Three Essays on Frictions of Trade



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Abstract

By examining the case of the West Austria retail fuel market, Chapter 1 investigates the nature of price competition in a spatially differentiated, but otherwise homogeneous product market. A spatial model is utilised for estimating the spatial dependence relationship among various locations. With the aid of statistical and machine learning tools, no prior knowledge is required regarding the structure of spatial dependence. This feature distinguishes this paper from the precedent works in the field. The results indicate that competition is highly localised but differs greatly in terms of market concentration. In addition, while location centrality affects firms pricing strategies, distance (or closeness) between competitors is not an adequate proxy for measuring the strength of competitive interactions.

The absence or poor quality of transport infrastructure can make it difficult for certain regions to access international markets. However, there is little empirical evidence on how improvements in domestic transport infrastructure stimulate international trade. Chapter 2 examines the relationship between China's regional trade patterns and national road infrastructure in the early 2000s. The analysis is based on an adapted gravity model with several alternative specifications for robustness checks. The result suggests that improvements on the road network lead to trade expansion on both intensive and extensive margins, but the effects vary across the regions. At the same time, sectors producing time-sensitive products benefit more from road construction and improvement. These findings support the claim that intranational trade costs, which have the same impact as international trade costs, are a determinant of comparative advantage and affect international trade patterns.

Chapter 3 evaluates the potential economic costs of China's pronounced unilateral trade sanctions on Japan in the early 2000s and provides an interpretation of the strategies used by both countries. A two-type goods version of Eaton–Kortum model of trade is used. The model captures the basic features of the China–Japan trade relations. I experiment with counterfactual simulations and explore the economic costs on China, Japan and other countries with respect to the unilateral Chinese boycotts, embargoes, two-way blockages, import tariffs and export taxes. The results show that were China to implement trade sanctions against Japan, it would have lost more than Japan in terms of welfare change. Neighbours of both countries would have been impacted due to the spillover effects.

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Chapter 0

Introduction

As early as 1933, Ohlin endeavoured 'to demonstrate that the theory of international trade is only a part of a general localisation theory'. Since then, many scholars have examined the relationship between trade theory and location theory. Ohlin criticised the classical trade theory for ignoring a significant portion of the transport-oriented industry where location decisions are primarily influenced by the cost of transporting raw materials, fuels and produce. Ohlin claims that classical trade theory is abstract and far removed from reality. It almost completely ignores trade frictions. Scholars hold different views regarding whether his statement was sufficiently justified. However, few would dispute its significance by pointing out the crucial role of trade costs in empirical studies of trade.

Trade costs are generally the product of trade frictions. Currently, there is no consensus regarding what trade frictions exactly are. In this paper, trade frictions are defined as all the factors that increase trade costs or impede trading. The reality of world trade is far from being frictionless. J. E. Anderson (2014) claims that Friedman

(2005)'s assertion 'the world is flat' is largely incorrect as world trade constitutes less than 10% of the frictionless trade benchmark enshrined in the trade gravity model.

Spatial friction is a ubiquitous form of trade frictions. Because trading almost always denotes commodity movement between points in geographical space, the distances separating such points are important factors to be considered. Distance is incorporated into some trade models as an approximation of transport costs and time. However, it can also encompass other factors affecting trade, such as national borders, legal and economic institutions, and cultural and technological barriers. The deceptively simple concept of distance is a multifaceted one with its measurement and interpretation often subject to discussion.

In addition to geographical separation, a range of other barriers also give rise to trade frictions. Trade barriers are government-induced restrictions on trade. They take many forms but are usually grouped into two main categories—tariffs and non-tariff barriers. Most trade barriers aim to impede trade by imposing additional costs.

Unfortunately, not all trade frictions can be explicitly measured. J. E. Anderson and Van Wincoop (2004) point out that friction implied by the gravity model is much greater than can be explained by measured trade costs. With the recent development of new spatial concepts and the appearance of new data on interregional flows, it seems appropriate to re-examine the problem of trade, location, and friction by analysing specific phenomena in different places and on a different scale.

The first chapter examines spatial friction on a microscopic scale. It studies retail fuel prices in two states of West Austria from 2010 to 2012. Due to spatial friction, the 'Law of One Price' does not hold in that market, as the same fuel can be sold in

different locations at different prices. A spatial autoregressive (SAR) model is used to explore the spatial interactions among pricing behaviours in different locations. The main finding is that location has a substantial effect on competitive interaction as well as on market equilibrium prices.

The second chapter examines domestic trade frictions on a larger scale by examining inter-regional trade activities. It investigates the domestic leg of international trade within China from 2000 to 2006. The result confirms the hypothesis that intranational trade costs decrease over time as the transport network improves. The distribution of trade, however, does not correspond perfectly with transport costs. Time-sensitivity of a sector matters for the effect of transport costs on the sector-level trade flows. The overall lesson is that intranational trade frictions behave the same as international ones in adversely affecting trade. The reduction of intranational transport costs stimulate international trade on both intensive and extensive margins.

The final chapter looks at trade on an international level by quantifying the after-effects of imposing various trade barriers between two countries. The trade flows between China and Japan in the early 2000s are simulated using a computational general equilibrium Eaton-Kortum model (Eaton and Kortum 2002). The trade barriers not only adversely affect the welfare of the two countries, they also distort the trade patterns of their respective trade partners. In other words, bilateral trading policies have led to multilateral consequences.

Chapter 1

Spatial Competition in the West Austria Fuel Retail Market

1.1 Introduction

Empirical studies demonstrate that the 'Law of One Price' has probably been violated more than any other economic law. Paradoxically, the non-existence of institutional differences, trade barriers and national borders provide no guarantee for price uniformity of similar products at different locations. Besides the economic factors at a specific location, such as consumer income and production technology, which induce heterogeneity of market demand and supply, geographical distinction among different supply locations plays a deterministic role in price differentials.

The geographical distinction is often referred to as 'distance'. The term is a multifaceted concept in economics, and its measurement and interpretation are subject to continuous debate. In this paper, distance literally denotes geographical distance,

which is the length measured along the surface of the earth between two points.

For similar products with disparate prices in different places, suppliers usually set prices higher than marginal costs. This results in a non-competitive market structure which is often characterised as imperfect competition for the products. Product supply location is the source of market power. Numerous models, classified as spatial (location) models, have been developed to incorporate consumer preferences with supplier location under the monopolistic competition framework. In contrast to traditional models, consumers in spatial models display preferences for both the utility gained from the characteristics of a particular product and its geographic location. These two factors form an enhanced 'product characteristic space' in which consumers are willing to compromise utility from products for a closer geographic location, and *vice versa*. The canonical model developed in Hotelling (1929) has achieved great success theoretically and in practice. His model serves as the foundation for subsequent studies. The spatial model framework is usually based on the game-theoretic assumption that a firm's revenue and profit are dependent on prices of its own products and of its competitors'.

The availability of extensive spatial datasets have improved the capacity of the field of spatial econometrics to address spatial economic phenomena and test theoretical spatial models. It is a refinement of classical econometrics, as it enables consistent estimation notwithstanding interactions between different entities in the theoretical model. The analysis usually incorporates spatial dependency or autocorrelation and involves the co-variation of properties within geographic space. These spatial relationships are defined formally through values called spatial weights and structured as

a spatial weights matrix $\mathbf{W}$. The conceptual idea is to use w_{ij}—the value in the ith row, j^{th} column to assess the spatial relationship between firm i and j.

This paper attempts to investigate the relationship between price, location, and distance under a spatial model in the West Austrian fuel retail market. The sample includes daily diesel prices of 435 filling stations from July 2010 to June 2012. As the problem is of high dimension, the study applies spatial econometrics techniques as well as statistical and machine learning tools.

The fuel market is particularly apt for empirical analysis to test theoretical spatial models. In terms of physical properties, fuel from various suppliers is a rather homogeneous product. The product may be considered to differ only with regard to sales location (Barron and Umbeck 1984). The sales locations are typically filling stations. For research purposes, this has the merit of easy traceability, given that they are generally fixed, transparent and well-documented. Additionally, the entry and exit costs of filling stations are significant; thus, the competition can be modelled by treating the number of suppliers and their locations as exogenous if the time span is not extremely long. While this is a simplification, decisions on market entry and location choice are long-run and can be considered as predetermined, as opposed to short-run pricing decisions. Finally, reselling or providing fuel outside the retail system is impractical and expensive. Hence, an alternative market for fuelling hardly exists. The possibility of arbitrage is excluded.

The price variation in retail fuel market affects numerous parties and attracts serious attention. Consumers spend a considerable share of their income on fuel. In recent years, UK's highest expenditure category was 'Transport', where motor fuel was

the most substantial contributing factor (Office for National Statistics 2016). Several country's market regulators follow the price evolution in the domestic market closely. There is a widespread perception in a considerable number of countries that regional fuel price variation results from inefficient competition. The Canadian oil industry has been under scrutiny for the past 50 years (Bott, Carson, and Henderson 2004). Australia's antitrust regulator, Australian Competition & Consumer Commisson, has raised flags on the petrol market under several circumstances. Thus, an investigation on the impact of fuel retailers' market power is in the interest of multiple stakeholders.

With varying approach and focus, a number of previous studies have utilised petrol market data. A few studies have tested the compatibility of game-theoretical spatial models with observed fuel price fluctuations in a given market. However, the majority of research studies have focused on rather small markets in cross-sectional settings. Most econometric analyses have shown that retail fuel prices vary across geographic space, and that proximity to and concentration of competitors determine the incidence of price matching behaviour (Eckert and West 2005).

Despite an abundance of related studies, a number of issues remain insufficiently addressed. Firstly, the omitted variable bias problem is universal in cross-sectional settings. Several factors including some of supply and demand drivers, and consumers' knowledge about price differentials, are generally unobservable. To solve the omitted variable bias problem, this paper utilises a panel dataset which helps to control for individual-specific, time-invariant and unobserved heterogeneity that is not detectable in pure cross-sections.

Secondly, the relationship between distribution of firms' locations and competi-

tion intensity has seldom been examined. Most models have assumed that firms are located symmetrically. For example, the canonical model formulated by Salop (1979) assumes that firms are distributed equidistantly in a circular market. However, competition intensity, or strength of competitive interactions, should not only be assessed by the number of direct competitors and the distance in-between. The geographical distribution pattern and the relative location of firms also constitute an important dimension of spatial competition and require further exploration. This paper investigates the importance of location *centrality*—as defined by Firgo, Pennerstorfer, and Weiss (2015)—for market power and firms' pricing strategic behaviour.

In terms of application, the vast majority of empirical analysis in spatial econometrics has relied on predetermined spatial relation, that is, the elements in the spatial weights matrix $\mathbf{W}$ are specified *ex-ante*. Some rules of thumb are used widely to determine $\mathbf{W}$, which includes using inverse distance, fixed distance, K-nearest neighbours, and contiguity relation. The choice of spatial weights has been a focus of criticism of spatial econometric methods since estimation results depend highly on the choice of $\mathbf{W}$, or in the words of Arbia and Fingleton (2008), this approach suffers from 'the arbitrary nature of weight matrix' and 'the results obtained [are] conditional on somewhat arbitrary decisions taken about its structure.' More seriously, the predetermined $\mathbf{W}$ conceals the insights of the drivers of socio-economic interactions and general equilibrium effects. The model is then limited in its ability to measure the average strength of pre-defined interactions. This paper attempts to determine the structure of spatial dependence without any priori assumption by applying LASSO[1]

[1]LASSO is a regression analysis method used widely in statistics and machine learning for both

(least absolute shrinkage and selection operator) regression.

The main contribution of this paper is that it provides a way to utilise econometric, statistic, machine learning, and GIS (geographic in-formation system) tools for investigating the price differentials in a specific market. This would also provide further insights into competition policy. Additionally, it tests a theoretical spatial model and addresses specific issues that have not been investigated thoroughly.

The major finding in the Austrian fuel retail market is that competition is highly asymmetric. More centrally located filling stations are more likely to affect the pricing behaviour of others as well as the market price. Additionally, the distance between two filling stations is not a good proxy for measuring competition intensity, conditional on the knowledge that the two outlets are competitors. This is quite intriguing, as it would mean that the common practice of using distance to define relevant markets—such as Clemenz and Gugler (2006) and Perdiguero and Borrell (2012)—may be inappropriate or even incorrect in the context of West Austrian fuel retail market.

The remainder of the paper is organised in the following fashion. The following section provides background information on the spatial model, present studies on the fuel market, and spatial econometrics analysis. In Section 1.3 the econometric framework and the theoretical model underpinning the investigation is discussed. Section 1.4 profiles the dataset used and describes specific findings based on the preliminary analysis. In Section 1.5, the identification strategies are outlined. Section 1.6 describes the estimation results and their implications, followed by the final Conclusion section.

variable selection and regularisation.

1.2 Background Information

1.2.1 Competition in Spatial Models

In attempting to model markets where firms supply similar goods at different locations, most models assume that sales and profits depend on prices of both its own and of its competitors. However, this assumption varies between models. For example, classical one-dimensional spatial models such as those by Hotelling (1929) and Salop (1979) assume that a firm is in direct competition with its neighbours. This implies that conditional on fixed direct neighbour prices, changes in prices for more distant competitors do not affect own pricing. By contrast, numerous models of monopolistic competition are based on the notion of global and symmetric competition (Chamberlin 1951; Spence 1976; Dixit and Stiglitz 1977). This means that a firm's sales and profits only depend on the distribution of market prices, regardless of the exact locations of the firms that post price changes. Some other models lie somewhere between these two extremes. Baumol (1967) and Gorman (1980) argue that firms compete along several dimensions. As the number of dimensions increases, so does the number of rivals. Indeed, there is an entire spectrum of assumptions for spatial dependence, ranging from extremely localised competition to symmetric global.

The model used in this paper follows that in Pinkse, Slade, and Brett (2002), which differentiates between local and global competition. According to S. P. Anderson, De Palma, and Thisse (1989), local competition denotes a situation in which firms interact with direct competitors, such as neighbours in a similar space, but the dimension of the space does not need to be homogenous, whereas global competition

denotes a situation in which all firms compete with all others, but competition does not need to be symmetric.

1.2.2 Studies on Fuel Markets

Previous researches have utilised fuel data quite commonly, although their works vary significantly in approach and focus.

In the public sector, a resolution has been sought for excessive pricing and profitability of retail fuel for many years. Regulators in a considerable number of countries, such as the United States, Canada, the United Kingdom and Australia, have attempted to ascertain market power with varying results (Australian Competition & Consumer Commisson 2017; State of California, Deparment of Justice 2014; Competition Bureau of Canada 2005; Competition and Markets Authority 2014).

Meanwhile, there have been several empirical studies that have attempted to quantify the extent to which high fuel prices is due to market power. An area of research is the price differentials between large, integrated outlets (majors) and small, independent and unbranded filling stations. Some studies claim that filling stations gain some market power by spatial differentiation as well as by offering extra services, such as convenient shops, car wash, and ATM. Unbranded stations typically compete by charging lower prices. Thus, branded filling stations are forced to charge low prices in local markets where there are unbranded filling stations. Alternatively, the major filling stations increase spatial differentiation in order to mitigate the effects of price competition (Van Meerbeeck 2003; Hastings 2004; Clemenz and Gugler 2006).

Such results have played a role in the ongoing policy debate in Austria. For example, Benigni and Prince (2005) support the proposal to increase the number of unbranded gas stations in regions where prices are relatively high. Nonetheless, some studies present a contrary narrative. For example, Taylor, Zimmerman, and Kreisle (2007) conclude that integrated petrol stations generally have either a small or insignificant effect on pricing decision in Southern California market examined by Hastings (2004), who claimed the acquisition of an independent gasoline retailer is associated with sizeable price increases.

Other recent studies investigate the geographical distribution of filling stations. As suggested by Braid (2013) and Firgo, Pennerstorfer, and Weiss (2015) in their studies, filling stations are considered as nodes in a network, while roads are viewed as edges. Both studies maintain that firms characterised by a more central position in a spatial network are more powerful, as they have a stronger impact on their competitors' and market equilibrium prices.

Various methods have been developed in the literature to model the interdependencies in the retail fuel market. For example, Slade (1998) estimated the demand equation and calculated the reaction function for each firm. In another study, Slade (1992) assumed that a filling station's price depends on the prices charged by its competitors in the previous period and the intertemporal reaction function can be used to predict the price. Pinkse, Slade, and Brett (2002) also formulated a cross-sectional framework for price competition with spatial dependencies and differentiated local and global competitions.

