravity into a general equilibrium model because it can affect our estimates on welfare gains from MP. I show that ignoring headquarters gravity will make us overestimate Chinese welfare gains but underestimate the U.S. welfare gains from MP. I conclude that getting precise estimates on multinational firms' export costs is crucial for evaluating trade and FDI policies.

Chapter 2

Multinational Production and External Economies of Scale

2.1 Introduction

"Those jobs aren't coming back."

— New York Times, Jan. 20th, 2012

In recent decades the U.S. and other rich countries have offshored a large fraction of their manufacturing jobs to developing countries. Why do they do so? Will these jobs come back? Previous theories mainly ascribe offshoring to factor price differences. An implication of these theories is that once the wages in developing countries rise, the offshored jobs will start to come back. This paper argues that in addition to factor price differences, external economies of scale can be an important driving force for offshoring. As a consequence, it can be challenging for offshored jobs to come back to rich countries.

In an article at New York Times on Jan. 20th, 2012, the authors argue that:

> *"It isn't just that workers are cheaper abroad. Rather, Apple's executives believe the vast scale of overseas factories as well as the flexibility, diligence and industrial skills of foreign workers have so outpaced their American counterparts that 'Made in the U.S.A.' is no longer a viable option for most Apple products."*

This argument illustrates the importance of external economies of scale in deciding the production locations. An individual factory relies heavily on the parts and components provided by other factories, on the workers' pool in industry clusters, and on technology spillovers from their peer factories[1]. Once a large fraction of these factories have been moved to developing countries, these inter-factory networks would also move there. External economies of scale will stick these factories in the host countries, even when the wages in these countries start to rise.

External economies of scale has been ignored in quantitative trade models. The primary reason is that external economies of scale often lead to multiple equilibria which impede quantitative analysis. In this paper I incorporate locally external economies of scale into a standard multi-country general equilibrium model with trade and multinational production (MP)[2]. Two contributions are made. First I provide sufficient conditions under which my model has a unique equilibrium. Second, I identify external economies of scale from productivity differences by a new instrument. My model is used to examine the implications of MP liberalization on welfare and production distribution.

My model is an extension to the framework developed by Arkolakis et al. (2015). As in their work, the representative household consumers a continuum of final varieties, each of which is produced by a firm. The firm can choose production sites with minimum costs to serve certain markets. My model departs from Arkolakis et al. (2015) by assuming that production also requires a continuum of intermediate varieties that can only be produced locally (within a country). Moreover, providing a new intermediate variety incurs a fixed cost. With this simple mechanism, the measure of intermediate varieties will increase with the production scale of final varieties, which will in turn decrease the production costs and increase the production scale of final varieties.

By its nature the feedback loop described above can lead to multiple equilibria. I provide a set of sufficient conditions for the uniqueness of equilibrium. Intuitively, the uniqueness requires that external economies of scale are not stronger than the

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[1] Ellison, G. and Glaeser, E. (1997) provides a good summary for sources of external economies of scale.

[2] Here multinational production is defined as production that is carried out by firms outside their headquarters countries. However, my model can apply to the offshoring cases in which firms in host countries do not have ownership relations with firms in source countries such as Apple outsourced its production to Foxconn. The reason I consider only MP in this paper is due to the data for other outsourcing forms is not available.

dispersion of firm productivity. With uniqueness I show that the welfare gains from trade and MP relate both to the trade elasticity and external economies of scale. This result leads to a simple welfare measure derived from the observed trade and MP flows as well as trade elasticity and external economies of scale.

The main empirical challenge of this paper comes from separating external economies of scale from comparative advantage. Utilizing the panel data I have, I find a novel instrument that can affect the production scales but do not directly relate to productivity changes. This instrument is the event of China joining WTO. China joining WTO will have larger effects on production scales in countries with closer connections with China. But its productivity effects, if there are any, should not be related to distances from China. With this instrument, I recover external economies of scale. The estimates fall into the region of parameters that ensure the uniqueness of equilibrium.

With the estimates on external economies of scale, I calibrate my model to match the aggregate bilateral trade and MP flows. I then use the calibrated model to conduct counterfactual exercises to examine the implications of external economies of scale on welfare gains from MP liberalization. I look at what happens when bilateral MP costs decrease by 5%. I find that the welfare gains from MP liberalization are considerably sensitive to external economies of scale. With external economies of scale, developing countries with large net MP inflows gain substantially more from MP liberalization. For example, in my baseline model Chinese real wage increases 57% more than in the model without external economies of scale. These benefits are driven exactly by the feedback loop I described before. The opposite occurs in developed countries that have net MP outflows. On average their gains from MP liberalization decrease by 10% in existence of economies of scale. While the firms that offshore their production benefit from cost reduction, the firms that still produce in developed countries suffer from the shrinking industry sizes. This implication echoes the worries that offshoring may "hollow-out" the manufacturing sectors in developed countries.

External economies of scale also affect the third-party effect of bilateral investment agreements. This paper takes the under-negotiated US-China Bilateral Investment Treaty (BIT) as an example. I quantify BIT by decreasing the MP costs between the U.S. and China by 10%. BIT can divert production from the U.S. to China and benefit both countries. However, without external economies of scale, BIT can hurt Germany since the U.S. multinationals bid up Chinese wage. With external economies of scale, Germany can gain from the increase of Chinese productivity. This result highlight the importance of external economies of scale in multi-country policy analysis.

My work builds on and contribute to quantitative models of trade and MP. In particular, my model is an extension to Arkolakis et al. (henceforth, ARRY, 2015) by introducing national external economies of scale into a multi-country general equilibrium model. My model shows that MP does not only benefit the host countries by technology flows but also by the increasing production scales. This implication is consistent with many examples and empirical evidences. Ramondo and Rodriguez-Clare (2013) and Alviarez (2014) develop quantitative models with trade and MP. These models also consider only constant-return-to-scale production.

This paper is also related to the empirical studies on how MP affects productivities in both source and host countries. Keller and Yeaple (2009) find that FDI leads to substantial productivity gains for domestic firms. This finding can be rationalized by external economies of scale. Monarch, Park, and Sivadasan (2013) find that offshoring has negative impact on the output, employment, and capital stand of the remaining domestic firms. This "hollow-out" effect can hardly be captured without external economies of scale.

My work is also related to the models with external economies of scale (See Rodriguez-Clare (2007), Grossman and Rossi-Hansberg (2008), and Kucheryavyy, Lyn, and Rodriguez-Clare (KLR, 2014) for recent developments.). This paper contributes to this literature in two dimensions. Firstly I provide a set of sufficient conditions for the uniqueness of equilibrium in a gravity model with offshoring and localized external economies to scale. My proof extends the condition of uniqueness in KLR (2014) by considering the input-output linkages across industries. Secondly, I use a new instrument to separate the external economies of scale with comparative advantage. This method can be useful in estimating any gravity model with external economies of scale.

The paper is structured as follows. In section 2.2, I build a model with MP and the localized external economies of scale in production, and then provide the conditions for the existence and uniqueness of the equilibrium. In section 2.3, I discuss how to measure the welfare effects of trade and MP liberalization and how to link the model with the data. In section 2.4, I estimate the model using a two-period panel dataset of bilateral trade and MP flows. In section 2.5, I conduct counterfactual experiments to evaluate the welfare gains from openness. Section 2.6 concludes.

2.2 The model

2.2.1 Environment

Preference and Technology: There are N countries endowed with labor $\{\bar{L}_i\}_{i=1}^{N}$. Labors are homogeneous ex ante and immobile across countries. In country d the representative consumer has a CES preference over a continuum of final goods varieties:

$$U_d = [\int_{\omega\in\Omega} q_d(\omega)^{\frac{\sigma-1}{\sigma}} d\omega]^{\frac{\sigma}{\sigma-1}}, \tag{2.1}$$

where $q_d(\omega)$ is the quantity of the variety ω consumed in country d and $\sigma > 1$. A multi-industry case can be interesting and more realistic. I stick to the single industry model for two reasons. Firstly it is the simplest model combining multinational production and external economies of scale into a multi-country framework. Secondly a multi-industry model with MP can hardly be identified in the data.

Each variety is produced by a firm originated from country i in production site l via a production function:

$$q(\omega) = z_{li}(\omega) L_l^{\eta} L_l(\omega), \tag{2.2}$$

where z_{li} is the fundamental productivity of firm ω which is originated from country i and produces in country l, L_l is the total laborforce allocated to production in country l, and $L_l(\omega)$ is the labor in country l employed by firm ω. η characterizes the localized external economies of scale in production.

$\mathbf{z}_i = (z_{1i}, \ldots, z_{Ni})$ follows multivariate Pareto distribution:

$$G_i^f(\mathbf{z}) = 1 - T_i[\sum_{l=1}^{N} (z_l)^{-\frac{\theta}{1-\rho}}]^{1-\rho} \tag{2.3}$$

where $z_i \geq \underline{T}_i := [T_i N^{1-\rho}]^{\frac{1}{\theta}}$. T_i represents the productivity level of the firms from country i. $\theta > \sigma - 1 > 0$ represents the dispersion of the productivities within a country. And $\rho \in [0, 1)$ represents the correlation of the productivities across production sites within a firm. Before drawing $\mathbf{z}_i$, each firm in country i pays a fixed cost E_i in terms of labor in country i.

A firm in country i who wants to produce in country l incurs iceberg MP costs $\zeta_{li} \geq 1$. I assume that final goods are tradable subject to an iceberg trade cost $\tau_{dl} \geq 1$ from l to d. Moreover, if a firm wants to sell at market d, it has to pay a fixed marketing cost F_d in terms of d's labor. As mentioned before, labors are homogeneous ex ante. So they can switch between producing, establishing new varieties, and marketing freely.

My model is the same with the one in ARRY (2014) except that here the production exhibits localized external economies of scale which is characterized by η. However, as I will show, introducing external economies of scale can generate multiple equilibria and change the welfare effects of MP liberalization.