A few other studies have also investigated the compatibility of game-theoretical

models with the observed fuel price fluctuations in a given market. Most of these analyses have focused on rather small markets. For example, Slade (1992) used retail gasoline data to test dynamic models of tacit collusion in Vancouver. Douglas and Herrera (2010) also tested the theory of price stickiness on 15 Philadelphia retail gasoline stations. Furthermore, S.-Y. Lee (2007) examined the nature of competition in San Diego's retail gasoline market.

The scope of Austria's fuel retail market has been explored in various studies. Clemenz and Gugler (2006) demonstrated the necessity of including the spatial element in pricing decisions. They assert the impact of the market space upon the pricing decision of retail fuel outlets has to be estimated upon the locational factors in the market space. Pennerstorfer (2009) employed a spatial Durbin model, which accommodates the effects of market space as well as the difference in the pricing decisions of rivals to differ between major and independent outlets. Firgo, Pennerstorfer, and Weiss (2015) explored the retail market in Vienna and highlighted the importance of centrality for pricing. They implemented the concept of centrality in a theoretical model of spatial product differentiation and empirically tested it. These studies validate the existence of spatial dependence among Austrian filling stations. However, the nature of dependence is complex and non-uniform.

The Austrian Federal Competition Authority (Bundes Wettbewerbs Behörde—BWB) also conducted a market enquiry into diesel and premium petrol products as well as competition in regional retail markets from 2009 to 2011 (Bundes Wettbewerbs Behörde 2014). Kaltenbrunner and Schwabl (2010) compared the Platts quotations in Rotterdam with the prices at domestic filling stations and found that price increases

were transferred to domestic customers significantly faster (about two days earlier) than price reductions. Also, Gruber and Zobel (2011) claim that despite the limited spatial extent of Austria's relatively homogeneous regional economic and demographic structure, there are significant differences in fuel prices in different regions. They also divided the cost component into three categories. The first two categories include raw costs dominated by the international market and taxes levied at filling stations. These two categories comprise about 90% of the total costs and are uniform at all domestic locations. The third category includes costs specific to the filling stations, such as the investment costs for the construction of distribution network, maintenance costs, secondary transport costs, and advertising costs, which accounts for less than 10% of total cost. Despite cost differentials, the structural differences on both demand and supply sides in each area also contribute to the disparity in fuel retail prices. Additionally, Gruber and Puglisi (2010) also assert that the difference between the margins of the motorway filling stations and non-motorway gas stations is significant.

1.2.3 Spatial Dependence

Spatial econometrics extend traditional econometrics by considering the potential effects associated with the location of data collection (LeSage and Pace 2009). Specifically, the potential effects of location are regarded as spatial effects. These effects can be further divided into spatial dependence and spatial heterogeneity. Spatial heterogeneity is a property of a spatial stochastic process whose mean (or 'intensity') varies from point to point. Spatial dependence suggests outcomes at different locations may

be dependent. Recent developments in spatial econometric modelling have focused on spatial dependence (Charlton, Fotheringham, and Brunsdon 2009).

The spatial dependency structure is formally defined through values called spatial weights and structured as spatial weights matrix $\mathbf{W}$. The conceptual idea is to use w_{ij}—the element in the ith row, j^{th} column to quantify the spatial relationship between location i and j.

Defining the spatial weights matrix is critical in spatial econometrics. Most empirical analysis in spatial econometrics relies on the predetermined spatial dependence, that is, the elements in the spatial weights matrix $\mathbf{W}$ are specified *ex-ante*. $\mathbf{W}$ is generally regarded as a *priori* and is not well connected to theories (Leenders 2002).

Several different approaches have been developed to define spatial relationships between two locations. The first is the spatial contiguity approach. This approach defines first-order neighbours as sharing the same boundary, and second-order neighbours as the neighbours of first-order neighbours. The second approach is based purely on distance. Two locations are defined as neighbours if their geographical distance is within a certain threshold. The third is known as K-nearest neighbour approach. For example, using the 5-nearest neighbours to define the spatial weight matrix, each location then has five neighbours which are within the top five shortest distances. While numerous approaches are available to define a spatial weight matrix, there is no agreement on the best practice. The choice of spatial weights matrix has been the focus of criticism towards spatial econometric methods since estimation results highly depend on the choice of $\mathbf{W}$.

Despite the fact that the limitations of pre-determined spatial weights are widely

known in spatial econometrics literature, very few researchers undertook to estimate spatial weight matrices without imposing substantive *ex-ante* structures. Pinkse, Slade, and Brett (2002) had the first attempt to conduct inferences in a cross-sectional setting where the spatial weights matrix is partially unknown. They propose a semi-parametric smooth function to accommodate some variations of spatial dependencies. The parametric component of the estimator relies on the observable distance measured. Additionally, Beenstock and Felsenstein (2012) provided a nonparametric moment estimator for the spatial weights matrix, while Bhattacharjee and Jensen-Butler (2013) suggested an estimation of the spatial weight matrix by first estimating the error covariance matrix. However, their spatial weights matrix is only partially identifiable and a large error covariance matrix estimation can be highly inaccurate.

With the aid of machine learning tools such as LASSO regression proposed by Tibshirani (1996), Ahrens and Bhattacharjee (2015) proposed to estimate the spatial weight matrix in a spatial model with exogenous instruments using a two-step LASSO which imitates a two-stage least square (2SLS) estimation but with an additional penalisation factor. Lam and Souza (2015) introduced another LASSO-type estimator for spatial weights, which requires only one-step estimation. In addition to the theoretical works, other GIS applications focused on estimating spatial models also applied the LASSO for various purposes. For example, Seya, Yamagata, and Tsutsumi (2013) inferred a given spatial weights matrix and applied LASSO to filter variables. The process treats the spatial weights as nuisance parameters and aims to maintain the minimum number of nonzero weights.

This paper uses an adaptive LASSO to discover the spatial dependency in the West

Austrian fuel retail market. It follows the approach developed by Lam, Souza, et al. (2013) and adds some simplifications. The aims for adopting the method are two-fold. Firstly, the important requirement of spatial econometric models that specifies the spatial weight matrices prior to estimation is removed. The identification process is purely data-driven. Consequently, the model is less prone to the misspecification problem. Secondly, the structure of spatial weight matrix in this context is the object of interest. It relates to the scope of the market. By relying entirely on data to would reveal the dependence structures that have often been arbitrarily specified in many previous researches. Further implications of price competition can be inferred by examining the details of the identified spatial weights matrix.

1.3 Theoretical Model

The main component of the theoretical model in this paper is based on the approach developed by Pinkse, Slade, and Brett (2002). Whereas the original model is used for cross-sectional data only, this paper extends the specification for a panel dataset. In the model, fuel is differentiated by the sales location only. In other words, when anticipating travel and search costs, consumers would consider fuel from nearby filling stations as close substitutes given the control of other outlets' exogeneity. Hence, consumers maintain preferences for diversity regarding sales location differentiation. Filling stations act strategically according to consumers' demand. Price is assumed to be the only strategic variable, and each outlet sets prices simultaneously and independently to maximise profit. The model also enables the nesting of competing

interactions from both local and global spectrums, which is accomplished through the examination of spatial autocorrelation.

1.3.1 Demand Side

The model assumes that there are n outlets of filling stations, whose locations are exogenous and fixed. For $i = 1, ..., n$, let $\tilde{p_i}$ be the fuel price of the ith outlet. Consumers have alternative option of purchasing an outside good with a price p_0. A representative consumer c purchases fuel quantities of a vector $q^c = (q_{1c}, ..., q_{nc})'$ for the spatially differentiated fuel, in which q_{ic} stands for the purchased fuel quantity at outlet i, so $q_{ic} \geq 0$ for $\forall i = 1, ...n$. The consumption of the outside goods is $q_{0c} \geq 0$. The total number of consumers is denoted as h, hence $\forall c = 1, ..., h$.

Each consumer is located at a specific point within the product characteristic space, where the fuel is only differentiated by its associated sales location. A point in the product characteristic for fuel selling at all filling stations. Hence, consumers choose a unique optimised plan in terms of quantity and location for fuelling. Despite consumer preferences, this plan is also affected by income level and fuel price. These are modelled in each consumer's indirect utility function, which reflects the consumer's maximal attainable utility. In contrast to numerous location models, this set-up integrates the consumers' locations and travelling costs into their preferences instead of approximating both with some presumed structures.

The indirect utility function of a consumer c is denoted by $\tilde{V_c}(p_0, \tilde{P}_n, \tilde{y}_c)$, where $\tilde{y}_c$ is the consumer's income level and $\tilde{P}_n$ is a price vector of fuel prices at all filling

stations, that is, $\tilde{P}_n = (\tilde{p}_1, \ldots \tilde{p}_n)'$. Derived demand studies approximate the individual's indirect utility with a flexible functional form. For example, Berndt, Fuss, and Waverman (1977) suggest a second order approximation of an arbitrary utility function without any restriction on the possibility of product substitution. Similar to their approach, approximation is formulated with quadratic term and normalised with respect to the outside goods' price p_0:

$$V_c(1, P_n, y_c) = -[\alpha_{0c} + \alpha_c' P_n - p_0 y_c(\gamma_0 + \gamma' P_n) + \frac{p_0}{2} P_n' S_{n,c} P_n], \tag{1.1}$$

where $P_n = p_0^{-1}\tilde{P}_n$, $y_c = p_0^{-1}\tilde{y}_c$, and $S_{n,c}$ is an arbitrary symmetric $n \times n$ negative semidefinite matrix with the diagonal elements capture the own-price effect and off-diagonal elements cross-price effects.

The demand of a consumer c for fuel at outlet i can be derived after applying Roy's identity (Roy 1947):

$$q_{i,c} = -\frac{\frac{\partial V_c}{\partial p_i}}{\frac{\partial V_c}{\partial y_c}} = \frac{\alpha_{ic} + \sum_{j=1}^{n} s_{ij,c} p_j - \gamma y_c}{p_0(\gamma_0 + \gamma' P_n)}, \tag{1.2}$$

For simplicity, the denominator $p_0(\gamma_0 + \gamma' P_n)$ is the price index and can be normalised to one without loss of generality. α_{ic} represents filling station's non-price related heterogeneities for consumer c. $s_{ij,c}$ is the element in i^{th} row, j^{th} column of consumer c's matrix of price elasticity demand. y_c represents consumer c's income level.

By aggregating over all consumers, the market demand for outlet i is derived as:

$$q_i = \alpha_i + s_{ii}p_i + \sum_{j \neq i}^{n} s_{ij}p_j - \gamma_i y, \tag{1.3}$$

where $\alpha_i = \sum_{c=1}^{h} \alpha_{ic}$, $s_{ij} = \sum_{c=1}^{h} s_{ij,c}$, and $y = \sum_{c=1}^{h} y_c$. Of all the parameters, the coefficient α_i captures the heterogeneities of filling stations other than location factor, such as the brand name, the add-on services. Specifically, brand loyalty and better services would lead to a higher level of α. The filling station's demand response to a change in its own prices is captured by the coefficient s_{ii}. The coefficient s_{ij} reflects the substitution effects between outlet i and j. y is aggregated income. The income effect for outlet i is hence described by the coefficient γ_i.

1.3.2 Supply Side

As the goal of a firm is profit maximisation, it is presumed that each filling station determines its price to maximise profit, given the pricing strategy of all others. The other assumption is the constant returns to scales for each filling station. So it is defined that for a filling station i, it incurs the constant marginal cost MC_i. As there are several cost drivers contributing to the total cost, the marginal cost MC_i can hereby be decomposed into a linear function of a vector of various cost factors as mc_i, that is, $MC_i = \delta_i' mc_i = \sum_{l \in C} \delta_{li} mc_{li}$, where mc_{li} is the marginal cost associated with cost factor l within the set of all costs. According to the market study carried out by Gruber and Zobel (2011) in Austria, the major cost components are the raw costs of fuel and taxes. Additionally, there are some outlet-specific costs, such as investment

costs, maintenance costs, secondary transport costs, and advertising costs.

Given the prices of others, the filling station i chooses p_i to maximise its objective function:

$$\pi_i = (p_i - \delta_i' mc_i)(\alpha_i + s_{ii}p_i + \sum_{j \neq i}^{n} s_{ij}p_j - \gamma_i y) - F_i, \tag{1.4}$$

where F_i is the fixed cost. By solving the first order condition for the price with respect to the objective function, filling station i's best response function can be derived as follows:

$$p_i = R(p_{-i}) = -\frac{\alpha_i}{2s_{ii}} - \frac{1}{2}\sum_{j \neq i}^{n} \frac{s_{ij}}{s_{ii}} p_j + \frac{\gamma_i}{2s_{ii}} y + \frac{1}{2}\delta_i' mc_i, \tag{1.5}$$

where $p_{-i} = (p_1, \ldots, p_{i-1}, p_{i+1}, \ldots, p_n)$ denotes the price vector except the outlet's own price p_i. This equation shows that the best response function of outlet i depends on others' prices, the aggregated consumer income level, as well as the outlet's specific characteristics.

As it is not generally possible to estimate all parameters, additional structural assumptions are placed on the model. According to the proposed solution in Pinkse, Slade, and Brett (2002), the intercept term $-\frac{1}{2}(\frac{\alpha_i}{s_{ii}} - \frac{\gamma_i}{s_{ii}} y - \delta_i' mc_i)$ can be decomposed into a linear combination of outlet i's individual, regional and overall market characteristics. This implies that the variables y and mc_i are partitioned into some local and global factors that are associated with outlet i's price strategy. Although the simplification of the model is somewhat restrictive, it does not conflict with the assumption that the decision is optimised individually and independently by each

filling station.

1.3.3 Spatial Dependence in Model

The model set-ups and the assumptions mentioned above produce the response function of outlet i in the following form:

$$p_i = \sum_{j \neq i}^{n} w_{ij} p_j + \mathbf{X}_i \beta + u_i, \tag{1.6}$$

where $\mathbf{X}_i$ is a matrix that combines $m = 1, ..., M$ elements of observed individual, regional and market characteristics. β contains the coefficients to the M element columns correspondingly. The last term u_i is a random error, which captures the influence of unobserved demand and cost factors.

The slopes of the response function $w_{ij} = -\frac{s_{ij}}{2s_{ii}}$ should be positive provided that outlet i and j are competing with each other and play Bertrand price-setting game. This implies outlet i's market demand denoted in Equation (1.3) has q_i depending negatively on p_i ($s_{ii} < 0$), and positively on p_j ($s_{ij} > 0$). Indeed, the slope is proportional to the *diversion ratio*, which measures the fractions of diverted consumers from outlet i that would switch to outlet j if i charged a higher price. Mathematically, the diversion ratio is often approximated by the ratio of cross-price elasticity to own-price elasticity multiplied by the ratio of relative sales quantities (Shapiro 1995). A higher value of diversion ratio often indicates that both products are considered as close substitutes by consumers. It is an intuitive measure of how the pricing of one product is constrained by another and is particularly informative in situations where own and

cross price elasticity are not available (Mathiesen, Nilsen, and Sørgard 2011).

Additionally, the *retention ratio*, also known as the market recapture rate for a product, is defined as the sum of all diversion ratios with respect to the competitors. The retention ratio often provides a guideline for defining the relevant market. Under the premise that all consumers have concave preferences, a retention ratio of one implies that other outside products are independent of the sales of this particular product. In other words, the relevant market or the local market boundary for a product can be determined by defining all competitors with positive diversion ratios which sum up to one. In all, the parameter w_{ij}, measuring outlet i's responsiveness to outlet j's price change. Thence, its magnitude is an indicator of rivalry and competition intensity.

It is worth noting that the influence of the price of outlet j on the price of outlet i depends solely on the price interaction, and not on any other characteristics of outlet j. More specifically, outlet j's characteristics in $\mathbf{X}_j$ are not included in outlet i's best response function.