Before proceeding into the equilibrium, I will clarify my notations. The subscript "dli" means originated from country i, producing in country l and selling to country d. For example, the sales of affiliates originating from country i, producing in country l, and selling to country d is X_{dli}. The total expenditure in country d is $X_d = \sum_{l,i} X_{dli}$. The total production value in country l is $Y_l^m = \sum_{d,i} X_{dli}$. And the total affiliate sales from country i is $Y_i^f = \sum_{d,l} X_{dli}$. The subscript dl means trading from country l to d or offshoring from l to d.

2.2.2 Firms' Problem and Aggregation

The unit cost for a firm originated from country i to produce in country l and sell to country d is

$$c_{dli}(\omega) = \frac{\xi_{dli}}{z_{li}(\omega)}, \tag{2.4}$$

where

$$\xi_{dli} = \tau_{dl}\zeta_{li}L_l^{-\eta}w_l, \tag{2.5}$$

and w_l is the wage in country l.

A firm in i will choose its production location to serve market d by solving:

$$l(\omega) = \arg\min_{k=1,\ldots,N} c_{dki}(\omega), \tag{2.6}$$

taking $\{L_k\}_{l=k}^N$ as given.

Let c_i^* be the cost cut-off above which firms will not enter market i. Firms' markup is $\tilde{\sigma} = \sigma/(\sigma - 1)$. Then c_i^* can be given by

$$c_i^* = (\sigma w_i F_i / X_i)^{\frac{1}{1-\sigma}} P_i / \tilde{\sigma}, \tag{2.7}$$

where P_i is the price index of final goods in country i.

Let M_i be the measure of firms in i. Let $\mathbf{w} := (w_1, \ldots, w_N)$, $\mathbf{M} := (M_1, \ldots, M_N)$, and $\mathbf{L} := (L_1, \ldots, L_N)$. If $\xi_{dli} > \underline{\mathrm{T}}_i c_i^*$ for all (d, l, i), then the trilateral trade flows X_{dli} can be expressed by $(\mathbf{w}, \mathbf{M}, \mathbf{L})$ and the technology and geography terms.

Firstly, given a firm in country i wants to serve market d, the probability of producing in country l is:

$$\psi_{dli}(\mathbf{w}, \mathbf{L}) := \frac{L_l^{\frac{\theta\eta}{1-\rho}} (w_l \zeta_{li} \tau_{dl})^{-\frac{\theta}{1-\rho}}}{\sum_k L_k^{\frac{\theta\eta}{1-\rho}} (w_k \zeta_{ki} \tau_{dk})^{-\frac{\theta}{1-\rho}}}. \tag{2.8}$$

Then the expenditure share of country d on goods originated from country i is:

$$\lambda_{di}(\mathbf{w}, \mathbf{M}, \mathbf{L}) := \frac{T_i M_i [\sum_k L_k^{\frac{\theta\eta}{1-\rho}} (w_k \zeta_{ki} \tau_{dk})^{-\frac{\theta}{1-\rho}}]^{1-\rho}}{\sum_h T_h M_h [\sum_k L_k^{\frac{\theta\eta}{1-\rho}} (w_k \zeta_{kh} \tau_{dk})^{-\frac{\theta}{1-\rho}}]^{1-\rho}}. \tag{2.9}$$

So the trilateral trade flows can be expressed by:

$$\pi_{dli}(\mathbf{w}, \mathbf{M}, \mathbf{L}) := \frac{X_{dli}}{X_d} = \psi_{dli}(\mathbf{w}, \mathbf{L}) \lambda_{di}(\mathbf{w}, \mathbf{M}, \mathbf{L}). \tag{2.10}$$

The value of production in country l is given by

$$Y_l^m = \sum_{d,i} \pi_{dli} X_d. \tag{2.11}$$

And the sales of all affiliates originated from country i is

$$Y_i^f = \sum_{d,l} \pi_{dli} X_d. \tag{2.12}$$

The measure of firms associated with X_{dli} is $M_{dli} = (\theta - \sigma + 1)/(\sigma\theta) X_{dli} / (w_d F_d)$. Therefore, the profits net of marketing costs but gross of firm entry costs have a constant share of sales: $\Pi_{dli} = \tilde{\delta}^f X_{dli}$ where $\tilde{\delta}^f = 1/(\theta\tilde{\sigma})$. The marketing costs to sell X_{dli} is equal to $\tilde{\delta} X_{dli}$ where $\tilde{\delta} = (\theta - \sigma + 1)/(\sigma\theta)$.

The labor income in country i consists of wages of final good innovators, wages of specialist innovators, wages of the production workers, and the wages of market workers.

$$w_i \bar{L}_i = \tilde{\delta}^f Y_i^f + (1 - \tilde{\delta}^f - \tilde{\delta}) Y_i^m + \tilde{\delta} X_i. \tag{2.13}$$

The aggregate expenditure in country i is equal to its aggregate labor income:

$$X_i = w_i \bar{L}_i. \tag{2.14}$$

So the current account balance condition can be expressed as:

$$w_i \bar{L}_i = \delta^f \sum_d \lambda_{di}(\mathbf{w}, \mathbf{M}, \mathbf{L}) w_d \bar{L}_d + \delta^m \sum_{d,k} \pi_{dik}(\mathbf{w}, \mathbf{M}, \mathbf{L}) w_d \bar{L}_d, \tag{2.15}$$

where $\delta^f = \tilde{\delta}^f/(1 - \tilde{\delta})$ and $\delta^m = (1 - \tilde{\delta}^f - \tilde{\delta})/(1 - \tilde{\delta})$.

The free entry condition for the firms is:

$$M_i w_i E_i = \tilde{\delta}^f \sum_d \lambda_{di}(\mathbf{w}, \mathbf{M}, \mathbf{L}) w_d \bar{L}_d. \tag{2.16}$$

The labor market clearing condition is:

$$M_i E_i + L_i = (1 - \tilde{\delta}) \bar{L}_i. \tag{2.17}$$

Finally the price index for final goods in i is

$$(P_d)^{-\theta} = \gamma^f \left(\frac{w_d F_d}{X_d}\right)^{\frac{\theta - \sigma + 1}{1 - \sigma}} \{\sum_h T_h M_h [\sum_k L_k^{\frac{\theta \eta}{1-\rho}} (w_k \zeta_{kh} \tau_{dk})^{-\frac{\theta}{1-\rho}}]^{1-\rho}\}, \tag{2.18}$$

where γ^f is a positive constant.

2.2.3 Defining the Equilibrium

It is problematic to define the equilibrium simply as $(\mathbf{w}, \mathbf{M}, \mathbf{L})$ that satisfies equation (2.16), (2.17), and (2.15). To see this, let me define an interior solution for equation (2.16), (2.17), and (2.15) as a solution that $M_i > 0$ and $L_i > 0$, $\forall i$. Then for any interior solution, I can enforce $L_i = 0$ or $M_i = 0$ in some i and still make $(\mathbf{w}, \mathbf{M}, \mathbf{L})$ satisfies equation (2.16), (2.17), and (2.15). There will be a bunch of equilibria in which some or all countries have $L = 0$ or $M = 0$. Since in the data we never observe such complete specialization, I will refine the equilibrium concept to exclude these corner solutions.

The equilibrium concept I use is developed by Kucheryavyy, Lyn, and Rodriguez-Clare (2014). Firstly I define the equilibrium in a δ-economy:

Definition 6 *Given $\delta > 0$, the equilibrium in the δ-economy is $(\mathbf{w}, \mathbf{M})$ such that:*

1. $(\mathbf{w}, \mathbf{M}, (1-\tilde{\delta})\bar{\mathbf{L}} - \mathbf{M})$ *satisfies equation (2.15).*
2. *Complementary slackness conditions (CSC):*
   - *(a)* $\delta \leq M_i \leq (1-\tilde{\delta})\bar{L}_i - \delta$, $\forall i$.
   - *(b) For* $G(\mathbf{w}, \mathbf{M})$ *where* $G_i(\mathbf{w}, \mathbf{M}) := M_i w_i E_i - \tilde{\delta}^f \sum_d \lambda_{di}(\mathbf{w}, \mathbf{M}, (1-\tilde{\delta})\bar{\mathbf{L}} - \mathbf{M}) w_d \bar{L}_d$,

$$M_i = \delta, \quad G(\mathbf{w}, \mathbf{M}) \geq 0; \tag{2.19}$$

$$\delta < M_i < (1-\tilde{\delta})\bar{L}_i - \delta, \quad G(\mathbf{w}, \mathbf{M}) = 0; \tag{2.20}$$

$$M_i = (1-\tilde{\delta})\bar{L}_i - \delta, \quad G(\mathbf{w}, \mathbf{M}) \leq 0. \tag{2.21}$$

The δ-economy can be regarded as a special case in which measure δ of labors are locked in creating final varieties or producing. CSC implies that the wages of these "locked-in" workers are no greater than "unlocked" workers. By construction in the δ-economy no country will incur complete specialization.

Then I can define the equilibrium in the actual economy:

Definition 7 *The equilibrium in the actual equilibrium is $(\mathbf{w}, \mathbf{M})$ such that $(\mathbf{w}, \mathbf{M}) = \lim_{\delta \to 0}(\mathbf{w}(\delta), \mathbf{M}(\delta))$ where $(\mathbf{w}(\delta), \mathbf{M}(\delta))$ is an equilibrium in the δ-economy. In other words, $(\mathbf{w}, \mathbf{M})$ satisfies:*

1. $(\mathbf{w}(\delta), \mathbf{M}(\delta))$ *is an equilibrium in the δ-economy for all $\delta > 0$.*
2. $\forall \varepsilon > 0$, $\exists \bar{\delta}$ *such that* $\forall \delta \leq \bar{\delta}$, $||(\mathbf{w}, \mathbf{M}) - (\mathbf{w}(\delta), \mathbf{M}(\delta))|| < \varepsilon$.