The system of the best response functions can be generated by stacking the individual ones. Hence, it is described as:

$$p = R(p) = \mathbf{W}p + \mathbf{X}\beta + u, \tag{1.7}$$

where p is a vector of fuel prices at all filling stations, $\mathbf{X} = (x_{im})$, $i = 1, ..., n$ and $m = 1, ..., M$, is a $n \times M$ matrix. The $n \times n$ matrix $\mathbf{W} = (w_{ij})$ has zero diagonal elements, that is, $w_{ii} = 0$, since the own price of the ith filling station is not treated as

an explanatory variable. The off-diagonal elements w_{ij} for $i \neq j$ are relevant slopes in Equation (1.6). u contains the error terms which are assumed to be conditionally independent of the observed characteristics, that is, $E[u|\mathbf{X}] = 0$.

1.3.4 Specification for Panel Dataset

As yet, the spatial model developed is purely cross-sectional. It can be easily assembled in a panel setting under the assumption that the spatial dependencies do not change during the investigated period. While an exploration into dynamic relation is theoretically possible, it would only complicate the process with little benefit, particularly for analysis with relatively short time span.

Using the subscript $t = 1, ..., T$ to designate the time period, the modelled market price at a given time period t is formulated as:

$$p_t = \mathbf{W}p_t + \mathbf{X}_t\beta + u_t, \tag{1.8}$$

where p_t is an $n \times 1$ vector of fuel prices for all filling stations at time t, $\mathbf{W}$ is a $n \times n$ static spatial weights matrix. $\mathbf{X}_t$ is a $n \times M$ matrix containing the observed station-specific, regional, and market characteristics at time t. β is a vector of M parameters for the exogenous variables. u_t is assumed to have mean zero and variance Σ_t and is independent of X_t. The matrix Σ_t is assumed to have uniformly bounded entries as $n, T \to \infty$.

By stacking the cross-sectional observations successively, the overall model becomes:

$$p = (\mathbf{I}_T \otimes \mathbf{W})p + \mathbf{X}(\mathbf{I}_T \otimes \beta) + u, \tag{1.9}$$

with $\mathbf{I}_T$ as an identity matrix of dimension $T \times T$, and variables are stacked vertically across all time periods, such that $p = \begin{bmatrix} p_1 \\ \vdots \\ p_T \end{bmatrix}$, $\mathbf{X} = \begin{bmatrix} \mathbf{X}_1 \\ \vdots \\ \mathbf{X}_T \end{bmatrix}$, and $u = \begin{bmatrix} u_1 \\ \vdots \\ u_T \end{bmatrix}$.

1.4 Data and Preliminary Analysis

The retail fuel price dataset is provided by the ÖAMTC (Öesterreichischer Automobil-, Motorrad- und Touring Club), the largest motorists club in Austria. The club maintains an accurate record of fuel prices at Austrian filling stations. These prices are obtained from the reports of filling station managers and consumers, or gathered by the club. Due to the voluntary reporting nature, the recorded time is unsystematic. Data are compiled daily and an average is taken if multiple prices are reported in a single day for each outlet. In the rare case of missing data points, data are imputed using a simple two-way fixed effects model of prices on individual-specific and time-specific fixed effects. The study period was from July 2009 to June 2012.

The original dataset includes the prices of two types of fuels' diesel and Eurosuper (unleaded gasoline containing 95 octane) for 443 filling stations in the two most western states of Austria—Tirol and Vorarlberg. However, as the two types of fuel share similar evolution patterns over time, it is not necessary to conduct an analysis on both fuels. Diesel is selected for this study, as the sample contains more comprehensive price records of this type. Filling stations with little or no record of diesel prices are

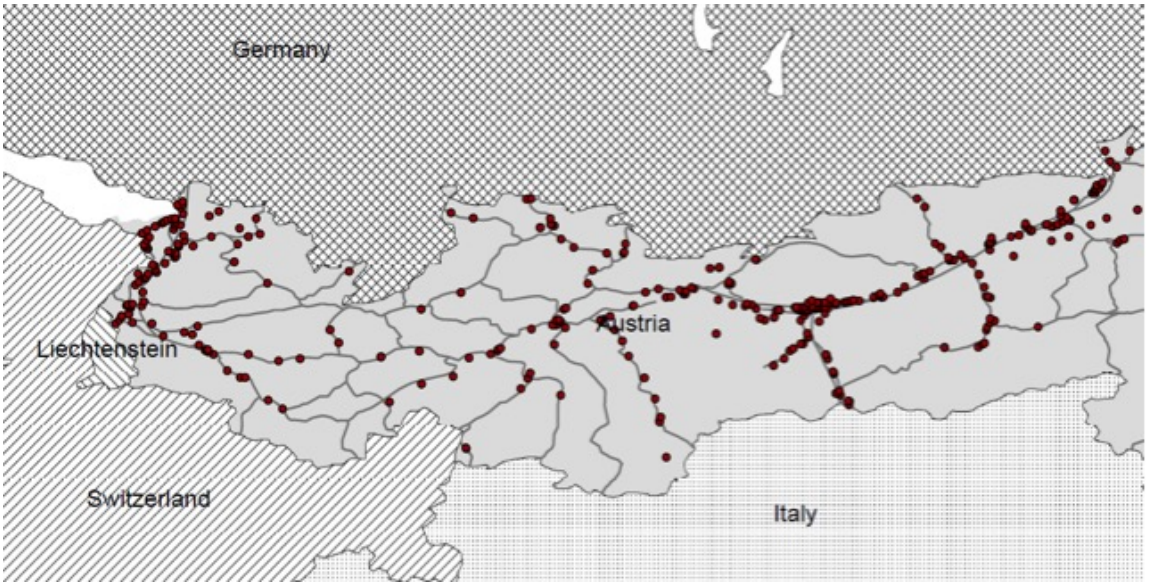
exempted from the analysis. Thus, the total sample size is 435 filling stations. Besides price records, information on the brand name, the geographical coordinates, and the address of each filling station are also obtained for this research.

1.4.1 West Austria

Tyrol and Vorarlberg are the two most western states in Austria. The research area covers 172 municipals spread over 15259 km^2, and is predominantly rural and mountainous. According to Statistik Austria (2015), the median population density during the research period is about 240 people/km^2. By contrast, the capitals of both states—Tyrol's Innsbruck and Vorarlberg's Bregenz—as well as nearby cities have significantly higher population. For example, the district Vols and Hall in Tyrol near Innsbruck has the highest population densities among all, which is about 2000 people/km^2. The economy of the regions does not differ greatly. This is confirmed by the relatively small variances in regional GDP per capita and wage income during the period. In fact, Gruber and Zobel (2011) also describe the country's regional economic and demographic structure as relatively homogeneous.

435 filling stations are to be studied, which is more than 98% of all in the area. All the outlets' locations are marked in Figure 1.1 on the following page. The figure indicates that many filling stations are clustered together along the major roads in the area. Based on the coordinates received, more than half of the filling stations have the closest neighbour located within 1 km overland. The two farthest stations in the sample are about 400 km apart. Also, only 4% of the filling stations identified are

Figure 1.1: West Austria and Filling Stations



Credit to Prof. Ferdinand Rauch

Table 1.1: Location and Brand: Summary Statistics

Location	**Mean**	**SD**	**Obs.**
Motorway	1.358	0.159	16
Non-motorway	1.236	0.159	419

Brand	**Mean**	**SD**	**Obs.**
BP	1.247	0.161	65
Shell	1.253	0.162	64
OMV	1.255	0.162	50
Eni	1.241	0.160	49
Disk	1.229	0.158	42
Esso	1.237	0.160	26
Avanti	1.226	0.157	22
Jet	1.221	0.158	21
Avia	1.244	0.158	14
Jet	1.221	0.158	21
Avia	1.244	0.158	14
Other	1.228	0.159	82

located along the motorway, which sometimes may only have accessibility from one direction. Gruber and Puglisi (2010) conducted a market investigation on the price margin differentials between the motorway and non-motorway filling stations. The primary finding reveals that the differences between the margins of filling stations on the motorway and non-motorway were blatant. This finding is in line with the observations in the sample. As shown in Table 1.1 on the previous page, the average price of filling stations on the motorways as opposed to those off the motorways is about 10% higher. Nevertheless, majority of the filling stations are accessible from various directions through the street grids. This indicates that the spatial dependence might be more complicated than Hotelling's linear city model.

In terms of the brands of fuel retailers, there are 179 filling stations under BP, Shell, and OMV, which are the major brands in Austria. Other brands, such as Eni and Disk, also have a great number of outlets operating in the area. The four largest brands in the area account for more than half of the total filling stations in the sample. Most branded stations are owned and operated by its parent company. In the case of dealer-owned branded stations, the dealer signs a contract with a branded refiner to sell its brand of fuel. Nevertheless, the filling stations can set prices independently, such that outlets under the same brand name charge different prices at different outlets. The average diesel price and its standard deviation are summarised in Table 1.1. While the standard deviation of average prices are similar, diesel sold at major filling stations is more expensive, confirming the brand premium found in many studies which attests that unbranded filling stations charge lower prices while offering fewer additional amenities such as car washing or service bays.

1.4.2 Price Evolution

Gruber and Zobel (2011) indicate that crude oil price is a significant component of the cost of retail fuel. The Brent crude oil price in Rotterdam can proxy this cost. The price of Brent crude—a major trading classification of sweet light crude—serves as a primary benchmark for the purchase of oil worldwide, particularly in Europe. The spot prices of Europe's Brent crude oil are available from the U.S. Department Of Energy (2015). As the original unit is in \$/Barrel, they are converted to €/L, using the corresponding daily \$/€ exchange rate from Bloomberg (2015) to keep the consistency with retail fuel prices.

Figure 1.2 on page 31 displays the evolution of average daily prices of diesel in the dataset as well as the daily Brent crude oil prices in the unit of €/L. According to the figure, the retail diesel price had a consistent upward trend until early 2011, and maintained a steady price for the rest of the year. In 2012, the price increased sharply but soon reduced to mid-2011 level. The Brent oil price showed a similar pattern to the retail diesel price with a synchronised trend (the correlation between two sequences was 0.82). The price volatility level of Brent crude was relatively smaller compared to the retail price of diesel, as the standard deviation of the former was 0.09 and 0.16 of the latter. Before 2011, the mark-up between the price of Brent crude and the retail price of diesel showed minor fluctuations ranging from 0.66 to 0.79, but experienced sudden increase at the beginning of 2011. The surge soon flattened out and the mark-up became quite stable and oscillated between 0.82 to 0.94.

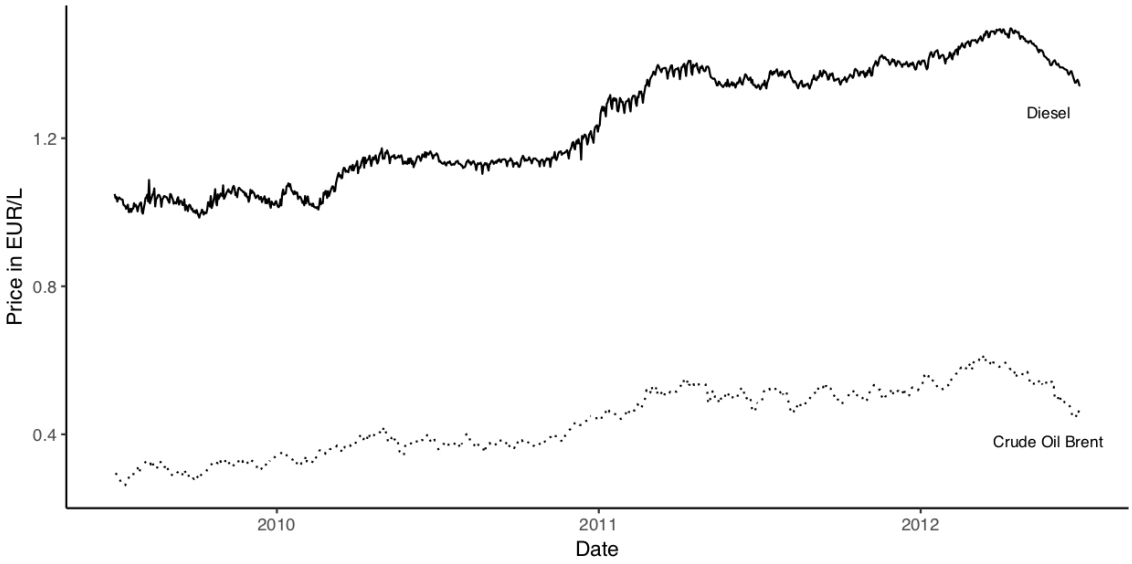
There are duty charges and VAT (value-added tax) levied on retail diesel price. The duty charges on diesel is a lump sum tax. It was 0.39 €/L in 2010 and increased to 0.44 €/L in 2011 and 2012. In contrast, the VAT is an *ad valorem* tax which was fixed at 20% throughout the study period. The annual average VAT on diesel was 0.18 €/L in 2010, 0.22 €/L in 2011, and 0.23 €/L in 2012 (Statistik Austria 2015).

The sudden increase in the mark-up in 2011 is partly caused by the increase in diesel duty. Nonetheless, the change in diesel duty alone cannot explain the degree of change, as the increase in mark-up persists even when the duty and VAT are accounted for. It is also possible that the change in mark-up is partially driven by the implementation of new fuel price regulation policy. From 1st January 2011, the regulatory price policy prohibits filling stations from increasing prices more than once per day, and each price increase must co-occur at noon. The main intent of the policy is to avoid price uncertainty and ensure that fuel consumers can easily assess and evaluate prices. A single fuel price increase within a day becomes less volatile and enhances regulation. However, several studies found that the policy might have produced unintended consequences, such that the daily minimum and average prices become higher (Obradovits 2012; Boehnke 2014). The reasons for retail fuel price distortion and the impact on consumer welfare are beyond the scope of the paper.

1.4.3 Spatial Dependence Detection

Despite the modelled spatial dependencies of fuel prices, the appropriateness of applying the model in this context remains unjustified. Fortunately, it is possible to explore

Figure 1.2: Daily Diesel and Brent Crude Oil Price



the spatial autocorrelation in the data by examining observations from pairs sampled at different locations. A standard tool called *semi-variogram* measures the similarity between two locations and plots the squared difference between the measured values (Curran 1988). In this context, if the spatial autocorrelation exists, observed fuel prices at a pair of filling stations located nearby should exhibit smaller squared differences. When the distance between the pair becomes farther away, the difference should be greater. More often, there is a certain distance threshold, beyond which the squared difference levels out. Hence, pairs of locations beyond this distance are considered to be spatially independent. Further details are given in Appendix A.

Mathematically, the semi-variogram is defined as:

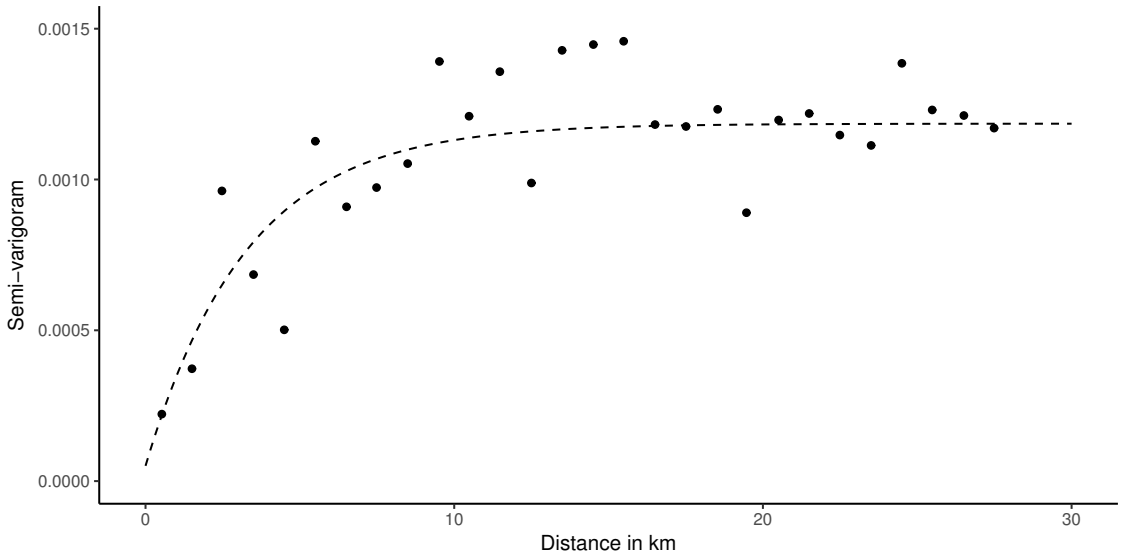
$$\hat{\gamma}(d) = \frac{1}{2\,|N(d)|} \sum_{i,j \in N(d)} |v_i - v_j|^2 \tag{1.10}$$

where $N(d)$ denotes the set of pairs of observation at location i and j, such that the direct distance between them is within the distance band d, and $N(d)$ is the number of such pairs in the set. v_i and v_j are the measured values at two locations. Given the background, since the fuel data is structured in longitudinal format, the average of diesel prices across the entire study period is taken for each filling station. For simplicity, the distance used here is the geographical distance and the bandwidth is 1 km. In other words, it noted the sequential bands for filling stations located within 1 km, between 1 km and 2 km, and so forth. This study plots a total of 30 distance bands to compare diesel prices of two stations located up to 30 km apart.

The application of semi-variogram aims to achieve two objectives. First, an observation of the pattern of semi-variogram can help to determine the existence of spatial dependence. Second, it provides further information for structuring the spatial weights matrix and helps to achieve more efficient variable selection.

Figure 1.3 on the next page presents the variation of the average retail diesel prices at different filling stations. On average, there are approximately 500 outlets represented in each band. Therefore, the sample size within each band is large enough to produce representative averages. The points represent the average semi-variogram at the corresponding distance range. It is worth noting that the semi-variogram value is not zero at an infinitesimally small separation distance, signifying the presence of heterogeneous characteristics other than the location factor of filling stations, that may have driven the price differentials. Nonetheless, price similarity can still be observed between filling stations that are located nearby. A best-fitted theoretical semi-variogram model in the Gaussian spherical form is also depicted in Figure 1.3.

Figure 1.3: Semi-variogram for Diesel Prices



According to the fitted parameters,[2] the effective range is 3.3 km, indicating the distance in which the semi-variogram values becomes stable. For stations located apart at longer distances, the diesel price variations appear to be more random and exhibit little trend with respect to distance.

Thus, the semi-variogram confirms the existence of spatial dependence in the West Austria retail fuel market. Moreover, it provides additional information that the prices at filling stations located within 3.3 km are more similar. This serves as one of the criteria used in selecting relevant variables for the spatial weights matrix.

[2]The formula of the spherical model is: $\gamma(d) = \begin{cases} 0, & d = 0 \\ C_o + C(\frac{3d}{2a} - \frac{d^3}{2a^3}), & 0 < d \leq a \\ C_0 + C, & d > a \end{cases}$, where C_0 is the nugget constant (the value at which the semi-variogram is almost intercepts the y-axis), $C + C_0$ is the sill, the value at which the model first flattens out. C is the structure variance. The effective range, that is, the distance at which the model first flattens out is captured by a.

1.5 Identification Strategies

The equation sepecification in Equation (1.7) on page 23 has a similar form as the spatial autoregressive model (SAR), which is also known as the spatial lag model. The model incorporates spatial effects by including a spatially lagged dependent variable as an additional predictor. A general form of SAR model is usually specified as $y = \rho\mathbf{W}^*y + x\beta + \varepsilon$, where $\mathbf{W}^*$ is a predetermined spatial weights matrix that stores the spatial relationship information. Under this setting, the problem of identification is reduced to estimate the spatial lag coefficient ρ, which measures the average strength of spatial dependence. The spatial weights w_{ij}^*'s are non-zero when location i and j are spatially dependent, and zero otherwise. By convention, the self-dependent relation is excluded, so the diagonal elements of $\mathbf{W}^*$ are all zeros.

Pairwise geographical proximity or distance is extensively used to select the weights. However, space is irregular and heterogeneous and the influences may be of any type across space. Tobler (1970) claims that 'nearness' is just one possibility. The question of specifying a matrix seems quite complex, although the majority of previous studies prefer simple solutions. By and large, the dominant approach involves an exogenous treatment of the problem.

In principle, the weighting function should reflect the spatial structure of the interaction process. In practice, however, this is not obvious and the specification of the weights is often rather *ad hoc* (Anselin 2013). Technically, it is difficult to identify all elements of the spatial weights matrix. Bavaud (1998) mentioned that 'there is no such thing as true, universal spatial weights, optimal in all situations', the weights

matrix 'must reflect the properties of the particular phenomena, properties which are bound to differ from field to field'. This means that the problem of selecting a weighting matrix is a problem of model selection. Unlike the conventional approaches, this paper identifies the structure of spatial relation without placing a priori restriction and applies adaptive LASSO, which also accommodates the heterogeneity of spatial dependence strength.

1.5.1 Adaptive LASSO

When treating all elements in spatial weights matrix W as unknowns, the estimation of the model in Equation (1.9) poses the main challenge of under-identification. Principally, the model is not identified unless the number of parameters is smaller than the number of observations, otherwise it requires further assumptions. The identification assumption considered in this study is the sparseness of the spatial weights matrix which demonstrates that only a limited number of location sets interact in space. This assumption fits the purpose of the study, as only the spatial dependence between nearby filling stations is of particular interest. Any spatial dependency for filling stations afar, may only be caused by spurious relationship.

Proposed by Tibshirani (1996), LASSO has become a popular regularisation technique for variable selection in regression models. This paper employs an improved version developed by Lam, Souza, et al. (2013) to select the elements in the spatial weights matrix.

As mentioned above, the spatial weights matrix has zeros diagonally. Addition-

ally, it is assumed that there exists a constant $\eta < 1$, such that $\|W\| < \eta < 1$. This is a plausible assumption, as any change in the competitor's price is often not fully matched by the rival outlet due to the existence of individual market power which arises from spatial differentiation. This condition ensures the model denoted in Equation (1.8) on page 24 has a reduced form:

$$p_t = \mathbf{\Pi}\mathbf{X}_t\beta + \mathbf{\Pi}u_t, \quad \mathbf{\Pi} = (\mathbf{I}_n - \mathbf{W})^{-1}, \tag{1.11}$$

where $\mathbf{\Pi}u_t$ has finite variances and $\mathbf{I}_n$ is the identity matrix of size $n \times n$. By simplifying the approach of Lam, Souza, et al. (2013) and not including the spatial dependence relation for exogenous variables, the minimisation problem for the purpose of regularisation is written as:

$$\min_{\mathbf{W},\beta} \sum_{t=1}^{T} \|p_t - \mathbf{W}p_t - \mathbf{X}_t\beta\|^2 + \gamma_T \sum_{i,j} \left(v_{ij} \left|w_{ij}\right|\right), \tag{1.12}$$

where γ_T is a tuning parameter and $v_{ij} = |\tilde{w}_{ij}|^{-k}$ is the penalty factor of w_{ij}, for some integer $k \geq 1$, with $\tilde{w}_{ij}$ being the solutions of the above minimisation problem with all v_{ij}'s set to 1 through ridge regression. The $\tilde{w}_{ij}$ś represent the LASSO solutions with constraints (Zhao and B. Yu 2006). The v_{ij} becomes the weight for penalisation. The larger the magnitude of w_{ij}, the smaller v_{ij} becomes, and *vice versa*. Hence, adaptive LASSO eventually penalises coefficients more with lower initial estimates. Preferably, the application of adaptive LASSO in spatial panel data enjoys the oracle property that ensures its estimators are consistent in parameter estimation and variable selection under the assumption that error variance reduces to zero as time span increases

(Lam, Souza, et al. 2013).

In terms of practical implementation, the Block Coordinate Descent (BCD) algorithm is used in carrying out the minimisations for Equation (1.12). Each step is detailed in Lam, Souza, et al. (2013). In brief, the minimisation process is iterated, starting from the initial coefficients of $\tilde{\beta}_0$ generated from simple OLS estimates by ignoring the spatial autocorrelated term. The elements of spatial weights are then obtained from LASSO process with the penalty factors and $\tilde{\beta}$ updated accordingly in each step, until the coefficents' values from two iterations converge. The tuning parameter γ_T is selected by comparing the Bayesian information criteria (BIC) rather than using the cross-validation (CV) methods. Selection using information criterion is faster and more adequate for some applications, particularly time-series, as cross-validation may impose further complications.

1.5.2 Fixed Effects Model

One of the advantages of panel dataset is the ability to control for individual-specific, time-invariant, unobserved heterogeneity that is not detectable in pure cross-sections (Hsiao 2014). The fixed effects are also applicable in spatial panel models. Despite incorporating the individual fixed effect, there remains a two-way error component regression method in spatial panel data literature which can further integrate the time-specific effect (L.-f. Lee and J. Yu 2010). Despite the applicability, Elhorst (2014) demonstrates that the evidence in favour of interactive spatial effects is weak when time fixed effects are also accounted for in practice. This is because variables

in different spatial units are driven by similar underlying factors and tend to increase and decrease congruently along the overall evolution of the drivers over time.

As indicated in Section 1.4.2, the cost of Brent crude oil and relevant taxes are the main drivers of retail fuel price. With the control of both factors, most price fluctuations common to all filling stations are removed. The inclusion of the time fixed effect produced daily would be redundant and only mask the interdependent relations of filling stations.

On the other hand, the effect of time-invariant characteristics of filling stations on pricing is not the primary focus of this study. Hence, factors such as brand name and motorway accessibility can all be categorised as individual fixed effects. It is ideal to include the local and regional dynamic characteristics of each filling station, such as GDP and population. Unfortunately, socio-economic statistics are usually available for a longer time span (usually at annual frequency) and at a higher geographical hierarchy (such as municipal or state levels), which might not be the most relevant in this application. In contrast to available data, each outlet's catchment area is smaller, and local market condition changes more frequent. Fortunately, Gruber and Zobel (2011) assert that Austria has relatively homogeneous regional economic and demographic structures. Meanwhile, the study period is not particularly long to determine if the characteristics vary significantly across different locations and if the inclusion of individual fixed effects would be sufficient. In sum, for any time $t = 1, ..., T$, the model is empirically specified as:

$$p_t = \mathbf{W}p_t + \mathbf{X}_t\beta + \alpha + u_t, \tag{1.13}$$

where α is a vector of length n that measures the individual fixed effects, $\mathbf{X}_t$ is the matrix of daily Brent crude oil price and diesel duty. VAT rate is not included, as it does not change during the period. Moreover, its *ad valorem* nature is not compatible with the linear model. The error term is denoted as u_t, which is assumed to be conditionally independent of $\mathbf{X}_t$.

1.5.3 Simplifications

Although it is theoretically applicable to identify the spatial weights using the adaptive LASSO under fixed effects specification, the actual identification process in this study is complex due to the large sample of 435 stations over a period of 1096 days. However, two critical simplifications can aid the identification process and promote efficient execution.

Firstly, the data profiling in Section 1.4 provides useful information to exclude a significant number of parameters which are unlikely to be spatially related. The semi-variogram analysis reveals that prices at filling stations located within 3.3 km are similar compared to stations farther apart. Hence, we can limit the scope of neighbouring distance within 3.3 km, which is also the justified effective range according to the best-fitted semi-variogram model. Any filling stations located more than 3.3 km apart are presumed not to interact strategically in terms of pricing. So the corresponding spatial weights are set to zeros. This assumption makes the spatial weights highly sparse and reduces the candidate parameters w_{ij} from 188790 to 432, as there are 216 pairs of filling stations located within 3.3 km.

On average, each filling station has approximately seven neighbours located within 3.3 km in terms of geographical distance. Nevertheless, the density of filling stations differs significantly across the studied area. A filling station in Innsbruck has 39 neighbours located within 3.3 km, while 55 outlets do not have any within the distance band. In cases where the filling stations do not have any neighbour within 3.3 km, they are assumed not to be spatially dependent on other filling stations.

Moreover, the study does not enforce the symmetric assumption of spatial weights, the impact that outlet i exerts on j can be different from that of j on i. Indeed, it allows the competitive interaction to be unilateral.

The choice to set the cut-off point at 3.3 km is more generous than most of the distance bands used in previous fuel market studies. For example, a study based on interviews with service station owners by Hastings (2004) intimates that stations compete with other stations within one mile. S.-Y. Lee (2007) experiments with several distances, including 0.1, 0.5, and 1.0 miles, for the spatial weights matrix in a study of filling stations in San Diego County. Despite significantly reducing the dimension of the identification problem, the restriction is in line with the objective of the study and should not indicate the de-selection of any spatial dependent pairs.

Secondly, the study adopts the variable-demeaning approach to eliminate the individual fixed effect. The within-subject mean for each variable (either explanatory or dependent) is subtracted from the observed values of the variables. Mathematically, the demeaning transformation is defined as $p^*_{it} = p_{it} - \frac{1}{T}\sum_{t=1}^{T} p_{it}$, $x^*_{it} = x_{it} - \frac{1}{T}\sum_{t=1}^{T} x_{it}$ for outlet i's dependent and explanatory variables. Consequently, such alteration would eliminate variables that do not change over time and make them unidentifi-

able. Nevertheless, these variables are not the concerns of this research.

1.6 Result and Discussion

Under the assumption of steadily decaying error variance, adaptive LASSO recovers the correct locations of zeros and non-zeros in a sparse matrix in their correct magnitudes. By applying the identification strategies in Section 1.5, the spatial weights matrix is obtained. Some stylised findings that characterise the nature of price competition in the West Austrian retail fuel market are highlighted in this section.

1.6.1 Empirical Findings

Before delving into the results, the following nomenclature is laid out for precise phrasing in this section.

Definition. The element w_{ij}, in the ith row and j^{th} column of spatial weights matrix, reflects filling station i's spatial dependency on j. When $w_{ij} \neq 0$, i responds to any price change of j. The filling station j, hence, is defined as the *initiator*, while filling station i is the *reactor*.

This definition emphasises that the competition effect is directional. One can imagine that the owner of a filling station i continues to monitor the price of i's targeted competitor j. When j's price changes, the owner adjusts i's price accordingly. In contrast, the owner of outlet j may or may not keep track of the price change at i.

Five propositions with respect to the West Austria fuel retail market are presented below in order from general to specific.

Empirical Finding 1.

Prices are strategic complements.

The first finding is validated by the signs of all nonzero w_{ij} terms in the identified spatial weights matrix. All nonzero w_{ij}'s are positive, implying that to a reactor, price reduction is the profit-maximising response to its initiator's price cut, with similar principle applying to a price increase. Consequently, an initiator's action reinforces that of its reactor. This result is in compliance with the model setting of Bertrand competition on the supply side. In this sense, when two filling stations are mutually spatial dependent, it is equivalent to say they are competing with each other in pricing. Further details regarding the identified spatial weights are presented in Appendix B.

Empirical Finding 2.

The competition is asymmetric.

When filling station i considers j an initiator, the relation may not be reciprocal, as j may not necessarily consider i an initiator. Even if either outlet is the other's initiator, the degree of responsiveness is not always uniform. Specifically, this proposition can be verified by comparing the coefficients of paired (w_{ij}, w_{ji}) from the spatial weights matrix $\mathbf{W}$. Out of the 380 established competition relations, only 174 (87 pairs), maintain bilateral dependency. As explained before, the coefficient value quantifies competition intensity. Among 87 pairwise competitive relations, 61 have their coefficients differ by less than 1.0×10^{-3}, implying the symmetric impact.

At a higher granularity, one specific filling station, having the brand name Shell and located near Innsbruck, is the initiator to 25 other filling stations. In contrast,

169 filling stations are reactors only. Consequently, a price change by a reactor-only filling station will not trigger any price change of others. This again signifies the asymmetricity in spatial dependence, as well as in filling stations's pricing strategies. As the spatial weights matrix identified purely based on data distinguishes from those conventional ones, this finding departs from the common assumption of symmetric competition in spatial econometrics.

Empirical Finding 3.

The competition is highly localised in general, while market concentration varies.

Adaptive LASSO selects 380 important features, which are the prices at 380 outlets. This means that each reactor only responds to a single initiator. However, the caveat is not to conclude that filling stations only compete in pairs. A reactor i, despite having its own initiator j, may also be outlet k's initiator. When a price change at outlet j triggers a change in price at outlet i, it in turn also triggers a change at outlet k. This is called domino spatial effects according to Pinkse, Slade, and Brett (2002), which potentially links many locations and enables the competition to be from local to global.