2.2.4 Characterizing the equilibrium

In this section I will characterize the existence and the uniqueness of the equilibrium. It will be easier to do so by characterizing equilibrium allocation, $\mathbf{M}$, and equilibrium wage, $\mathbf{w}$, sequentially. In the δ-economy I denote the equilibrium allocation $\mathbf{M}$ given $\mathbf{w}$ by $\mathbf{M} = \mathbf{M}(\mathbf{w}, \delta)$. In other words, for all $\mathbf{w} \in \mathbb{R}^N_{++}$ and $\delta > 0$, the equilibrium allocation, $\mathbf{M}(\mathbf{w}, \delta)$ is the solution of the following mixed complementarity problem (MCP)[3]:

1. $\delta \leq M_i \leq (1 - \tilde{\delta})\bar{L}_i - \delta$, $\forall i$.
2. For function $G(\mathbf{M})$ where

$$G_i(\mathbf{M}) = w_i - \tilde{\delta}^f \sum_d \frac{T_i[\sum_k a_{dki}((1-\tilde{\delta})\bar{L}_k - M_k)^\alpha]^{1-\rho}}{\sum_h T_h M_h [\sum_k a_{dkh}((1-\tilde{\delta})\bar{L}_k - M_k)^\alpha]^{1-\rho}} w_d \bar{L}_d, \tag{2.22}$$

and

$$a_{dli} = (w_l \zeta_{li} \tau^f_{dl})^{-\frac{\theta}{1-\rho}}, \quad \alpha = \frac{\theta\eta}{1-\rho}, \tag{2.23}$$

I have

$$M_i = \delta, \quad G_i(\mathbf{M}) \geq 0; \tag{2.24}$$

$$\delta < M_i < (1-\tilde{\delta})\bar{L}_i - \delta, \quad G_i(\mathbf{M}) = 0; \tag{2.25}$$

$$M_i = (1-\tilde{\delta})\bar{L}_i - \delta, \quad G_i(\mathbf{M}) \leq 0. \tag{2.26}$$

The equilibrium in the δ-economy is then $\mathbf{w}(\delta)$ such that $(\mathbf{w}, \mathbf{M}(\mathbf{w}, \delta))$ satisfies equation (2.15). Moreover, $\mathbf{M}(\mathbf{w}) := \lim_{\delta \to 0} \mathbf{M}(\mathbf{w}, \delta)$ is the equilibrium allocation in the actual economy given $\mathbf{w}$. And $(\mathbf{w}, \mathbf{M}(\mathbf{w}))$ satisfying equation (2.15) is the equilibrium in the actual economy.

2.2.4.1 Equilibrium labor allocation

Firstly, I will establish the existence and the uniqueness of the equilibrium labor allocation in the actual economy, $\mathbf{M}(\mathbf{w})$, for all $\mathbf{w} \in \mathbb{R}^N_{++}$.

Proposition 8 *Let $\mathbf{M}(\mathbf{w}, \delta)$ be the solution space for MCP. For all $\mathbf{w} \in \mathbb{R}^N_{++}$ and $\delta > 0$, $\mathbf{M}(\mathbf{w}, \delta)$ is nonempty and compact.*

Proof. In the appendix. ■

The proof of proposition 8 is basically to show that the equivalent nonlinear complementary problem (NCP) of the MCP satisfies conditions of proposition 2.2.3 in Facchinei and Pang (2003).

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[3] Without loss of generality, I set $E_i = 1$.

The uniqueness of the solution to MCP requires regularities on trade and MP costs. Let $X_{li}^{MP} = \sum_d \pi_{dli}(\mathbf{M}) w_d \bar{L}_d$ and $X_{dl}^{TR} = \sum_i \pi_{dli}(\mathbf{M}) w_d \bar{L}_d$.

The following assumption is sufficient for the uniqueness of the solution to MCP:

Assumption 9 *1. The matrices $[(\tau_{dl}^{f})^{-\frac{\theta}{1-\rho}}]$ and $[\zeta_{li}^{-\frac{\theta}{1-\rho}}]$ are nonsingular.*

2. For any $\mathbf{M}$ that solves MCP, $X_{ji}^{MP} \leq \sum_d \lambda_{di} X_{dj}^{TR}$ for all $i \neq j$.

The first condition in assumption 9 is straightforward to verify. The second condition needs more explanation. Since it requires to be held for all solutions of MCP, it cannot be verified in practice except for few special cases. However, I believe that it can still be relevant in the real world economy. Firstly, it requires the MP costs to be large so that the MP sales from country i to country j with $i \neq j$ is upper bounded by a weighted sum of country j's exports to all destinations (including itself). In the data the domestic production is still prevalent and usually $X_{ji}^{MP} << X_{jj}^{TR}$ for $j \neq i$. So the second condition in assumption 9 is reasonable in the real world. Secondly, although I cannot verify this condition for all $\mathbf{M}$ that solves MCP, I can verify it for the observed equilibrium and do simulations to see if it holds under other labor allocations.

I also provide a weaker but still sufficient condition as an alternative to the second condition in assumption 9: the matrix with entries $[\frac{\alpha}{L_j M_i}(X_{ji}^{MP} - \sum_d \lambda_{di} X_{dj}^{TR})]$ is a P0-matrix, i.e. all of its principal minors are nonnegative. This condition is less intuitive. However, if the second condition of assumption 9 does not hold in the observed economy, then I can check the alternative condition numerically.

The following proposition establishes the uniqueness of equilibrium allocation for any $\mathbf{w} \in \mathbb{R}_{++}^N$.

Proposition 10 *Suppose that $\alpha := \frac{\theta\eta}{1-\rho} \in [0,1]$ and the assumption 9 holds. Then $\mathbf{M}(\mathbf{w}) := \lim_{\delta \to 0} \mathbf{M}(\mathbf{w}, \delta)$ is a singleton for all $\mathbf{w} \in \mathbb{R}_{++}^N$.*

Proof. In the appendix. ■

The proof of proposition 10 is far from trivial. Firstly I prove that for all $\mathbf{w} \in \mathbb{R}_{++}^N$ and $\delta > 0$, the solution $\mathbf{M}(\mathbf{w}, \delta)$ to MCP is a singleton. This is basically done by checking the conditions for theorem 4 in Simsek, Ozdaglar, and Acemoglu (2005) are satisfied. Then I show that $\mathbf{M}(\mathbf{w}, .)$ is right continuous on 0 by theorem 3.1 in Kyparisis (1986).

The following result follows directly from proposition 2 in Kucheryavyy, Lyn, and Rodriguez-Clare (2014) showing that there will be multiple equilibria if $\alpha > 1$.

Proposition 11 *If $\alpha > 1$, then $\mathbf{M}(\mathbf{w})$ contains multiple allocations for any $\mathbf{w} \in \mathbb{R}^N_{++}$.*

Proof. The result follows directly from proposition 2 in Kucheryavyy, Lyn, and Rodriguez-Clare (2014). ■

2.2.4.2 Equilibrium wages

From equation (2.15), I denote the excess labor demand in country i:

$$Z_i(\mathbf{w}) := \delta^f \sum_d \lambda_{di}(\mathbf{w}, \mathbf{M}(\mathbf{w})) \frac{w_d}{w_i} \bar{L}_d + \delta^m \sum_{d,k} \pi_{dik}(\mathbf{w}, \mathbf{M}(\mathbf{w})) \frac{w_d}{w_i} \bar{L}_d - \bar{L}_i. \tag{2.27}$$

By proposition 10, $Z_i(\mathbf{w})$ is a singleton for all $\mathbf{w} \in \mathbb{R}^N_{++}$ and all country i.

Let $Z(\mathbf{w}) := (Z_1(\mathbf{w}), \ldots, Z_N(\mathbf{w}))$. Then the equilibrium wage, $\mathbf{w}$, is the solution to

$$Z(\mathbf{w}) = 0. \tag{2.28}$$

The following proposition establishes the existence of the equilibrium wage, hence the equilibrium, when $\alpha \in [0, 1]$.

Proposition 12 *Suppose that $\alpha \in [0, 1]$ and the assumption 9 holds. There exists $\mathbf{w}$ that solves equation (2.28).*

Proof. The result follows directly from proposition 2 in Kucheryavyy, Lyn, and Rodriguez-Clare (2014). ■

Proposition 13 *Suppose that $\alpha \in [0, 1]$ and the assumption 9 holds. For $N = 2$, there is a unique to scale $\mathbf{w}$ that solves equation (2.28).*

Proof. In the appendix. ■

2.3 Welfare Analysis

The aim of this paper is to evaluate the gains from trade and MP liberalization. In this section, I will show how to measure gains from openness by the equilibrium trade and MP flows.

Since the preference is CES, I can measure the welfare by real wage $W_i = \frac{w_i}{P_i}$. Then gains from openness are the changes of welfare from autarky to the observed economy: $GO_i = W_i/W_i^A$ where W^A is autarky real wage. The following result shows that the gains from openness can be expressed as a function of the equilibrium trade and MP flows.

Proposition 14 (Gains from Openness)

$$GO_i = \underbrace{[(\pi_{iii})^{-\frac{1-\rho}{\theta}}\lambda_{ii}^{-\frac{\rho}{\theta}}]}_{\textit{New trade.}}[\underbrace{(\frac{\sum_{d,l}\pi_{dli}X_d}{X_i})^{\frac{1}{\theta}}}_{\textit{More final varieties.}}\ \underbrace{(\frac{\sum_{d,k}\pi_{dik}X_d}{X_i})^{\eta}}_{\textit{Larger production scale}}]. \tag{2.29}$$

Proof. In autarky $\pi_{iii} = \lambda_{ii} = 1$ and $X_i = \sum_{d,l}\pi_{dli}X_d = \sum_{d,k}\pi_{dik}X_d$. Inserting equation (2.18) into equation (2.10), I can get equation (2.29). ■

Proposition 14 contrasts our model to ARRY (2014). Their model can be regarded as a special case of our model in which $\eta = 0$. In this case, the gains from openness are given by $GO_i = [(\pi_{iii})^{-\frac{1-\rho}{\theta}}\lambda_{ii}^{-\frac{\rho}{\theta}}](\frac{\sum_{d,l}\pi_{dli}X_d}{X_i})^{\frac{1}{\theta}}$. It means that countries that have net MP outflows can gain from the expansion of final varieties while countries that have net MP inflows will suffer from the decline in final varieties.

In my model, however, there is an additional term reflecting the scale economies in production. Equation (2.29) illustrates that rich countries can gain from the increase in final varieties while developing countries can gain from the increase in production scale. Note that $\frac{\partial \log(GO_i)}{\partial \log(L_i)} = \eta$. Therefore, η determines how quantitatively important the scale economies of production are for gains from openness. I will calibrate η in the empirical section.