The visualisation of the spatial dependence is depicted in Figure 1.4 on page 45 using dependency graph. The nodes indicate the filling stations, while the directed edges indicate the linkage from an initiator to a reactor. This allows for both direct and indirect competition. Hence, all linked nodes indicate that they are in the same market, as the price change at some outlets would potentially affect the prices at all others. The relations are also mapped to the filling stations' locations in Figure 1.5

on page 46. The ring size implies the number of filling stations that react to the location.

In general, the market is small in terms of the geographical area. Nonetheless, the number of filling stations in the same market varies significantly. Most markets have about three to six filling stations. However, the market concentration is extremely high in two capital cities—Innsbruck and Bregenz. A single large market with 34 filling stations involved characterises the competition in Innsbruck. The 'hotspot' is the aforementioned Shell service station, which has 25 reactors, with some of its reactor being others' initiators. In contrast, the markets are relatively more segmented along the Austrian border near Bregenz.

Empirical Finding 4.

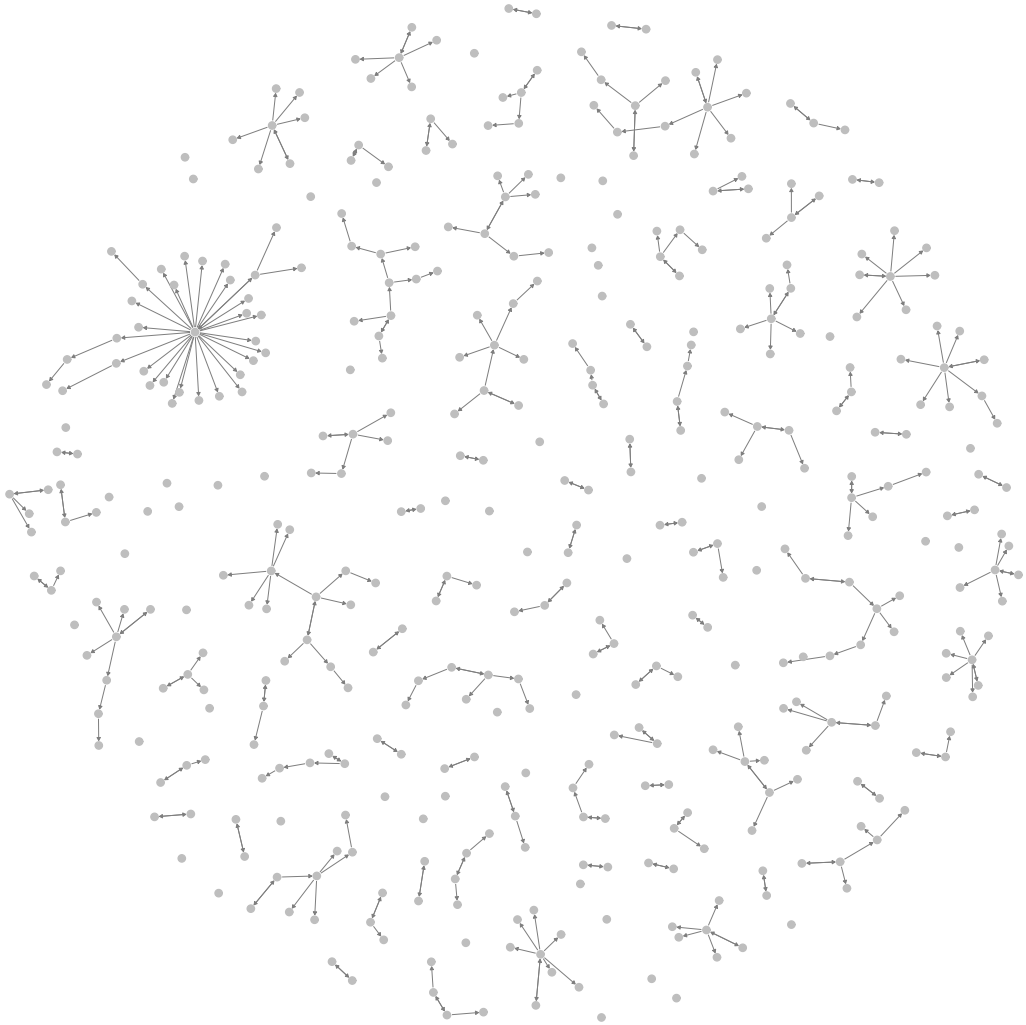
Filling stations are more likely to respond to price changes emanating from a 'central' outlet than from a 'remote' one.

Centrality, the most fundamental concept in the social network literature, is defined as the extent to which agents are connected to other agents. The concept of the degree of centrality adopted follows Opsahl, Agneessens, and Skvoretz (2010) and it measures the number of times a particular location is among the H nearest neighbours of other locations. Mathematically, the centrality degree is given by:

$$dc_j^H = \sum_{h=1}^{H} \sum_{i=1}^{N} L_{ij}^h, \tag{1.14}$$

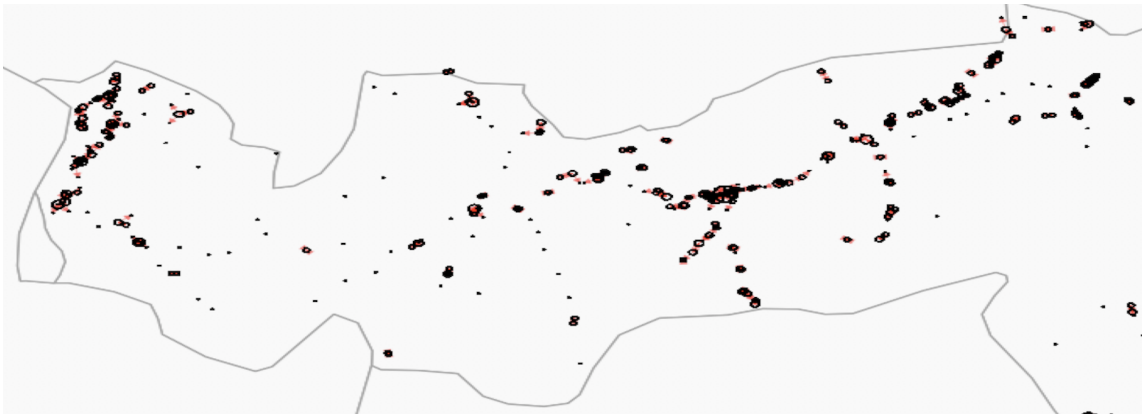
where $L_{ij}^h = 1$ if outlet j is the hth nearest neighbour of outlet i, and $L_{ij}^h = 0$ otherwise. Unlike other measures, such as distance to the nearest neighbour or the number

Figure 1.4: Spatial Dependence—Network



In the graph, network nodes are defined as filling stations. The directed edges linking initiators and reactors represent the dependency relations.
This figure represents a network. The points do not match their locations. The distance between two points is not drawn to scale.
In graph theory, it is possible to derive an evolution order or the absence of an evolution order that represents the given dependencies from the dependency graph based on a node-link incidence matrix, which is similar to a binary spatial weights matrix. Based on the graph, it is possible to identify transmission (or non-transmission) mechanism given any price change.

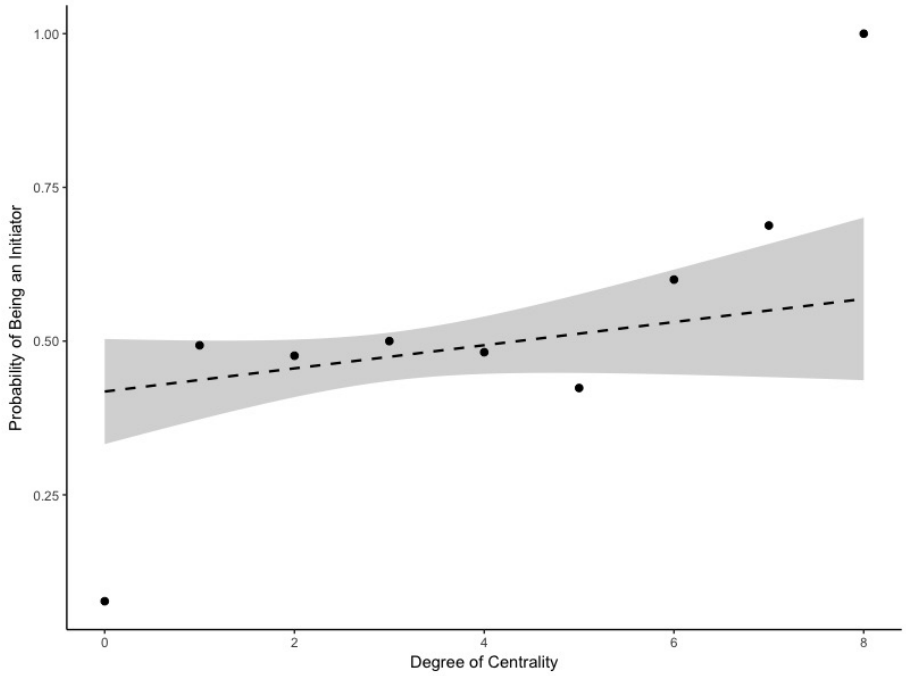
Figure 1.5: Spatial Dependence—Map



of neighbours within a given diameter, centrality degree incorporates additional information regarding the relative locations. A filling station in an area with many other outlets can be highly remote if its neighbours are relatively closer to other neighbours than to it. Thus, centrality characterises the 'importance' of a location without the need to specify the exact cut-off distance for being close or far. This paper tested various values for H and obtained similar qualitative results for H equals to 2 to 6. For $H = 3$, the centrality degree varies from 0 to 8. The most central filling station with $dc^3 = 8$ is a Shell service station located in the town centre of Telfs, while one of the 13 most remote filling stations are located only 14 km away. This observation implies the market concentration is not necessarily correlated with market insiders' centrality degree.

Figure 1.6 on the following page outlines the information of whether each of the 435 filling stations is an identified initiator to any other outlet and their centrality degrees. It plots the average probability of being an initiator against the centrality degree, as well as the best fitted line with a 95% confidence interval. The figure

Figure 1.6: Centrality and Probability of Being an Initiator



reflects a positive relation.

This finding also has an implication for equilibrium market prices, as it implies a central filling station is more likely to transmit shocks. An exogenous shock to filling station i not only directly affects its own price but also indirectly affects the prices of its reactors and triggers price adjustments by the reactors' reactors. This includes the feedback effects to station i if the spatial dependency is bilateral. Such simultaneous feedback is a feature of the spatial autocorrelation model. To further explore the nature of this, Equation (1.13) on page 38 can be expressed in a different way by using an infinite series to expand the inverse term (Debreu and Herstein 1953):

$$\mathbf{\Pi} = (\mathbf{I}_n - \mathbf{W})^{-1} = \mathbf{I}_n + \mathbf{W} + \mathbf{W}^2 + \mathbf{W}^3 + \ldots,$$

which leads to a re-expression of the specification:

$$
\begin{aligned}
p_t &= \mathbf{\Pi X}_t\beta + \mathbf{\Pi}\alpha + \mathbf{\Pi}u_t \\
&= \mathbf{X}_t\beta + \mathbf{WX}_t\beta + \mathbf{W}^2\mathbf{X}_t\beta + \alpha + \mathbf{W}\alpha + \mathbf{W}^2\alpha + u_t + \mathbf{W}u_t + \mathbf{W}^2u_t + \ldots .
\end{aligned}
$$

The spatial weights matrix $\mathbf{W}$ provides the first-order interactive relation. The matrix $\mathbf{W}^2$ then reflects the second-order, and signifies those that interact with the first-order ones. If two filling stations are mutually dependent, that is, $w_{ij} > 0$ and $w_{ji} > 0$, then two of the diagonal terms in $\mathbf{W}^2$—$w_{ii}^{(2)}$ and $w_{jj}^{(2)}$ are also positive. This transmits further feedback impacts on the prices of outlet i and j's prices. Based on the proposition, if i and j are both central filling stations, they are much more likely to compete with each other than with other remote outlets. Consequently, simultaneous feedback is likely to exist and the shock may induce more substantial price changes than any induced by changes of remote ones.

Empirical Finding 5.

Conditional on spatial dependence, there is no specific relation between competition intensity and spatial differentiation.

As discussed before, the values of w_{ij} in $\mathbf{W}$ reflects the competition intensity, as a higher value indicates reactor i responds more strongly to initiator j's price change. However, the identified spatial weights matrix implies that distance between the two filling stations is not a good proxy for the price responsiveness, given the

prior information that an outlet exerts influence on the pricing strategy of the other.

Positive coefficients generated by adaptive LASSO are plotted against two types of distance. The first type is the widely used geographical distance which can be measured directly from the filling stations' coordinates. The second is the shortest road distance which may be more relevant in this context as fuel consumers surely travel by car. The distances from initiators to reactors are obtained from Google Distance Matrix API. This measure is asymmetric, as the shortest route from outlet i to j is different from that of travelling from j to i if one-way road exist in-between. Anyhow, the difference is trivial in this sample.

Nevertheless, Figure 1.7 on the following page shows that regardless of the distance measure used, there is no clear inverse relation between the distance lengths and coefficient values based on the plots and best fitted linear line with a 95% confidence interval. The strength of impact does not ebb at all as distance increases. In fact, the coefficient values are quite similar, which suggests a homogeneous degree of competition intensity in the area.

This finding is rather counter-intuitive, as empirical investigations in the field often uses 'distance decay' measure to pre-structure spatial dependence. It is often assumed that the interaction between two locations declines as the distance between them increases. However, this specification may not be appropriate in the West Austrian retail fuel market, especially when the spatial dependency is already established. On the other hand, distance still plays a crucial role. When distance between two filling stations is beyond the effective range, they are assumed not to compete with each other.

Figure 1.7: Distance and Competition Intensity

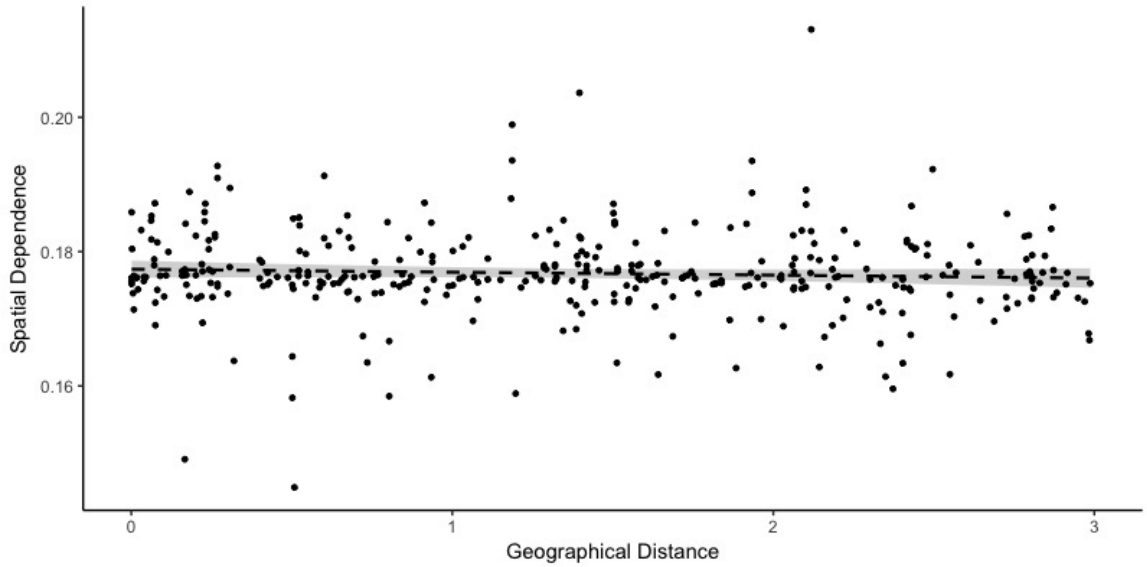
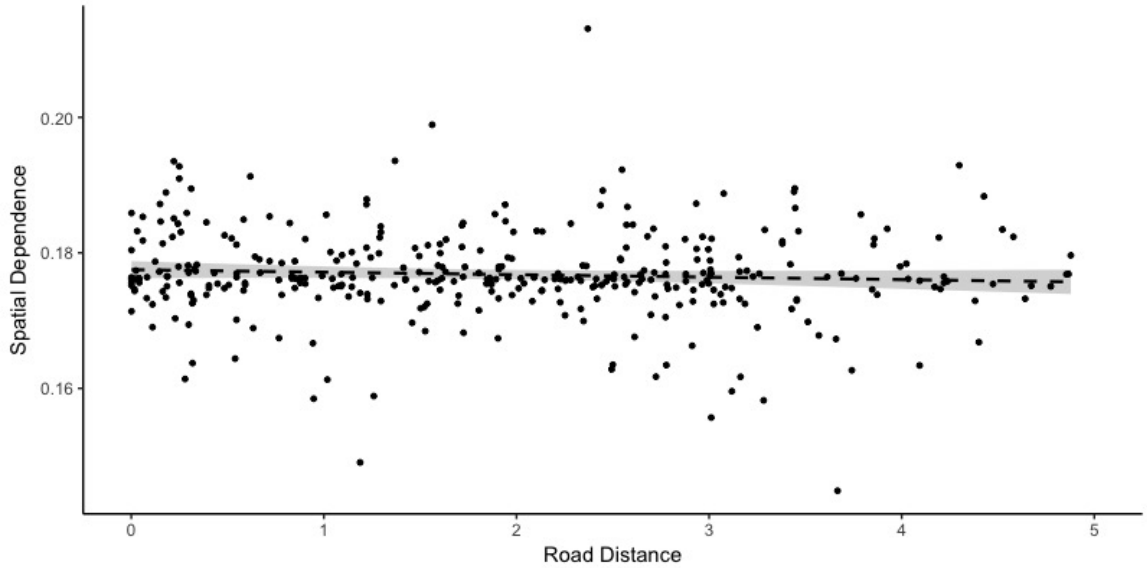


Figure 1.8: Distance and Competition Intensity



1.6.2 SAR Model Result

The last proposition reveals that the competition effect is rather homogenous. Hence, it is appropriate to apply the SAR model, that is, $y = \rho \mathbf{W}^* y + \mathbf{X}\beta + \varepsilon$ in this context. This reduces the spatial dependence relation to a single coefficient and measures the average strength of spatial dependence. The spatial weights matrix $\mathbf{W}^*$ is hence defined as a binary matrix based on the adaptive LASSO recovered $\mathbf{W}$, such that $w_{ij}^* = 1$ if $w_{ij} > 0$, and zero otherwise. The scalar ρ represents a regression parameter to be estimated. The parameter ρ would reflect the spatial dependence inherent in the sample data, measuring the average influence of competition given the spatial weights matrix. In other words, adaptive LASSO has aided the selection of the pairs of locations which are spatially dependent, while other coefficients are estimated in a more econometrical way.