2.4 Empirical Estimates

2.4.1 Data sources

To conduct counterfactural exercises as Dekle, Eaton, and Kortum (2008), I need to calibrate $\{\theta, \sigma, \eta, \rho\}$ and $\{\pi_{dli}\}$.

I combine several data sources for calibration. The calibrated economy is the world economy averaged over 2005-2007. I select 22 major economies[4] and consider only the manufacturing sector. The trilateral trade flow, a combination of international trade and multinational production, is calibrated to bilateral trade and MP flows. I employ bilateral MP flows averaged over 2005-2007 from GTAP free satellite database "Global Database of Foreign Affiliate Sales" developed by Fukui and Lakatos [5]. The bilateral trade flow data comes from WIOD over 2005-2007.

It is challenging to identify scale economy from comparative advantage in cross-sectional data. To address this difficulty, I estimate scale economy from a two-period panel data. Besides the baseline period (averaged over 2005-2007), I also employ bilateral MP flows averaged over 1996-2001 from from Ramondo, Rodriguez-Clare, and Tintelnot (RRT,2014). The bilateral trade flows averaged over 1996-2001 come from WIOD.

Furthermore, distance and other gravity controls are from CEPII gravdata. The manufacturing wages come from the U.S. Bureau of Labor Statistics, international labor comparison. Finally, to identify the elasticity of substitution within multinationals, I employ the US multinational sales data from BEA Financial and Operating Data.

2.4.2 Calibrating σ, θ, ρ, and $\{\pi_{dli}\}$

I calibrate (σ, θ) out of the model as follows. First, the share of profit in revenue is given by $1/\sigma$. So the elasticity of substitution σ gives the information about the profit share in manufacturing sectors. I calibrate $\sigma = 4$ from ARRY (2014), which is consistent with the idea that the profits of manufacturing firms are about 25% in their total sales.

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[4] The sample includes "the rest of the world".

[5] Fukui and Lakatos (2012) gives a detailed description about the database construction, its advantages and limitation.

θ is related to the elasticity of bilateral trade flows with respect to bilateral trade costs (trade elasticity). θ is also the dispersion parameter of the firm productivities. As a result there are two ways to recover θ. In ARRY (2014), they estimate trade elasticity in macro data based on their structural gravity equation. In Chapter 1 of this dissertation, instead, I recover θ directly from the dispersion of firm sales. Here estimating structural gravity equation is computationally challenging. Consequently, I use the calibrated θ from Chapter 1 of this dissertation, which gives $\frac{\theta}{\sigma-1} = 1.39$. So I have $\theta = 4.17$.

(ρ, π_{dli}) can be estimated jointly from two sets of data moments. First, given (θ, ρ), $\{\pi_{dli}\}$ can be given by

$$\pi_{dli} = \frac{[\sum_k (\tilde{T}_{ki}\tau_{dk})^{-\frac{\theta}{1-\rho}}]^{-\rho}[\tilde{T}_{li}\tau_{dl}]^{-\frac{\theta}{1-\rho}}}{\sum_h [\sum_k (\tilde{T}_{kh}\tau_{dk})^{-\frac{\theta}{1-\rho}}]^{1-\rho}}. \tag{2.30}$$

where $\tilde{T}_{li} = (T_i)^{-1/\theta} M_i^{-1/\theta} L_l^{-\eta} w_l \zeta_{li}$. The bilateral trade and MP flows derive $\frac{X_{dl}^{TR}}{X_d^f} = \sum_i \pi_{dli}^f$ and $\frac{X_{li}^{MP}}{X_i^f} = \sum_d \pi_{dli}^f \frac{X_d^f}{X_i^f}$. Therefore, given (θ, ρ), there is a unique (to scale) $(\tilde{T}_{li}, \tau_{dl}^f)$ that fits the trade and MP shares. I normalize $\min_k \tau_{dk}^f = 1$ and $\zeta_{ii} = 1$.

The second set of moments is the sales of the US multinational affiliates in country l back to the US market, $X_{US,l,US}$. Equation (2.30) implies that

$$\frac{X_{US,l,US}}{X_{US,CA,US}} = (\frac{\tilde{T}_{l,US}\tau_{US,l}}{\tilde{T}_{CA,US}\tau_{US,CA}})^{-\frac{\theta}{1-\rho}}, \quad l \notin \{US, CA\}. \tag{2.31}$$

Intuitively, $\{X_{US,l,US}\}$ characterizes the U.S. multinationals' production locations to serve the U.S. market. Consequently, this set of moments provides information about the elasticity of substitution within multinational firms, which identifies the correlation parameter of the productivity distribution, ρ.

I estimate (ρ, π_{dli}) by the following procedures:

1. Guess ρ. Compute $(\tilde{T}_{li}, \tau_{dl}^f)$ from Equation (2.30).
2. Compute the model-implied $\frac{X_{US,l,US}}{X_{US,CA,US}}$.
3. Select $\rho \in [0, 1)$ that minimizes the distance between $\frac{X_{US,l,US}}{X_{US,CA,US}}$ implied by the model and in the data.
4. Given the estimated ρ, compute $\{\pi_{dli}\}$ from $(\tilde{T}_{li}, \tau_{dl}^f)$.

This algorithm gives $\rho = 0.39$. In addition, the derived $\{\pi_{dli}\}$ ensures that the condition 2 in assumption 9 holds in the observed equilibrium.

Finally, by assuming that $\zeta_{li} = \zeta_{il}$ for all i, l, I obtain the level of MP costs by

$$\zeta_{li} = \sqrt{\frac{\tilde{T}_{li}\tilde{T}_{il}}{\tilde{T}_{ii}\tilde{T}_{ll}}}. \tag{2.32}$$

2.4.3 Estimating η

η characterizes the increasing returns to scale within a country. To separate the returns to scale with the technology fundamentals, I utilize a two-period panel in order to eliminate any the fixed differences across countries. The first period is the average over 1996-2001. And the second period is the average over 2005-2007.

Suppose (θ, ρ) is constant over time. Then I compute $(\tilde{T}'_{li}, \tau'_{dl})$ and $(\tilde{T}_{li}, \tau_{dl})$[6]. Denote $\hat{Z} = Z'/Z$.

By definition

$$\log(\hat{\tilde{T}}_{li}) = -\frac{1}{\theta}\log(\hat{M}_i) - \eta\log(\hat{L}_l) + \log(\hat{w}_l) + \log(\hat{\zeta}_{li}) + u_i, \tag{2.33}$$

where $u_i = \log((\hat{T}_i)^{-\frac{1}{\theta}})$.

In equilibrium $\hat{M}_i = \frac{\hat{Y}_i^f}{\hat{w}_i}$ and $\hat{L}_i = \frac{\hat{Y}_i^m}{\hat{w}_i}$. I normalize $\hat{\zeta}_{ii} = 1$. Then for some country 0

$$\log\left(\frac{\hat{\tilde{T}}_{ii}/\hat{w}_i}{\hat{\tilde{T}}_{0i}/\hat{w}_0}\right) = -\eta\log\left(\frac{\hat{L}_i}{\hat{L}_0}\right) - \log(\hat{\zeta}_{0i}) + v_{0i}, \tag{2.34}$$

where $v_{0i} = \frac{u_i}{u_0}$.

The endogeneity comes from the fact that v_{0i} is correlated with $\frac{\hat{Y}_i^m/\hat{w}_i}{\hat{Y}_0^m/\hat{w}_0}$. In order to estimate η, I need an instrument which is correlated with $\hat{L}$ but independent with the changes in fundamental productivity. I use the event that China joined WTO as an instrument. Note that period 1 here is 1996-2001, period 2 is 2005-2007, and China joined WTO in 2002. China is one of the most important manufacturing exporters in the world, so this event can essentially change production scales in every country. More importantly, this event can be regarded as exogenous to the technology changes since it is a result of a long-term political and economic negotiation. I use

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[6] Z' means Z in the next period.

the variation of the effects of this event across countries to identify η. I assume that countries that are farther away from China are affected less by China joining WTO. The validity of this assumption comes from gravity equation in international trade. As a result, my instrument is $\mu_i = (\log(Dist_{i,CHN}, \mathbf{1}_{CHN}))$ where all variables take values of period 1 and $\mathbf{1}_{CHN}$ is a dummy indicating whether a country is China. Moreover, I take ROW, the rest of the world, as the numeraire country 0.

Estimating equation (2.34) using instrument regression, I get the results in table 2.1. The coefficient of $\log(\hat{L})$ is significant and with the expected sign. The coefficient of $\log(\hat{\zeta}_{0i})$ is close to -1, which is predicted by equation (2.34).

	IV	OLS
$\log(\hat{L})$	-0.10*	0.019
	(0.055)	(0.11)
$\log(\hat{\zeta}_{0i})$	-0.91***	-0.935**
	(0.1)	(0.2)
_cons	0.065	0.037
	(0.09)	(0.06)
R-squared	0.5	0.55
N. of Obs.	21	21

Table 2.1: The estimation of σ_m

(Note: the dependent variable is $\log(\frac{\hat{\hat{T}}_{ii}/\hat{w}_i}{\hat{\hat{T}}_{0i}/\hat{w}_0})$. Country 0 is ROW, the rest of the world.)

The instrument regression suggests that $\eta = 0.10$. The calibrated $\frac{\theta\eta}{1-\rho} = 0.68 < 1$. The calibrated parameters fall into the region that ensures the uniqueness of the equilibrium.

2.5 Counterfactual exercises

In this section I explore how exogenous shocks such as $\hat{\tau}_{dl}$, $\hat{\zeta}_{li}$, and $\hat{T}_i$ would affect equilibrium real wage W_i and the measure of firms M_i. As mentioned before, the parameters I need are $(\theta, \sigma, \eta, \rho)$ and $\{\pi_{dli}\}$.