For proper estimation, the spatial weights must be treated as endogenous and the methods must account for this endogeneity. Consequently, OLS (Ordinary Least Squares) will be inconsistent due to the simultaneity bias. Thus, alternative methods have to be adopted. Anselin (1988) addressed the application of MLE (maximum likelihood estimation) in spatial econometrics. Since then, it has been widely studied and proves to be consistent with spatial models (L.-F. Lee 2004). Additionally, the individual fixed effects in the panel setting also have to be considered. Elhorst (2003) proves that the use of demeaned spatial regression models is appropriate, if the interest is primarily to obtain consistent estimates for the time-varying variables.

The coefficients summarised in Table 1.2 on the next page are estimated using

Table 1.2: Summary of Output — Maximum Likelihood Estimation

Variable	**Coefficient**	**SE**
ρ — spatial lag	0.178	5.99×10^{-4}
β_B — Brent	1.062	9.24×10^{-4}
β_D — duty	1.476	3.36×10^{-3}
Observations		476760
R^2		0.976
log(likelihood)		-1.36×10^6
Individual Fixed Effect		Yes
Time Fixed Effect		No

MLE method with individual fixed effects. The magnitude of coefficient ρ is similar to the average of non-zero entries in previously identified $\mathbf{W}$. This verifies the consistency of adaptive LASSO approach.

Due to the existence of spatial dependence, it is erroneous to interpret the coefficients β_B for Brent crude oil and β_D for diesel duty as marginal effects on own pricing. As discussed previously, the competition is both local and global. Any change in the market condition which stems from direct and indirect connections would result in direct and indirect effects to each location. Specifically, for coefficient β_B to Brent crude oil price, the average direct effect is equivalent to the mean of diagonal elements of $(\mathbf{I}_n - \rho\mathbf{W}^*)^{-1}\beta_B$, the average indirect effect is the mean of off-diagonal elements of $(\mathbf{I}_n - \rho\mathbf{W}^*)^{-1}\beta_B$. The total effect is hence the sum of both effects (Vega and Elhorst 2013). These also apply to diesel duty's coefficient β_D.

The indirect effect is due to the existence of spatial autocorrelation, that is, $\rho \neq 0$. The effect is also known as global spillover effect, as it falls on many locations. Even if the spatial weights matrix $\mathbf{W}^*$ contains many zero elements, $(\mathbf{I}_n - \rho\mathbf{W}^*)^{-1}$ will not.

In fact, Elhorst (2014) claims that global spillovers tend to go together with sparser spatial weights matrix. In this sense, while $\mathbf{W}^*$ gives the local competition relation, $(\mathbf{I}_n - \rho\mathbf{W}^*)^{-1}$hints the extrapolated competition at the global level. Therefore, the impact reaches farther locations, even if they are not directly dependent in space.

1.7 Conclusion

This paper adapts the spatial autoregressive model (SAR) introduced by Pinkse, Slade, and Brett (2002) to a panel setting in investigating the West Austrian fuel retail market. It covered 435 filling stations and examined their daily average diesel prices from July 2010 to June 2012.

The core component in the specification is the spatial weights matrix which summarises the spatial dependencies among all spatial units, that is, the filling stations. Instead of using predetermined weights, it employs adaptive LASSO method to make the process purely data-driven. The identified spatial weights matrix has some major differences with conventional matrices used widely in spatial econometrics applications. The identified spatial dependence implies competition is highly asymmetric and localised. The strategic interaction in pricing between competing filling stations is related to the degree of centrality for the location. A particular filling station is more likely to react to a central outlet than to a remote station. Also, with regards to the established station dependence, the physical proximity is irrelevant to the strength of price responsiveness.

The results have significant implications for joint ownership and mergers between

filling stations. Often, filling stations are members of a brand or a network of multi-station firms and their pricing behaviours are sometimes coordinated within the network. When the filling stations are subject to collusive behaviour, the results in this study indicate that the effects of coordination will depend on the centrality of the sites involved. Filling stations with more coordination control will have stronger effects on market equilibrium prices and social welfare.

The results also stress the need to investigate entry and exit decisions in the market. In contrast to the classic assumption that consumers and suppliers are distributed uniformly and symmetrically, the location of s supplier forms an indispensable part of strategic decisions in this framework. Entry and exit at a central location impact the global spillover effects and may alter the price transmission mechanism in the area.

There are several ways to apply the methodology and techniques in this paper. For example, the technique of identifying the spatial weights matrix can be used to describe spatial relations and define the local market boundary, which is often a prerequisite for abuse of dominance investigation and merger simulation in competition economics. Furthermore, rather than focusing on the geographical differentiability, it can also be applied to the discovery of relevant products which are differentiated by the characteristics of the products themselves rather than their location.

Chapter 2

Domestic Road Networks and the Intranational Transport of International Trade

2.1 Introduction

The costs of trade are the costs associated with the exchange of goods and services. Trade costs impede economic integration and alter patterns of production specialisation under a wide range of international trade models. Among many component drivers of trade costs, *distance*, which essentially means geographical separation, plays a persistent role. The cost of transport, among all the distance-related costs of the logistical goods delivery, appears to be one of the most salient. Consequently, transport costs not only increase with distance, they are also negatively associated with higher availability and the superior quality of infrastructure that covers the distance

in between. Such cost drivers include, but are not limited to, the accessibility and condition of roads, railways, and ports, as well as the density of the transport network.

Economists have been estimating trade gravity models for decades to empirically justify the negative association between distance and trade flows. However, only recently, the international trade literature has started to employ a more quantified measure of transport costs to examine their effects on trade. Most of the on-going research, however, focuses on the international transport costs and has largely ignored the effect of intranational transport costs.

Transport costs, however, do not emerge or disappear at the border. A typical cross-country shipment involves both domestic and international legs of the journey. Commodities to be exported are first transported within the country to an international gateway such as a seaport, an airport, a railway station, or a land crossing. For imported commodities, they continue their course on arrival at the gateway until they reach their final destination. Consequently, inadequate access to a country's international gateways from its place of production increases the operational costs of the whole process, which in turn leads to a higher price on the export market. Beyond a certain threshold, such price increments will undermine the comparative advantage of commodities and render them unviable for sale on the international market. Similarly, an import becomes more expensive after adding domestic shipping and distribution costs. Analogous to the effect of international transport costs, intranational transport costs can also hamper trade flows and distort trade patterns.

Research that focuses on international trade often substitutes actual trade distance with direct distance between two major cities in different countries. Even large

countries such as Canada and China are abstracted into dimensionless points. Such simplification naturally makes it impossible to distinguish between the domestic and international components of transport distance and related cost.

Nevertheless, it is intuitive to suggest that domestic transport costs negatively affect international trade in the same way international trade costs do. J. E. Anderson and Van Wincoop (2004) show that if we consider trade costs in the form of decomposed *ad valorem* tax rates, then the trade costs between industrialised countries is approximately 170% of the raw cost. Notably, international transport costs total 21% while the domestic transport cost is 55%, about 1.5 times larger. Limao and Venables (2001) found that overland transport cost is significantly higher than the sea segment based on the data for container shipping costs from Baltimore to 64 cities. Furthermore, some studies suggest that domestic freight costs vary considerably in line with the degree of accessibility and quality of the transport infrastructure. Atkin and Donaldson (2015) estimate that intranational trade costs in Ethiopia and Nigeria are about five times higher than in the United States. Based on the existing research, some international organisations, such as the World Bank and Asian Development Bank, have launched policy initiatives to improve some nationwide transport networks in developing countries. They claim that the inadequacy of transport infrastructure and the inefficiency of their logistics sector can severely attenuate the competitiveness of developing countries (World Trade Organization 2004; Asian Development Bank 2009; The World Bank 2009). The World Bank (2009) also states that domestic transport and trade facilitation is the 'largest and most rapidly increasing trade-related work.' All the studies and facts mentioned above highlight the

importance of disentangling and quantifying the internal transport component from the total international trade costs, as well as understanding its impact channel, to assess the trade-related benefits of transport infrastructure investment.

This paper therefore aims to explore the impact of domestic transport infrastructure improvements on intranational freight cost reduction and international trade flow expansion across China since the beginning of the 21st Century. Like many other developing economies, China's transport infrastructure has been undergoing tremendous development since 2000. The different networks in the transport sectors—roads, railways, air, inland waterways, ports, and logistics—have been substantially expanded and improved to meet the growing demands of transport services. A steady flow of related investments buttresses the upgrading works. A report by The World Bank (2007) reviewed the annual investment in transport fixed assets in China from 2000 to 2006. In 2000, the total annual investment was $41.5 billion (US Dollars). Since then it has increased consistently each year to reach more than double this amount in 2006 ($103.41 billion). The primary investment has been in highway construction and the composite proportion has continued to increase over time. In 2006, highway construction accounted for nearly 90% of total transport infrastructure. As a result of large-scale investments such as these, the total length of road in China has increased from 1.4 million (2000) to 3.5 million (2006) km, with the overall quality of the road system improving considerably. The length of the best quality expressways has increased threefold from 16,000 to 45,000 km in 2000–2006.

However, the effects of the nationwide expansion and the upgrading of the transport network systems across regions were not homogenous. The projects affected

China's regions in different ways depending on where they took place. Connectivity to the international gateways improved in some regions more than others. To fully explain such variation, international trade flows in this study are disaggregated to regional level based on export origins or import destinations.

Preliminary exploration indicates that investment in road infrastructure reduced transport costs and thus contributed to the expansion of export and import trade flows. Furthermore, using the baseline estimate, it is also possible to generate the cost for domestic shipping over the road route distance in the dataset. More specifically, *ceteris paribus*, the cost of an average-distance shipment over 1374 km (the average cross-regional distance in China) would fall by about 90% if the road along the entire route were upgraded from low-quality to high-quality. The estimates also imply that each dollar invested on road infrastructure leads to a 15-year stream of trade flows worth between \$0.97 and \$1.96 in present value. Finally, when exploring trade in different sectors, sectors produce more time-sensitive products have enjoyed greater trade expansion in terms of both intensive and extensive margins. This result constitutes a plausible impact channel for the aggregate response of regional trade and strengthens the previous identification. The estimation is also robust in comparison to alternative model specifications and estimation methods.

Some more recent research studies highlight the prevalence and importance of issues relating to the domestic segment of transport costs, which is also the main concern of this paper. For example, Coşar and Fajgelbaum (2016) illuminate the regional specialisation pattern in export-oriented industries located close to seaports in China. Allen and Arkolakis (2014), on the other hand, use a spatial model of trade

with real topographical features to estimate the rate of return to the US Interstate Highway System. From a more historical perspective, Donaldson (2018) and Donaldson and Hornbeck (2012), analyse the welfare effects of railroads in India and the United States, respectively. This paper complements these studies by providing more detailed evidence on how nationwide public investments in transport infrastructure in China affects transport costs.

Meanwhile, this paper contributes to an estimation of the effect of transport infrastructure on international trade and sectoral productivity. Several research studies on such effects have already been conducted. Most of these are based on cross-country data. For instance, Limao and Venables (2001) and Yeaple and Golub (2007) both found that the availability of public infrastructure, including roads and railways, is an important determinant of trade costs, bilateral trade flows, and comparative advantage. Country-level studies are also widely available in the literature. For instance, Martincus and Blyde (2013) estimated the response of firm-level exports to geographical variation in access to main ports. Albarran, Carrasco, and Holl (2013) found that an improved transport infrastructure had a positive impact on the probability of exporting among small and medium-sized firms in Spain. Powell (2013) explores the importance of domestic transport infrastructure for regional exports in several Latin American countries. Finally, Coşar and Demir (2016) quantified the impact of a large-scale public project to improve the quality of the road network in Turkey. This paper complements these studies by proposing different measures of network quality and accessibility and an identification method for estimating its effect on trade volume and composition. Additional investigation also highlights the importance of

alternative impact channels through which transport infrastructure can exert effects on trade. The results of this exploration supplement those of previous findings and have implications for industrial, commercial, and trade policies.

A caveat to be warned here is that the analysis does not take account of traffic congestion induced by highway improvements. Traffic congestion has traditionally been addressed by expanding roadway capacity via constructing entirely new roads, adding additional lanes to existing roads, or upgrading existing highways. Many studies have examined the effectiveness of this approach to alleviate traffic congestion, and consistently conclude that it is not very effective to alleviate congestion in the long run. This is mainly due to the induced travel because of the lowered travel cost, and it counteracts the effectiveness of capacity expansion. However, this mechanism is not explicitly modelled in this study.

The rest of the paper proceeds as follows; Section 2.2 assesses the state of the transportation network and related public investment projects in China from 2000 to 2006. Section 2.3 describes the available datasets and summaries the results of the preliminary analysis. Section 2.4 outlines the empirical specifications and presents the estimates and statistics arising from the baseline model. This section also incorporates additional robustness checks by varying modelling components, including additional controls, applying different specifications, and using alternative estimation methods. Section 2.5 then presents the conclusions arising from this research.