2.5.1 Structural equations under unique equilibrium

Under unique equilibrium, I can compute the counterfactual equilibrium using the algorithm developed by Dekle, Eaton and Kortum (2008). Given $(\theta, \sigma, \eta, \rho)$, $\{\pi_{dli}\}$, $\{X_d\}$, and $(\hat{T}_i, \hat{\zeta}_{li}, \hat{\tau}_{dl})$, changes of equilibrium outcomes, $(\hat{w}_i, \hat{M}_i, \hat{L}_i)$, can be computed by solving the following system:

$$\hat{w}_i X_i = \delta^f \sum_{d,l} \hat{\pi}_{dli} \hat{w}_d \pi_{dli} X_d + \delta^m \sum_{d,k} \hat{\pi}_{dik} \hat{w}_d \pi_{dik} X_d. \tag{2.35}$$

where $\hat{\pi}_{dli} = \hat{\psi}_{dli} \hat{\lambda}_{di}$, $\hat{\psi}_{dli} = \frac{\hat{\xi}_{dli}^{-\frac{\theta}{1-\rho}}}{\sum_k \psi_{dki} \hat{\xi}_{dki}^{-\frac{\theta}{1-\rho}}}$, $\hat{\lambda}_{di} = \frac{\hat{M}_i \hat{T}_i [\sum_k \psi_{dki} \hat{\xi}_{dki}^{-\frac{\theta}{1-\rho}}]^{1-\rho}}{\sum_h \lambda_{dh} \hat{M}_h \hat{T}_h [\sum_k \psi_{dkh} \hat{\xi}_{dkh}^{-\frac{\theta}{1-\rho}}]^{1-\rho}}$, and $\hat{\xi}_{dli} = \hat{L}_l^{-\eta} \hat{w}_l \hat{\zeta}_{li} \hat{\tau}_{dl}$.

$$\hat{M}_i \hat{w}_i = \frac{\sum_d (\hat{\lambda}_{di}) \hat{w}_d \lambda_{di} X_d}{Y_i^f}. \tag{2.36}$$

$$\hat{M}_i \frac{Y_i^f}{(1-\tilde{\delta}) X_i} + \hat{L}_i \frac{Y_i^m}{(1-\tilde{\delta}) X_i} = 1. \tag{2.37}$$

Finally, in order to compute welfare changes, I compute $\{\hat{P}_i\}$ by

$$(\hat{P}_i^f)^{-\theta} = \{\sum_h \lambda_{ih} \hat{M}_h^f [\sum_k \psi_{ikh} \hat{\xi}_{ikh}^{-\frac{\theta}{1-\rho}}]^{1-\rho}\}. \tag{2.38}$$

I also conduct counterfactual exercises in the model with constant-return-to-scale (CRS) production. To do this I simply impose $\eta = 0$ into the system above.

2.5.2 Computing counterfactuals under multiple equilibria

As shown before, a general equilibrium model with locally external economies of scale is likely to have multiple equilibria. Moreover, if the model is extended to have multiple sectors and input-output linkages across sectors, it is very difficult to derive sufficient conditions for the uniqueness of equilibrium. Consequently, it is important to develop an algorithm to compute counterfactuals under multiple equilibria.

Consider a vector of equilibrium outcomes $\mathbf{X}$ defined by $F(\mathbf{X}, \Theta) = 0$ where function $F(.)$ has the same dimension with $\mathbf{X}$ and Θ are exogenous parameters.

Lemma 15 *Suppose a vector of equilibrium outcomes* $\mathbf{X}$ *is observed. If the Jacobian* *matrix,* $\bigtriangledown_{\mathbf{X}} F$ *is nonsingular, then* $\bigtriangledown_{\Theta}\mathbf{X} = -[\bigtriangledown_{\mathbf{X}} F]^{-1} \bigtriangledown_{\Theta} F$.

As a result, when $|\hat{\Theta}|$ is small, $\hat{\mathbf{X}}$ can be computed by

$$\hat{\mathbf{X}} - 1 = - \bigtriangledown_{\log(\Theta)} \log(\mathbf{X})(\hat{\Theta} - 1), \tag{2.39}$$

where $\bigtriangledown_{\log(\Theta)} \log(\mathbf{X})$ can be computed as follows.

Define matrix $A = [A_{ij}]$ by $A_{ij} = \frac{\hat{F}_i|\hat{\mathbf{X}}_j}{1+h} - 1$ where $|h|$ is small and $\hat{F}_i|\hat{\mathbf{X}}_j$ is the change of the ith element of F by $\hat{\mathbf{X}}_j = 1 + h$, keeping other things unchanged. Similarly I define $B = [B_{ik}]$ by $B_{ik} = \frac{\hat{F}_i|\hat{\Theta}_k}{1+h} - 1$. Then

$$\bigtriangledown_{\log(\Theta)} \log(\mathbf{X}) = -A^{-1}B. \tag{2.40}$$

If $|\hat{\Theta}|$ is not small, we can conduct counterfactuals as follows:

1. Decompose $\hat{\Theta} = \prod_{t=1}^{T} \hat{\Theta}^t$ where each $\hat{\Theta}^t$ is small.
2. Starting from the observed equilibrium, compute $(\hat{\mathbf{X}}^1)^0$ from Equation (2.39).
3. Solve $\hat{\mathbf{X}}^1$ by Equation (2.35), (2.36), and (2.37), using $(\hat{\mathbf{X}}^1)^0$ as the initial value.
4. Starting from the counterfactual equilibrium $\hat{X}^1$, repeat the previous two steps to get $\hat{\mathbf{X}}^2$.
5. Repeat to get $\{\hat{\mathbf{X}}^t\}$. Then $\hat{\mathbf{X}} = \prod_{t=1}^{T} \hat{\mathbf{X}}^t$.

2.5.3 The Gains from MP liberalization

To quantify the welfare effects of MP liberalization, I reduce ζ_{li} by 5% for all $l \neq i$. The results are shown in table 2.2. I report both welfare gains from MP liberalization as well as productivity changes. I measure the production productivity in country i by L_i^{η}, and the industry-level revealed productivity by $M_i^{\frac{1}{\theta}} L_i^{\eta}$. Clearly, countries with net MP inflows gain more from MP liberalization in my model than in the model with CRS production. In the model with CRS production, countries like China, India, and Mexico suffer from the decline in M led by trade and MP liberalization. In the full model, however, these losses are offset by the rise of L. The entry of foreign multinationals increases the production scales in these countries, lowering their production costs and attracting further inward MP.

At the meantime, countries with net MP outflows could suffer from the decline of their production scales. Our model predicts that in the long run small innovative countries like Denmark and Finland could experience substantial shrinkage in their production, which would increase the production costs for firms that still produce in these countries.

	$\eta = 0.10$			$\eta = 0$		Percentage Differences in Welfare Gains
% Change in:	W_i	L_i^η	$M_i^{\frac{1}{\theta}} L_i^\eta$	W_i	$M_i^{\frac{1}{\theta}} L_i^\eta$	
Australia	4.18	-0.59	3.09	4.64	3.47	-10.5
Austria	2.28	-0.16	1.06	2.43	1.24	-6.3
Benelux	3.58	-0.58	3.15	3.98	3.49	-10.5
Brazil	1.27	0.13	-1.63	1.15	-1.74	10.2
Canada	2.68	-0.32	1.81	2.93	2.08	-9.1
China	0.20	0.06	-0.62	0.14	-0.68	34.8
Germany	1.81	-0.06	0.46	1.86	0.51	-2.6
Denmark	3.07	-0.51	2.18	3.46	2.58	-11.9
Spain	0.76	-0.04	0.34	0.79	0.37	-4.1
Finland	2.97	-0.52	2.32	3.33	2.67	-11.4
France	1.95	-0.06	0.53	2.02	0.60	-3.7
Britain	2.28	0.04	-0.40	2.25	-0.39	1.2
India	0.51	0.05	-0.54	0.45	-0.59	11.2
Italy	1.13	0.01	-0.12	1.11	-0.14	1.7
Japan	0.36	-0.03	0.27	0.40	0.30	-9.2
Korea	0.32	0.04	-0.40	0.28	-0.43	12.4
Mexico	1.50	0.25	-3.80	1.27	-4.00	16.6
Portugual	1.55	0.16	-2.37	1.41	-2.54	9.4
Rest of World	1.94	0.22	-2.87	1.75	-2.98	10.2
Sweden	2.30	-0.08	0.52	2.40	0.71	-4.6
Taiwan	0.57	-0.05	0.41	0.62	0.46	-8.1
United States	1.70	-0.10	0.75	1.78	0.82	-4.7

Table 2.2: The Gains from a 5% MP cost reduction

(Note: the baseline is the calibrated economy over 2005-2007. ΔW^{Full} refers to the percentage changes of the real wage when $\eta = 0.10$. ΔW^{CRS} refers to the percentages changes of the real wage when $\eta = 0$. Percentage differences in welfare gains are computed by $100 * [\log(\Delta W^{Full}) - \log(\Delta W^{CRS})]$.)

2.5.4 Effects of US-China Bilateral Investment Treaty

The bilateral trade and investment agreements are increasingly prevalent in boosting international trade and MP liberalization. It would be interesting to evaluate these bilateral agreements on how they would affect the related parties as well as the third parties. In particularly, will the external economies of scale affect the welfare implications of bilateral trade and MP agreements to a third country?

My model is a suitable framework for this kind of evaluation since it incorporates external economies of scale into a multi-country general equilibrium model. A particular interesting example is the US-China Bilateral Investment Treaty (BIT). U.S. is the largest MP origin country while China is one of the largest MP host countries. BIT is still under negotiation. But the uncovered details show that it could substantially decrease the investment barriers between China and the U.S. In this paper I simply assume that BIT will lower the US-China bilateral MP costs by 20%.

Table 2.3 shows the impacts of BIT on MP and welfare in China, the U.S., and a third country, Germany. Note that the U.S. and Germany are both major MP sources for China while China is the major MP host for Germany and the U.S. When US-China MP costs decrease, U.S. will offshore more production to China and both countries gain from this bilateral MP liberalization. Similar to the gains from a universal MP liberalization, the U.S. gains less from BIT if there are external economies of scale. In contrast China could gain from the agglomeration of multinational affiliates.

The impacts of BIT on Germany are more subtle. Without external economies of scale, BIT will reduce German MP in China since the U.S. multinational firms bid up Chinese wages. BIT can then decrease Germany's real wage by 0.1%. The opposite happens when there are external economies of scale. BIT can increase Chinese manufacturing productivities, which can induce more production offshored from Germany to China. With external economies of scale, BIT can increase Germany's real wage by 0.1%.

2.6 Conclusion

By offshoring production to developing countries, multinational firms do not only gain from cheap labors but also from the industrial agglomeration in these countries.

	Data	$\eta = 0$		$\eta = 0.10$	
	%MP to China	%MP to China	$\%\Delta W$	%MP to China	$\%\Delta W$
US	7.12	18.1	1.11	18.3	0.96
Germany	11.22	11.13	-0.1	11.30	0.1
China	-	-	0.28	-	0.41

Table 2.3: The Effects of US-China Bilateral Investment Treaty (BIT)

(Note: the baseline economy is the calibrated economy over 2005-2007. BIT refers 20% reduction for bilateral MP costs between the U.S. and China. %MP to China refers to affilate sales in China as a share of the sales of all foreign affilates.)

In this paper I attempt to quantify the implications of external economies of scale in a world with trade and MP. Trade models with external economies of scale often encounter the problem of multiple equilibria. In this paper I provides a set of sufficient conditions for the uniqueness of equilibrium. As long as the external economies of scale are not stronger than the firm productivity dispersion, the equilibrium is unique.

To estimate external economies of scale, I utilize the event of China joining WTO. It is reasonable to assume that China joining WTO has larger impacts on production scales of countries closer to China, while a country's productivity shock does not depend on its distance with China. This instrument helps me to separate external economies of scale from comparative advantage. The estimated parameters fall into the region that ensures the uniqueness of equilibrium.

I apply my model to several counterfactual policy experiments. The results highlight the importance of external economies of scale to the welfare effects from trade and MP liberalization. In particular, with economies of scale in production, developing countries that have large MP inflows gain more from MP liberalization. The key mechanism is the interaction between offshoring and the external economies of scale. Offshored jobs from developed countries expand the industry size and hence increase the productivities of the developing countries through the external economies of scale. The increased productivities in turn attract more offshored jobs. This mechanism thus magnifies the welfare effects of MP liberalization in these countries.

This paper also echoes the worries that offshoring will "hollow-out" the manufacturing industries of the developed countries, lowering their productivities and making their production workers suffer. My model shows that these worries may be relevant when there exist external economies of scale in production. In this case firms that offshore their production can benefit from the cost reduction, but firms that still produce in developed countries may suffer from the shrinking industry size and the lowering productivities. This implication has been supported by empirical evidence.

Finally this paper shows that the external economies of scale can also influence the third-party effect of bilateral investment agreements. With external economies of scale, Germany can gain more from the US-China Bilateral Investment Treaty.

Appendix A

Headquarters Gravity: Data Construction

A.1 Merging Customs Records with Manufacturing Survey

The balance sheet data in manufacturing survey contains a numerical firm identifier which is consistent over time. The customs records also includes a numerical identifier for exports. Unfortunately, two numerical identifiers coming from different systems have no way to be connected directly. As in the literature (see, for example, Wang and Yu (2012)), a fuzzy matching algorithm is required. I use the standardized firm name, the manager name, phone number, and zip code as fuzzy identifiers. Exports are restricted within manufacturing goods whose 2-digit HS code is above 15 and below 98 (excluding 25, 26, 27).

One complication is the exports through intermediaries. My theory cannot rationalize the exports of intermediaries since they do not export what they produce. So I exclude them in the data by dropping exporters whose names contain key words such as “import”, “export”, “foreign trade”, “service trade”, and so on. This step excludes about 48% of the export transactions which account for about one third of Chinese manufacture exports in 2001. This result is in line with Manova and Zhang (2012).

Another complication is that the same exporter in the customs records may correspond to different names and phone numbers. The same occurs in the manufacturing survey. To address this problem, I first collect all names and other identifiers used by each exporter over 2000-2006 (the period covered by data), given it exports in 2001. I then do similar work in manufacturing survey for each firm operating in 2001. Then I merge two sets of fuzzy identifiers by a matching algorithm based on the weighted average of string distance. I allow multiple exporters to correspond to the same firm in manufacturing survey, but I do not allow multiple firms in manufacturing survey to correspond to the same exporter. For the latter case, I merge two datasets manually. This algorithm matches exporters which account for about 85% of Chinese manufacturing direct exports to their balance sheet data in manufacturing survey.

Foreign-invested-enterprise survey shares a unique numerical firm identifier with manufacturing survey. So merging this two datasets is straightforward.

A.2 Data Quality and Summary Statistics

Chinese Customs Records (CCR) provide transaction-level information on Chinese imports and exports. I compare Chinese aggregate exports in 2001 recorded by CCR with the one in UN COMTRADE. They turn out to be very close. In CCR, China exported $267065578080 in 2001, while in UN COMTRADE, Chinese exported $266098208590 in 2001. The difference is less than 0.5%.

To examine the quality of Chinese firm database I constructed in the previous section, I compare the aggregate sales of the U.S. affiliates in China in Chinese firm data with the records in the BEA database. I take the BEA database "Data on activities of multinational enterprises" in 2001 which contains information on, for each host country, the total sales of the U.S. affiliates, the sales to the host country, the sales to the U.S., and the sales to other countries. Table A.1 shows the comparison result. The aggregate statistics of the U.S. affiliates in China recorded in Chinese firm data is reasonably closed to the records in BEA database. This result suggests that the quality of Chinese firm data is good for my purpose.

Table A.2 presents some summary statistics of foreign affiliates in China. Several patterns are confirmed. First comparing to Chinese firms a larger fraction of foreign affiliates are exporters. Second, a large fraction of foreign affiliates in China export to their headquarters countries. Third foreign affiliates in China are larger than Chinese firms either in terms of total sales, number of employees, or value-added. Fourth the value-added share of foreign affiliates in China is not significantly lower

	The U.S. Affiliates in China in 2001	
	Chinese Data	BEA Data
Total Sales	32255	29578
Sales in China	21808	20419
Sales to the U.S.	3418	3066
Sales to other	7029	6094

Table A.1: The U.S. Affiliates in China: Chinese data vs BEA data

(Note: All values are in million dollars.)

than the value-added share of Chinese firms.

Origin	#Firms	#Exporters	#Exp to Origin	Sales	Value-added	Employment	Export	Exp. to origin
AUS	268	161	67	1260	353	45	328	54
AUT	49	35	13	383	100	17	59	1
BEL	40	26	13	1414	359	11	118	18
CAN	243	140	47	1828	387	41	320	18
DEU	429	299	206	14094	3815	131	1837	611
DNK	25	17	10	571	160	7	312	148
ESP	42	20	10	243	65	9	41	17
FIN	27	21	13	5759	740	8	2449	172
FRA	191	130	62	2651	707	42	442	100
GBR	495	330	122	7378	2070	196	2676	141
ITA	138	81	47	956	253	30	170	36
JPN	3088	2531	2319	37738	9375	927	20928	12631
KOR	1247	1049	889	14713	3136	456	10090	2558
NLD	163	122	45	5279	1045	55	2377	124
NZL	33	17	2	243	48	9	83	2
SGP	933	617	336	12155	3189	294	4387	460
SWE	67	43	21	2815	584	13	414	135
TWN	3400	2374	1117	14312	3578	743	6598	422
USA	2341	1515	1028	33415	9394	630	11607	3797
CHN	96804	15251	-	588496	147952	33185	37981	-

Table A.2: Summary Statistics for Manufacturers in China by Origin

(Note: Sales, value-added, exports, exports to origin are in million dollars. Employment is in thousands. Firms from Hong Kong and Macau are excluded.)

Appendix B

Headquarters Gravity: Robustness for the Reduced-form Evidence

To examine the robustness of the reduced-form evidence, I estimate the extensive and intensive margins of firm exports by industry. Table B.1 shows the results for two industries: apparel and machinery. These two industries are among Chinese largest export industries and they are very different with each other. Apparel exports are mostly by ordinary trade, for final consumption, and by arm's length trade (according to Bureau of Economic Analysis Data). In contrast, machinery exports are mostly be processing trade, as intermediates, and by related-party trade. Table B.1 shows that headquarters gravity is robust in both industries. This result implies that headquarters gravity cannot be entirely driven by processing trade, vertical integration, and global fragmentation.

I also divide exports into homogeneous goods and differentiated goods according to Rauch classification. Table B.2 shows that headquarters gravity is stronger in differentiated goods that in homogeneous goods. This is consistent with that multinationals transfer connections with international markets to affiliates. Intuitively, these connections are more important for selling differentiated goods than homogeneous goods.

	Dependent Variable			
	$\mathbf{1}\{x_{dni}(\nu) > 0\}$		$\log(x_{dni}(\nu))$	
	Apparel	Machinery	Apparel	Machinery
$\log(dist_{di})$	-.12***	-.022*	-.13	-.01
	(.03)	(.01)	(.09)	(.04)
$self_{di}$	.49***	.95***	1.0***	1.7***
	(.13)	(.08)	(.34)	(.19)
$lang_{di}$	.001	.06**	.21	-.013
	(.06)	(.03)	(.24)	(.1)
$sgdp_{di}$	.06*	.18***	-.03	.2
	(.02)	(.05)	(.027)	(.14)
Destination FE	Yes	Yes	Yes	Yes
Affiliate FE	Yes	Yes	Yes	Yes
R-square	-	-	.72	.50
N. of Obs.	21204	91636	2563	7949

Table B.1: Extensive and Intensive Margins of Foreign Affiliates' Exports

(Note: the sample excludes the firms from China, Hong Kong, Taiwan and Macau. Apparel is the industry with 2-digit HS code 62. Machinery is the industry with 2-digit HS code 85. The extensive margin is estimated by Probit model while the intensive margin is estimated by OLS. The estimation controlling for firm fixed effects excludes all firms with less than 3 export destinations.)