2.2 Background Information

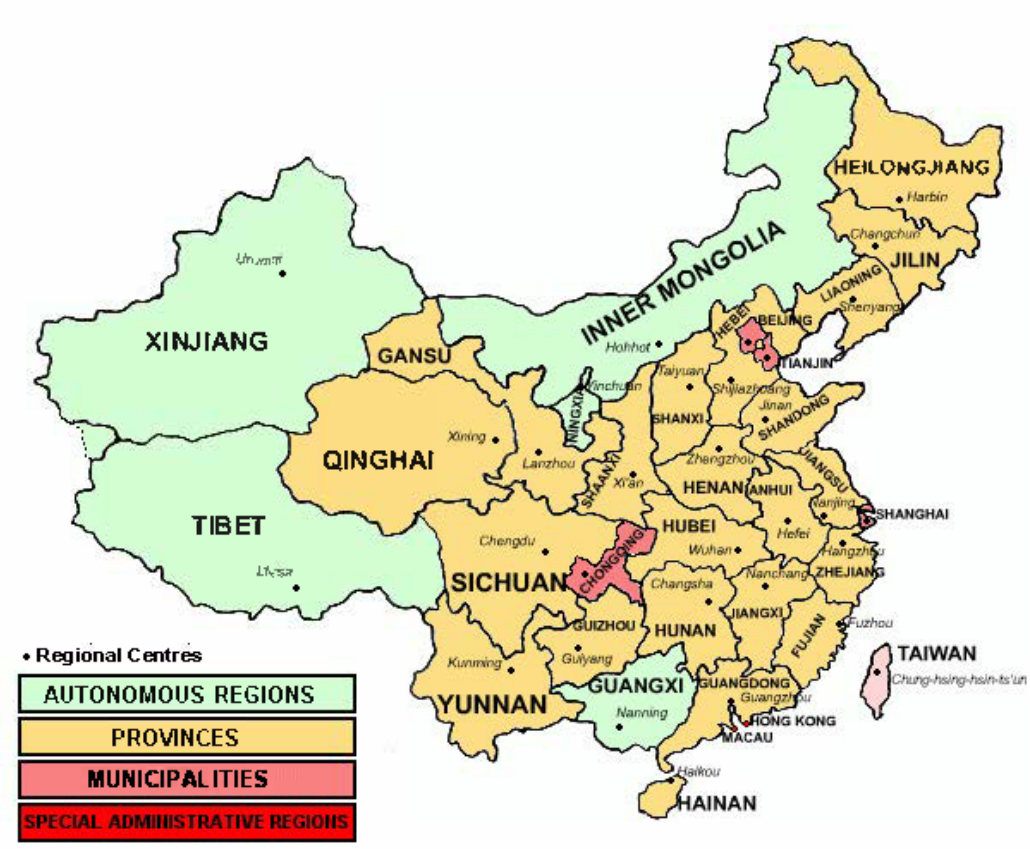
2.2.1 The Development of China's Transport Network

China has a diversified economy and the world's largest population (1.379 billion as of 2016). According to the IMF, the country is the world's second-largest economy by nominal GDP and the world's largest economy by purchasing power parity. China has been a member of the WTO since 11 December 2001. It is the largest exporter and the second-largest importer of merchandise goods by value (including intra-EU trade) (World Trade Organization 2016).

The country is divided into 34 regions, which are the highest-level administrative divisions. Formally, the People's Republic of China consists of 23 provinces (including Taiwan), four municipalities, five autonomous regions, and two Special Administrative Regions (SARs). Hong Kong and Macau, the two SARs, as well as Taiwan, maintain separate political and economic systems from the rest of China. This study excludes trades to and from these three areas—Taiwan, Hong Kong and Macau—and thus focuses on the other 31 regions. Figure 2.1 illustrates these regional boundaries and centres.

In terms of an overland transport network, China's road system is classified into six categories based on its technical standard. The categories are Expressway, Class I, Class II, Class III, Class IV, and Others (Asian Development Bank 2013). The technical details, such as road width, clearance height, and designed speed range are summarised in Table 2.1. In this paper, the top three categories—Expressway, Class I, and Class II— are grouped together and treated as high-grade classes. The

Figure 2.1: Administrative Divisions of China



Source: 'Administrative Divisions of China' http://www.gov.cn/

Table 2.1: Classification of Road in China

Classification	**Width (m)**	**Height clearance (m)**	**Designed Speed (km/hr)**
Expressway	28.0	5.0	$60 - 120$
Class I	25.5	5.0	$60 - 100$
Class II	12.0	5.0	$40 - 80$
Class III	8.5	4.5	$30 - 60$
Class IV	7.0	4.5	$20 - 40$

Source: 'People's Republic of China Road Classification Information', Asian Development Bank

remaining three are classed as low-grade.

Several characteristics of China's geography and the country's transport network suggest it is especially pertinent for the purposes of this investigation. Firstly, road transport is the primary mode of freight transport in China. It has contributed significantly to, and has also been strongly stimulated by, China's continuing economic development. Road freight transport has dominated overall freight traffic since 1990. From 2000 to 2006, over 74% of total freight traffic in China consisted of road freight and this proportion remained stable in recent years.

Additionally, before 1990, there was no highway system between Chinese cities, and almost all goods were transported by rail or river with less than 5% of freight ton-miles moved by road. From 1990 to 2006, China constructed $45,000$ km of high-grade tolled expressways following a series of social and economic development initiatives. These later became the National Trunk Highway System (NTHS). During the period, approximately $400,000$ km of local and township roads were upgraded (The World Bank 2007). Under the coordinated efforts of the central government and local gov-

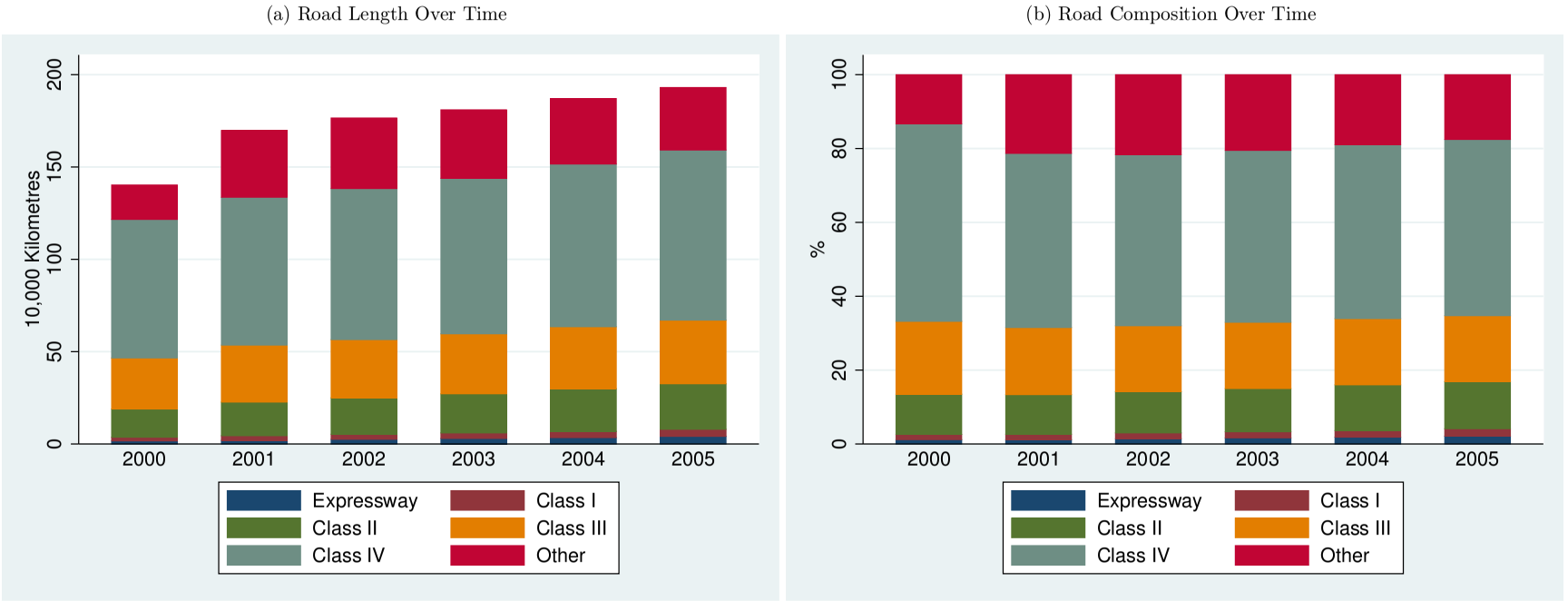
ernments, the construction of the expressway network was also complemented by the continuing development of both first and second-class roads.

Total road lengths, together with their main components in the period 2000–2005 are presented in Figure 2.2a and Figure 2.2b. It is important to note that, starting in 2006, town and village road length began to be included in the statistics for total mileage. Hence, due to the incompatibility of these figures with the remainder of the dataset, 2000–2005 statistics are presented. For comparison, aggregated national data on railway lengths are summarised in Table 2.2. As the figures show, total road length grew steadily over this period. Notably, the length of high-grade road (Expressway, Class I, Class II) also increased from 2000 to 2005. The road transport network therefore not only expanded and became more accessible in terms of total road length, it also underwent quality and capacity upgrading during this period regarding the share of high-grade road. This two-fold development suggests that the measurement of transport cost in this study needs to incorporate improvement in both aspects.

The NTHS is the most important component and backbone of the national road transportation network. By 2005, approximately $44,000$ km of the NTHS had been completed. This has facilitated direct connection between regional centres and over a hundred cities with populations exceeding $500,000$.

External evidence also highlights the success of the development of China's transport network. The Global Competitiveness Index, published annually by the World Economic Forum since 1988, evaluates the competitiveness of 138 economies and includes a direct assessment of the quality of countries' roads and railroad infrastructure

Figure 2.2: Road Length and Composition in China from 2001–2005



Source: 'China Statistical Yearbook of Communication and Transport (2000–2006)' National Bureau of Statistics of China

Table 2.2: China's Ground Transport Network—Stock and Composition

Year	**Road**	Expressway	Class I	Class II	Class III	Class IV	Other	**Rail**
2000	140.27	1.63	2.01	15.27	27.67	75.03	18.67	1.00
2001	169.80	1.94	2.52	18.21	30.86	80.07	36.20	1.10
2002	176.55	2.51	2.77	19.71	31.51	81.80	38.23	1.24
2003	180.98	2.97	2.99	21.19	32.48	84.24	37.11	1.26
2004	187.07	3.43	3.35	23.17	33.53	88.10	35.48	1.34
2005	193.05	4.10	3.84	24.64	34.47	92.13	33.88	1.32

Unit: in 10,000 km

Source: 'China Statistical Yearbook of Communication and Transport (2000–2005)' National Bureau of Statistics of China

for comparison across time and space. Scores denoting the quality of roads and rail infrastructure are explicitly provided. These are based on large-scale survey studies with options ranging from 1, 'underdeveloped and poorly maintained' to 7, 'extensive and well maintained.' In 2000, China scored 3.2 on the road index, and 3.6 on the railroad index (World Economic Forum 2000). In 2006, the road index improved significantly to 4.0 while the railroad index increased sightly to 3.8 (World Economic Forum 2006).

No other country in the world was able to develop an extensive traffic system within such a short period. Decentralisation might have been a key driver for China in the successful delivery of road network improvements in the 2000s. During this process, the Chinese Ministry of Communications (MOC) provided general guidance and technical support in the form of a blueprint, national policies, regulations, and work standards for the roads sub-sector. At the same time, Provincial Communications Departments (PCDs) were responsible for carrying out detailed planning, development,

and maintenance of the road networks within their administrative regions. During this period, the regional governments received limited funds from central government, unless the project had a high profile at a national level. Regional road projects were mainly financed from local government budgets, expressway tolls, road user charges, loans, and bonds.

Policy documents explicitly state that the programme's aim is to ensure the integrity of the national network and the goal by 2020 is 'to reach more than 1 billion people in China by connecting all regional centres and large cities of more than 500,000 inhabitants with cities of more than 200,000 inhabitants.' Increasing international trade in backwater regions was neither an explicit nor main goal of the programme. Nevertheless, it will be shown in this paper that a more extensive and higher quality road network increases overall international trade and may be viewed as an observable external shock to the cost of domestic freight transport at a domestic level. The road network was not intended to, and in fact, did not divert trade from one region to another in general. Concerns about the endogeneity problem are to be addressed further in ensuring empirical investigation.

2.2.2 China's International Trade Expansion

China became a member of the World Trade Organisation (WTO) in 2001. Since then, its exports and imports have grown at a phenomenal pace. According to the National Bureau of Statistics of China, the value of Chinese exports and imports more than tripled from 2001 to 2006. The annual growth rate over this period was

approximately 25%. In 2006, imports totalled $791 billion, and exports totalled $969 billion, which was equivalent to 35% of China's GDP at that time (World Trade Organization 2006).

However, growth rates within the country varied significantly. Gansu experienced the highest average annual growth rate in imports at 51%, in contrast, Tibet's grew by only 0.03%. Regarding exports, the variation among the regions was generally smaller. Xinjiang achieved the highest average annual growth rate of 45%, while Hainan experienced the slowest expansion of exports at a rate of 11% (National Bureau of Statistics of China 2012).

The export expansion concentrated in specific sectors, for example, textiles, metals, and machinery, and occasionally dominated by the grow of certain products. Expansion in imports was also not uniform as capital goods imports growth exceeded that of intermediate goods.

No single theory can explain the surge in China's trade expansion. General explanations such as China's exchange rate policy did play a role, but they failed to explain the imbalance in development in different sectors. However, although it is beyond the scope of this paper to comprehensively probe the underlying causes, it will endeavour to establish a link between China's trade boom and the development of its road network.

2.3 Data and Preliminary Analysis

2.3.1 Data

Data on region-level imports and exports for the period 2000–2006 were obtained from the Harmonized Commodity Description and Coding System (HS)-based China Customs Import and Export Data (CCD), which contains over 6900 8-digit commodity subdivisions in 22 Sections and 98 Chapters (UN Trade Statistics 2002). The HS is a multipurpose international product nomenclature developed by the World Customs Organisation (WCO). The codes in HS are logically organised by economic activity or component material. The first two digits refer to the chapter the product belongs to. The following sets of four and six digits give the heading and subheading of the goods, which describe them in more detail. The 8-digit code gives further information about the product. Chapters are arranged in order of a product's degree of manufacture or its technological complexity. The same rule also applies to the arrangement of the headings within each section. The HS classification is also concordant with the Standard International Trade Classification (SITC).

This dataset is derived from the General Administration of Customs of the People's Republic of China's official import/export declaration records. The records are documented for the intended use of handling customs imports and exports for China at regional ports. The data are aggregated on a yearly basis. Each import/export entry contains information regarding the product's HS Code, content description, unit, and value in US Dollars along with a breakdown of the import's destination/export's origin, the port at which the goods are declared, and the international transport

modes. Additionally, imports are valued on a CIF (cost, insurance, and freight) basis while exports are valued on a FOB (free on board) basis.

As noted earlier, a total of 31 regions are to be investigated, which includes 22 provinces, four municipalities, and five autonomous regions. China also runs customs clearance operations at 41 local ports. All the regions have at least one port, while some well-developed trade active regions have two or three ports. Customs declaration is mandatory in China whenever goods enter or leave the nation's borders. Therefore, the dataset that will be used contains integrated information on all international trade in a legitimate form.

Accordingly, the gateway is considered the first entry point for imports, and the final exit point for exports. In this sense, each regional port can be treated as an international gateway. Information regarding the shipments also makes it possible to aggregate the data at different levels of granularity. For the purpose of exploring the domestic component of international trade flows, the highest level of aggregation is that of the region–gateway–year. In this respect, each data-point gives the annual value of imports travelling inbound through the gateway to the destination region or exports from the region of origin travelling outbound through the gateway. Unfortunately, information on overseas origin/destination countries is not available in the dataset. This shortcoming is mitigated by dividing the data more finely regarding the mode of transport of goods. The mode of transport that is declared is the actual transport method used for the carriage of goods in (for imports) and out of (for exports) gateway customs. The specified transport modes given in the dataset are divided into six categories according to the shipping route and method, namely,

waterway, road, railway, air, mailing, and others. The first four are self-explanatory, however 'mailing' refers to small-scale trade activities at a personal level, where the goods are handled by post offices. The 'other' modes include other channels, such as pipeline transport.

The gateways are constrained to certain modes of transport. For instance, at an inland gateway, it is impossible to send or receive goods transported by waterways. Likewise, a gateway with limited access to an international airport would have few air-freight records. The far-reaching significance of information on international transport modes is that they provide valuable information about the gateway's trading partners. As mentioned by Behar and Venables (2011), the choice of transport model is primarily a trade-off between higher monetary transport costs and faster journey time. Researchers have been able to derive measures of the value of time saved in transit by comparing the freight costs of alternative transport modes with journey times. This line of thought can also be applied to gateway choices. Given two very similar trades that differ only in the choice of gateway–transport mode, it can be argued that shippers will be largely indifferent as to which option they choose. The dataset, however, does not include any information on the trading partners of these Chinese firms. Nevertheless, this problem is mitigated to a certain degree by considering 'the rest of the world' as one combined economic entity and assigning each gateway-transport mode a different distance. The term 'distance' has a broader meaning here than just physical distance, as it also incorporates the cost of transit time. Because the raw data contains the HS code and a detailed description for each group, it is possible to further divide the set by sectors, using the first 3-digits

from the HS classification. The disaggregated levels also facilitate an exploration of changes in different sectors to examine the impact channels.