	Dependent Variable			
	$\mathbf{1}\{x_{dni}(\nu) > 0\}$		$\log(x_{dni}(\nu))$	
	Homo.	Diff.	Homo.	Diff.
$\log(dist_{di})$	.02	-.02**	-.012	-.04**
	(.012)	(.01)	(.05)	(.02)
$self_{di}$	.85***	.93***	1.02***	1.35***
	(.07)	(.06)	(.19)	(.07)
$lang_{di}$	.04***	.06***	.09	.19
	(.03)	(.02)	(.11)	(.04)
$sgdp_{di}$	.081**	.23***	-.1	0.08*
	(.04)	(.03)	(.13)	(.04)
Destination FE	Yes	Yes	Yes	Yes
Affiliate FE	Yes	Yes	Yes	Yes
R-square	-	-	.65	.48
N. of Obs.	109385	188038	8438	39225

Table B.2: Extensive and Intensive Margins of Foreign Affiliates' Exports

(Note: the sample excludes the firms from China, Hong Kong, Taiwan and Macau. Apparel is the industry with 2-digit HS code 62. Machinery is the industry with 2-digit HS code 85. The extensive margin is estimated by Probit model while the intensive margin is estimated by OLS. The estimation controlling for firm fixed effects excludes all firms with less than 6 export destinations.)

Appendix C

Headquarters Gravity: Model Derivation and Empirical Implementation

C.1 Algorithm for computing general equilibrium

Algorithm 16 (Computing General Equilibrium Outcomes) *To compute* $(w_i, X_i, P_i)_{i=1}^N$*, I normalize* $X_{USA} = 1$*. Then*

- *Guess initial price indices* $(P_i^0)_{i=1}^N$*.*
  - *Guess initial wages and absorptions* $(w_i^0, X_i^0)_{i=1}^N$*.*
  - *Update wages into* $(w_i^1)_{i=1}^N$ *by Equation (1.30).*
  - *Update absorptions into* $(X_i^1)_{i=1}^N$ *by Equation (1.31).*
  - *If the distance between* $(w_i^0, X_i^0)_{i=1}^N$ *and* $(w_i^1, X_i^1)_{i=1}^N$ *is below the tolerance, stop. Otherwise repeat until stop.*
- *Update price indices into* $(P_i^1)_{i=1}^N$ *by Equation (1.25).*
- *If the distance between* $(P_i^0)_{i=1}^N$ *and* $(P_i^1)_{i=1}^N$ *is below the tolerance, stop. Otherwise repeat until stop.*

C.2 The Sample used in Estimating Entry Hurdles

For each foreign affiliate in China I observe its headquarters country i and its exports to each destination d (include sales in China). Exports to each destination are 0 for non-entrants and positive for entrants. The original data includes 116 headquarters countries (include China) and 172 destination countries (include China). Since I focus on exports, I exclude Chinese firms from the sample. Furthermore, I exclude firms from Hong Kong and Macau from the sample.

To estimate entry hurdles, I have to restrict my sample in two dimensions. First, since I control for the firm size by sales in China, I have to drop pure exporters which do not sell in China. These firms, mainly export processors, account for about a quarter of Chinese total exports.

Second, the identification of H_{dni} requires that some affiliates in China from country i export to market d while others do not. Therefore I restrict my sample by requiring that for each pair of the headquarters and destination countries, (d, i), there are at least 20 firms export while at least 20 firms do not. This restriction leaves me a sample with 10652 foreign affiliates in China from 15 headquarters countries, 48 destination countries, and 311 pairs of headquarters and destination countries.

C.3 Selection Bias

Conditional on $\eta^*_{dn}(\nu) \geq \bar{H}_{dni}(\nu)$, the export sales can be given by

$$\frac{x_{dni}(\nu)}{x_{nni}(\nu)} = -(\sigma - 1)\rho_\zeta D_{di} + \iota_{ni} + \kappa_{dn} + \log(\xi^*_{dn}(\nu)), \tag{C.1}$$

where $\iota_{ni} = (\sigma - 1)\log(\zeta_{ni})$ and $\kappa_{dn} = \log(X_d P_d^{\sigma-1}/X_n P_n^{\sigma-1}) - (\sigma - 1)\log(\tau_{dn})$.

Without loss of generality, I assume that the coefficient of $\log(dist_{di})$, $\rho_{\zeta,1}$, is greater than 0. Then $\log(dist_{di})$ is positively correlated with $\bar{H}_{dni}(\nu)$. Since $\eta^*_{dn}(\nu) \geq \bar{H}_{dni}(\nu)$, $\log(dist_{di})$ is positively correlated with $\eta^*(\nu)$. Since $cov(\eta^*, \xi^*) > 0$, $\log(dist_{di})$ is positively correlated with $\xi^*(\nu)$. So OLS estimator will upbias the estimates of $-\rho_{\zeta,1}$. Therefore, the OLS estimator will bias the estimates of $\rho_{\zeta,1}$ towards 0.

Appendix D

Multinational Production and External Economies of Scale: Proofs

D.1 Proof of proposition 8

Proof. Let $\mathbf{x} = (\mathbf{M}, \mathbf{L})^T$ and $\mathbf{y} = \mathbf{x} - \delta$. Then MCP can be restated as an equivalent NCP:

$$\mathbf{y} \geq 0, \quad \tilde{G}(\mathbf{y}) \geq 0, \quad \mathbf{y}^T \tilde{G}(\mathbf{y}) = 0, \tag{D.1}$$

where

$$\tilde{G}_{1,i}(\mathbf{y}) = w_i - \tilde{\delta}^f \sum_d \frac{T_i [\sum_k a_{dki} (y_k^L + \delta)^\alpha]^{1-\rho}}{\sum_h T_h (y_h^M + \delta)[\sum_k a_{dkh} (y_k^L + \delta)^\alpha]^{1-\rho}} w_d \bar{L}_d; \tag{D.2}$$

$$\tilde{G}_{2,i}(\mathbf{y}) = (y_i^M + \delta) + (y_i^L + \delta) - (1 - \tilde{\delta}) \bar{L}_i. \tag{D.3}$$

Let $D := \{x \in \mathbb{R}^{2N} : x_i > -\epsilon \quad for \quad i = 1, \ldots, 2N\}$ for $0 < \epsilon < \delta$. Then $\tilde{G}(\mathbf{y})$ is continuously differentiable on D. By construction D is an open convex set containing $\mathbb{R}_+^{2N}$.

I construct a set $L_{\leq}$ as:

$$L_{\leq} := \{\mathbf{y} \in \mathbb{R}_+^{2N} : \tilde{G}(\mathbf{y})^T \mathbf{y} \leq 0\}. \tag{D.4}$$

Note that $\tilde{G}(\mathbf{y})^T\mathbf{y} \le 0$ is equivalent to

$$\sum_i w_i y_i^M + \sum_i (y_i^M + y_i^L + 2\delta) y_i^L \le \tilde{\delta}^f \sum_{d,i} \frac{T_i[\sum_k a_{dki}(y_k^L + \delta)^\alpha]^{1-\rho} y_i^M}{\sum_h T_h (y_h^M + \delta)[\sum_k a_{dkh}(y_k^L + \delta)^\alpha]^{1-\rho}} w_d \bar{L}_d + \sum_i \bar{L}_i y_i^L. \tag{D.5}$$

Note that

$$\sum_{d,i} \frac{T_i[\sum_k a_{dki}(y_k^L + \delta)^\alpha]^{1-\rho} y_i^M}{\sum_h T_h (y_h^M + \delta)[\sum_k a_{dkh}(y_k^L + \delta)^\alpha]^{1-\rho}} w_d \bar{L}_d < \sum_{d,i} w_d \bar{L}_d = N \sum_d w_d \bar{L}_d. \tag{D.6}$$

So $L_\le$ is nonempty and bounded. By proposition 2.2.3 in Facchinei and Pang (2003), since $\tilde{G}(\mathbf{y})$ is continuous in an open convex set D containing $\mathbb{R}_+^{2N}$ and $L_\le$ is nonempty and bounded, the solution space of NCP, $\mathbf{x}(\mathbf{w}, \delta)$, is nonempty and compact for all $\delta > 0$. So the solution space for MCP, $\mathbf{M}(\mathbf{w}, \delta)$, is nonempty and compact. ■

D.2 Proof of proposition 10

Proof.

Lemma 17 *Suppose that $\alpha \in [0, 1]$ and the assumption 9 holds. Then for all $\mathbf{w} \in \mathbb{R}_{++}^N$ and $\delta > 0$, the solution space to MCP, $\mathbf{M}(\mathbf{w}, \delta)$, is a singleton.*

Proof. I will prove lemma 17 by showing that the NCP' satisfies the conditions of theorem 4 in Acemoglu, Ozdaglar, and Simsek (2005). Note that if $\alpha = 0$, then my problem degenerates into a one-industry Melitz model. The uniqueness of the equilibrium in this case has been shown by Kucheryavyy, Lyn, and Rodriguez-Clare (2014). Now I consider $\alpha \in (0, 1]$.

The MCP can be reformulated into MCP':

1. $\delta \le M_i \le (1 - \tilde{\delta})\bar{L}_i - \delta$, $\forall i$.
2. For function $\tilde{G}(\mathbf{M})$ where

$$\tilde{G}_i(\mathbf{M}) = \frac{w_i}{\tilde{\delta}^f (1-\rho)} - \frac{1}{1-\rho} \sum_d \frac{T_i[\sum_k a_{dki}((1-\tilde{\delta})\bar{L}_k - M_k)^\alpha]^{1-\rho}}{\sum_h T_h M_h [\sum_k a_{dkh}((1-\tilde{\delta})\bar{L}_k - M_k)^\alpha]^{1-\rho}} w_d \bar{L}_d, \tag{D.7}$$

I have

$$M_i = \delta, \quad \tilde{G}_i(\mathbf{M}) \geq 0; \tag{D.8}$$

$$\delta < M_i < (1-\tilde{\delta})\bar{L}_i - \delta, \quad \tilde{G}_i(\mathbf{M}) = 0; \tag{D.9}$$

$$M_i = (1-\tilde{\delta})\bar{L}_i - \delta, \quad \tilde{G}_i(\mathbf{M}) \leq 0. \tag{D.10}$$

By proposition 8, the solution space of MCP', $\mathbf{M}(\mathbf{w}, \delta)$, is nonempty and compact for all $\delta > 0$ and $\mathbf{w} \in \mathbb{R}^N_{++}$.

Let

$$A_{di} = \sum_k a_{dki}((1-\tilde{\delta})\bar{L}_k - M_k)^\alpha. \tag{D.11}$$

S is a matrix with entries like

$$S(i,j) = \sum_d \frac{T_i w_d \bar{L}_d A_{di}^{1-\rho}}{[\sum_h T_h A_{dh}^{1-\rho} M_h]^2} \{\sum_h T_h A_{dh}^{1-\rho} \frac{M_h}{L_j}[\psi_{dji} - \psi_{djh}]\}. \tag{D.12}$$

The Jacobian matrix for $\tilde{G}$ can be expressed as

$$J = \Lambda_{11}^T \Lambda_{11} + SV, \tag{D.13}$$

where for $i, j = 1, \ldots, N$

$$\Lambda_{11}(i,j) = \frac{T_j A_{ij}^{1-\rho}(w_i \bar{L}_i/(1-\rho))^{\frac{1}{2}}}{\sum_h T_h A_{ih}^{1-\rho} M_h}, \tag{D.14}$$

and V is a diagonal matrix with the diagonal entries like

$$V(i,i) = \alpha((1-\tilde{\delta})\bar{L}_i - M_i)^{\alpha-1}. \tag{D.15}$$

By the first condition in assumption 9, Λ_{11} is nonsingular for all $\mathbf{M}$ that solves MCP'. Note that the for all j

$$\sum_i S(i,j) = 0. \tag{D.16}$$

By construction,

$$S(i,j) = \frac{\alpha}{L_j M_i}[X_{ji}^{MP} - \sum_d \lambda_{di} X_{dj}^{TR}]. \tag{D.17}$$

By the second condition in assumption 9, matrix S is a Z-matrix[1] with the weakly row dominance:

$$S(j,j) \geq \sum_{i \neq j} |S(i,j)|. \tag{D.18}$$

So S is a P0-matrix[2]. Since $\Lambda_{11}^T \Lambda_{11}$ is positive definite and V is a diagnoal matrix with all of its diagonal entries positive, J is a P-matrix[3]. By theorem 4 in Acemoglu, Ozdaglar, and Simsek (2005), for all $\mathbf{w} \in \mathbb{R}_{++}^N$ and $\delta > 0$, $\mathbf{M}(\mathbf{w}, \delta)$ is a singleton.

■

Now I will prove the uniqueness of the equilibrium allocation in the actual economy given $\mathbf{w}$.

Let the function $\tilde{G}$ in MCP' given $\delta > 0$ be $\tilde{G}^\delta$. Denote a compact set Γ as

$$\Gamma := \{\mathbf{y} \in \mathbb{R}_+^N : \delta \leq M_i \leq (1 - \tilde{\delta})\bar{L}_i - \delta, \forall i\}. \tag{D.19}$$

For any $\delta > 0$, $\tilde{G}^\delta$ is uniformly bounded on Γ and all partial derivatives of $\tilde{G}_i'^\delta$ are uniformly bounded. So $\{\tilde{G}^\delta\}_{\delta > 0}$ is equicontinuous and uniformly bounded on Γ. By Arzela-Ascoli theorem, there is a sequence $\{\delta_h\}_{h=1}^\infty$ such that $\delta_h > 0$, $\delta_h \to 0$, and $\tilde{G}^{\delta_h}$ uniformly converges to some function on Γ as $h \to \infty$. By lemma 17, each element of this sequence has an associated point $\mathbf{M}^{\delta_h}$ which solves MCP'. Since Γ is compact, by Bolzano-Weierstrass theorem, there is a convergent subsequence of $\mathbf{M}^{\delta_h}$. To save notations, I denote this convergent subsequence by $\mathbf{M}^{\delta_h}$. Let $\mathbf{M} = \lim_{h \to \infty} \mathbf{M}^{\delta_h}$.

Now suppose $\exists \delta_h' > 0$ and $\delta_h' \to 0$ such that $\exists \varepsilon > 0\ \forall H > 0\ \exists h > H$ such that $||\mathbf{M}^{\delta_h'} - \mathbf{M}|| > \varepsilon$.

By lemma 17, the Jacobian matrix of $\tilde{G}$ is a P-matrix. So MCP' satisfies conditions of theorem 3.1 in Kyparisis (1986). Therefore, $\forall \delta^1, \delta^2 > 0$, $\exists C > 0$ such that $||\mathbf{M}^{\delta_1} - \mathbf{M}^{\delta_2}|| \leq C||\tilde{G}(\mathbf{M}^{\delta_1}, \delta^1) - \tilde{G}(\mathbf{M}^{\delta_1}, \delta^2)||$.

Since $\tilde{G}(\mathbf{M}, .)$ is continuous, $\exists \varepsilon' = \varepsilon/2 > 0$ such that $\forall H > 0\ \exists h', h > H$ such that $||\mathbf{M}^{\delta_h'} - \mathbf{M}|| > 2\varepsilon'$ and $||\mathbf{M}^{\delta_h} - \mathbf{M}^{\delta_h'}|| \leq C\frac{\varepsilon}{2C} = \varepsilon'$. By triangular inequality, $||\mathbf{M}^{\delta_h} - \mathbf{M}|| \geq ||\mathbf{M}^{\delta_h'} - \mathbf{M}|| - ||\mathbf{M}^{\delta_h} - \mathbf{M}^{\delta_h'}|| > \epsilon'$. But this contradicts that $\mathbf{M}^{\delta_h} \to \mathbf{M}$.

Therefore, for any sequence $\delta_h' > 0$ and $\delta_h' \to 0$, $\mathbf{M}^{\delta_h'} \to \mathbf{M}$. So $\lim_{\delta \to 0} \mathbf{M}^\delta = \mathbf{M}$. Therefore $M(\mathbf{w})$ is a singleton for all $\mathbf{w} \in \mathbb{R}_{++}^N$.

■

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[1] A matrix is a Z-matrix if all of its off-diagonal elements are nonpositive.

[2] A matrix is a P0-matrix if all of its principal minors are nonnegative.

[3] A matrix is a P-matrix if all of its principal minors are positive.

D.3 Proof of proposition 13

Proof. The Jacobian matrix of $Z(\mathbf{w})$ has entries as

$$\begin{aligned}\frac{\partial Z_i(\mathbf{w})}{\partial w_j} &= \delta^f \sum_d [\frac{\partial \lambda_{di}}{\partial w_j} + \sum_l (\frac{\partial \lambda_{di}}{\partial M_l} - \frac{\partial \lambda_{di}}{\partial L_l})\frac{\partial M_l}{\partial w_j}]\frac{w_d}{w_i}\bar{L}_d + \delta^f \frac{\lambda_{ji}}{w_i}\bar{L}_j - \mathbf{1}(j=i)\delta^f \sum_d \lambda_{di}\frac{w_d}{w_i^2}\bar{L}_d \\ &+ \delta^m \sum_{d,k}[\frac{\partial \pi_{dik}}{\partial w_j} + \sum_l (\frac{\partial \pi_{dik}}{\partial M_l} - \frac{\partial \pi_{dik}}{\partial L_l})\frac{\partial M_l}{\partial w_j}]\frac{w_d}{w_i}\bar{L}_d + \delta^m \sum_k \frac{\pi_{jik}}{w_i}\bar{L}_j - \mathbf{1}(j=i)\delta^m \sum_{d,k}\pi_{dik}\frac{w_d}{w_i^2}\bar{L}_d.\end{aligned} \tag{D.20}$$

By the free entry condition equation (2.16) and the implicit function theorem, the Jacobian matrix of $-Z(\mathbf{w})$ can be expressed by

$$-\nabla_{\mathbf{w}} Z = (\frac{1}{1-\tilde{\delta}} I + \Omega)(-\nabla_{\mathbf{w}}\mathbf{M}) + \mathbf{W}, \tag{D.21}$$

where Ω has entries as

$$\Omega(i,j) = \delta^m \sum_{d,k}(\frac{\partial \pi_{dik}}{\partial M_j} - \frac{\partial \pi_{dik}}{\partial L_j})\frac{w_d}{w_i}\bar{L}_d, \tag{D.22}$$

and $\mathbf{W}$ has entries as

$$\mathbf{W}(i,j) = \mathbf{1}(j=i)\delta^m \sum_{d,k}\pi_{dik}\frac{w_d}{w_i^2}\bar{L}_d - \delta^m \sum_{d,k}\frac{\partial \pi_{dik}}{\partial w_j}\frac{w_d}{w_i}\bar{L}_d - \delta^m \sum_k \frac{\pi_{jik}}{w_i}\bar{L}_j. \tag{D.23}$$

Since $N = 2$, I normalize $w_2 = 1$ and eliminate the equation for country 2 in the system $-Z(\mathbf{w}) = 0$. Then the Jacobian matrix of the remaining of the system, $-Z_1(w_1) = 0$, is:

$$-\frac{\partial Z_1}{w_1} = (\frac{1}{1-\tilde{\delta}} + \Omega(1,1))(-\frac{\partial M_1}{w_1}) + \mathbf{W}(1,1). \tag{D.24}$$

By assumption 9, $\delta^m \sum_{d,k}\frac{\partial \pi_{dik}}{\partial M_j}\frac{w_d}{w_i}\bar{L}_d > 0$. By the definition of π_{dli}, $\delta^m \sum_{d,k}\frac{\partial \pi_{dik}}{\partial L_j}\frac{w_d}{w_i}\bar{L}_d < \frac{1}{1-\tilde{\delta}}$. So $\Omega(1,1) > 0$. It is also straightforward to verify that $\mathbf{W}(1,1) > 0$.

Note that $-\frac{\partial M_1}{\partial w_1} = \frac{\partial \tilde{G}/\partial w_1}{\partial \tilde{G}/\partial M_1}$. By assumption 9 and the definition of $\tilde{G}$, $-\frac{\partial M_1}{\partial w_1} > 0$. So $-\frac{\partial Z_1}{w_1} > 0$ for all $w_1 > 0$. By theorem 4 from Gale and Nikaido (1965), the equation $-Z_1(w_1) = 0$ has the unique solution.

■

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