Key descriptive trade statistics from 2001 to 2005[1] are presented in Table 2.3 on the following page. As imports and exports are valued using different measures—CIF and FOB—the total trade flows are not aggregated for feature-by-feature comparison. As trade flow statistics in the top panel suggest, exports and imports both increased substantially between 2001 and 2005, regardless of observation unit and level of granularity. The number of gateways through which the regions trade and the number of industry sections in which they trade both exhibit an upwardly evolving tendency from 2001 to 2005. Records show that the domestic transport channels of international trade have increased at both intensive and extensive margins. However, it is notable that the average number of transport modes that were utilised did not change greatly from 2001–2005. Such stability may indicate that all regions already had adequate access to all international transport modes through gateways and utilised almost all possible transport modes at the beginning of the 2000s.

It is important to note that geographical distance is not the only factor for exporters and importers in making gateway choices. The data showed that international gateways have their specialisation in industries and transport mode. An overwhelming majority of trade in some industries use a specific transport mode and go through a single gateway. From 2001–2005, this pattern underwent substantial change. For instance, in 2001, almost all mineral product imports transported by air came through

[1]Chongqing municipality has shared the port with Sichuan province until late 2000. Hence, it was not until 2001 that Chongqing municipality's trade flow was fully documented and separated from that of Sichuan Province. Due to the inconsistency in statistics, data for 2000 are excluded.

Table 2.3: Summary of Trade Flow Statistics

Trade flow statistics (in US Dollars)								
	R–G		*R–G–T*		*R–G–I*		*R–G–I–T*	
	Mean	**Std**	**Mean**	**Std**	**Mean**	**Std**	**Mean**	**Std**
$\Delta \ln(exports)$	1.05	1.63	1.06	1.96	1.01	2.12	0.98	2.21
$\Delta \ln(imports)$	1.09	2.21	0.77	2.23	0.85	2.59	0.66	2.48
Extensive margin (per region #)								
	2001				2005			
	Mean	**Std**	**Min**	**Max**	**Mean**	**Std**	**Min**	**Max**
Gateways, *Exports*	30.00	6.50	11	39	32.74	5.56	19	39
Gateways, *Imports*	23.13	5.56	6	41	25.42	7.73	10	41
Industries, *Exports*	20.81	1.17	18	22	21.29	1.32	18	22
Industries, *Imports*	19.83	1.98	14	22	19.94	1.98	15	22
Transport, *Exports*	5.61	0.62	4	6	5.58	0.67	4	6
Transport, *Imports*	5.74	0.51	4	6	5.81	0.60	3	6

Beijing gateway; this total dropped to less than a quarter four years later. The pattern shift is a mixed result of shifting demand and supply, changing logistics technology, and the transport network system. These factors combine to induce substantial increasing returns to scale for some sectors in some regions. Apropos to this, it is therefore important to analyse all existing and newly formed region–gateway trade links and investigate the variations in specialisation patterns over time.

Data on the stock and composition of the ground transport network from 2001 to 2005 at a regional level are extracted from the China Statistical Yearbook of Communication and Transportation (volumes 2002–2006) published annually by the National Bureau of Statistics of China. The yearbooks contain exact information on the total length and classes of all roads and railways within the regional boundaries.

Unfortunately, there is no detailed information concerning the exact location of

the numerous network development programmes. The data on road stocks are only available at a regional level. Consequently, the exact road segment between the nodes of cities, or within a regional boundary, in which the actual expansion and improvement have taken place is not identifiable. However, as the trade data are at the same level of aggregation, and the exporters and importers are widely spread within the regional boundaries, this should not be an issue in this study.

The accessibility of a gateway to a certain region needs to be quantified to measure the improvement in the transport network throughout the study period. The disparity between a region r and a gateway g that is not in the region r is defined by the geographical distance (d_{rg}) between the regional centre and the gateway. Despite some gateways exhibits specialisation patterns in exports or imports, it is notable that, like the 'home effect' in international trade, regions usually have relatively more freight pass through their local gateways. For instance, in both 2001 and 2005, approximately half of Shanghai's imports and exports were declared at the local gateway. Therefore, a modified measurement of distance must be adopted to accommodate such cases.

In previous studies, different methods have been used to calculate the distance between economies. As well as complicated geometric approximations and disks with production or transport hub methods, fractions of distances to the centres of the nearest neighbour have been adopted by many studies. This is regarded as 'the best first attempt to an intrinsically difficult problem' (Head and Mayer 2002). There is, however, no consensus as to what the exact fraction should be. For this study, R. Wolf (1997) and P. R. Wolf and Dewitt (2000)'s fraction of one-half is used, in that within-unit distance is approximated by multiplying the distance to the nearest

neighbour by 0.5.

In traveling from a region r to a gateway g, the associated route is represented by J_{rg}. J_{rg} is a set of regions that need to be travelled through on the direct route. The set for the route includes both the origin and the destination regions. Due to symmetry, the distance from a gateway g to a region r is the same as the distance between the region r and the gateway g. This also applies to the associated route. Therefore, $d_{gr} = d_{rg}$ and $J_{gr} = J_{rg}$. In the special case where region r trades through its local gateways, the route set is denoted as J_{rr}, which contains only one element, namely, r itself. To obtain all route sets in practice, neighbouring relations of regions are represented as a 31×31 symmetric adjacency matrix with zeros on the diagonal. The value of the element a_{ij} is 1 if region i and region j are bordered, and 0 if they are not. The geographical distance between region i and j (d_{ij}) is used as the weight for the corresponding element when performing the shortest path search on the adjacency matrix. The gateways are then mapped back to their respective region to convert the sets from region–region level to region–gateway level.

Due to fixed geographical locations, the notations defined above are time-invariant. However, as road accessibility and quality change over time, a subscript t is included to represent a specific period of time. Moreover, in the following section, the lower-case notations denote variables at the local level while uppercase notations indicate variables at the route level.

Road density measures the coverage and accessibility of the road network. For a given region r, the road density at time t (ρ_{rt}) is calculated as the ratio between the length of the total road stock within the regional boundary at time t ($road_{rt}$ in km)

and the area of the region ($area_r$ in km^2). At the route level, the road conditions in all regions en route are taken into account. Hence, the counterpart measurement of road density for a route J_{rg} at time t is defined as:

$$P_{rgt} = \frac{\sum_{i \in J_{rg}} road_{it}}{\sum_{i \in J_{rg}} area_i}, \tag{2.1}$$

in which $road_{it}$ is the road length in region i at time t and $area_i$ is the total area of region i.

Accompanying the expansion of the road network, the quality of the roads has also been improved substantially following the completion of numerous related projects which mostly involved converting lower-graded roads to ones of a higher standard. Therefore, the high-grade road share—Expressway, Class I, and Class II—is used as a proxy to measure the quality of the road network. Thus, the proportion of high-grade road in region r at time t is represented as $hs_{rt} = \frac{exprss_{rt}+I_{rt}+II_{rt}}{road_{rt}}$, where $express_{rt}$, I_{rt}, and II_{rt} denote the lengths (in km) of the road as classified as Expressway, Class I, and Class II respectively in region r at time t.

To obtain the parallel measure at the route level, the regional high-grade road shares must be aggregated. There are several ways to index the quality of the road links between a region and a gateway. Firstly, the minimum high-grade road share to one of the regions en route can be applied. This measurement is based on the assumption that moderately risk-adverse shippers will avoid regions with extremely poor road conditions. The other options are shares averaged in varying ways. Alongside the simple average, the distance or area weighted averages are applicable too.

The area of an individual region varies greatly from 6,340 km^2 (Shanghai municipality) to 1,664,900 km^2 (Xinjiang). To allow for this disparity, the area-weighted quality measure is the most appropriate one to use in this context. Mathematically, the quality of the route from r to g at time t is denoted by:

$$HS_{rgt} = \sum_{i \in J_{rg}} (w_i \times hs_{it}), \tag{2.2}$$

where $w_i = \frac{area_i}{\sum_{i \in J_{rg}} area_i}$, provides the given weight according to the area of region i and does not change over time. Again, by symmetry, $HS_{rgt} = HS_{grt}$. Table 2.4 on the next page displays summary statistics on the road network system at both region and route levels. It reveals the whole picture over that period, including the fact that indicators of road density and quality increase steadily at both regional and route levels, signalling the continuing expansion of the network and upgrading of road conditions. The average distance from a regional centre to a gateway is 1374 km, and a representative route passes through four regions. Notably, the route level road density is lower than in the regions, suggesting that some larger rural areas, such as Tibet and Xinjiang in China, have more limited access to the road network.

A further investigation into the period changes in the regional road scale, where $\Delta road_r = road_{r,2005} - road_{r,2001}$, and the improvement in road quality, as $\Delta hs_{rg} = hs_{rg,2005} - hs_{rg,2001}$, is presented in Figure 2.3a and Figure 2.3b on page 80. The figures map the changes to their exact geographical location in each region. The darker the shade, the larger the change. Both heat maps exhibit considerable variation without any significant clustering pattern in any area. This evidence at a regional

Table 2.4: China's Road Transport Network—Region and Route Summary

Region Statistics—number of observations: 31								
Year	$area_r$ (in km^2)		$road_{rt}$ (in km)		$road_den_{rt}$ (in km/km^2)		hs_{rt}	
	Mean	**Std**	**Mean**	**Std**	**Mean**	**Std**	**Mean**	**Std**
2001	3.11×10^5	3.87×10^5	5.48×10^4	3.29×10^4	0.35	0.24	0.14	0.07
2005	3.11×10^5	3.87×10^5	6.23×10^4	3.45×10^4	0.42	0.28	0.18	0.09

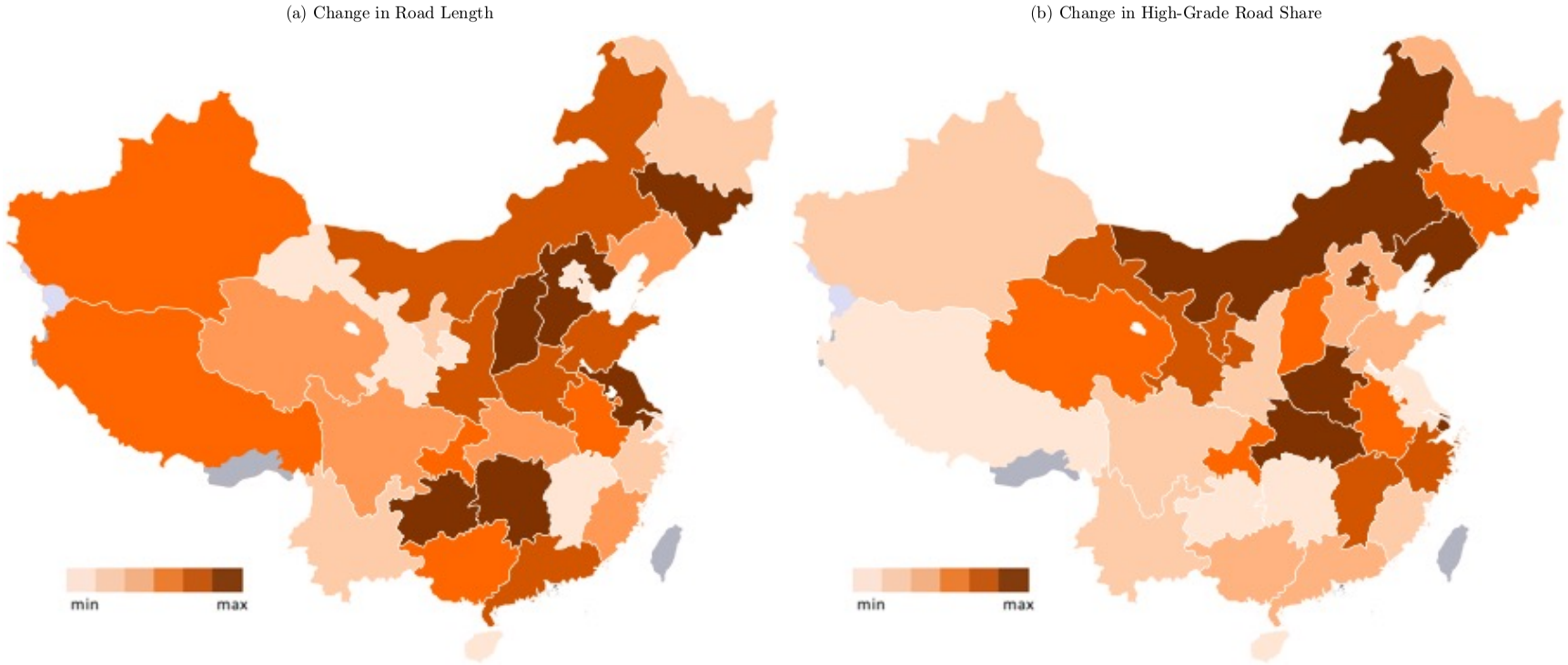
Route Statistics—number of observations: 1271								
Year	# of regions		d_{rg} (in km)		$ROAD_DEN_{rgt}$ (in km/km^2)		HS_{rgt}	
	Mean	**Std**	**Mean**	**Std**	**Mean**	**Std**	**Mean**	**Std**
2001	3.94	1.50	1374.02	747.82	0.30	0.14	0.14	0.05
2005	3.94	1.50	1374.02	747.82	0.35	0.16	0.17	0.06

Source: 'China Statistical Yearbook of Communication and Transport (2001 and 2005)' National Bureau of Statistics of China

level shows that roadwork projects have spread nationwide without targeting any specific areas from 2001–2005 and thus the concern about endogeneity can to some extent be relieved.

On the route level, the corresponding measurements of changes against initial values are plotted in Figures 2.4a and 2.4b on page 81. The x axis denotes the 2001 levels of road density and high-grade share in roads connecting regions and gateways, that is, $P_{rg,2001}$ and $HS_{rg,2001}$. The y axis denotes the relevant period changes in these variables, that is, $\Delta P_{rg} = P_{rg,2005} - P_{rg,2001}$ and $\Delta HS_{rg} = HS_{rg,2005} - HS_{rg,2001}$. Both plots reveal positive associations to some extent. Routes whose initial connections were stronger have experienced slightly better development in both constructing new roads and upgrading existing ones.

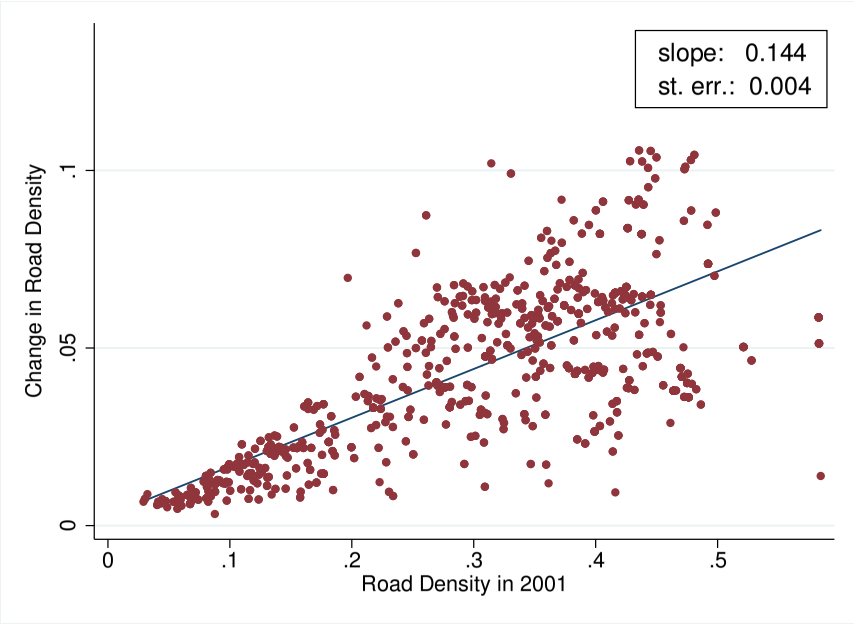
Figure 2.3: China's Regional Road Network Expansion and Quality Improvement from 2001–2005



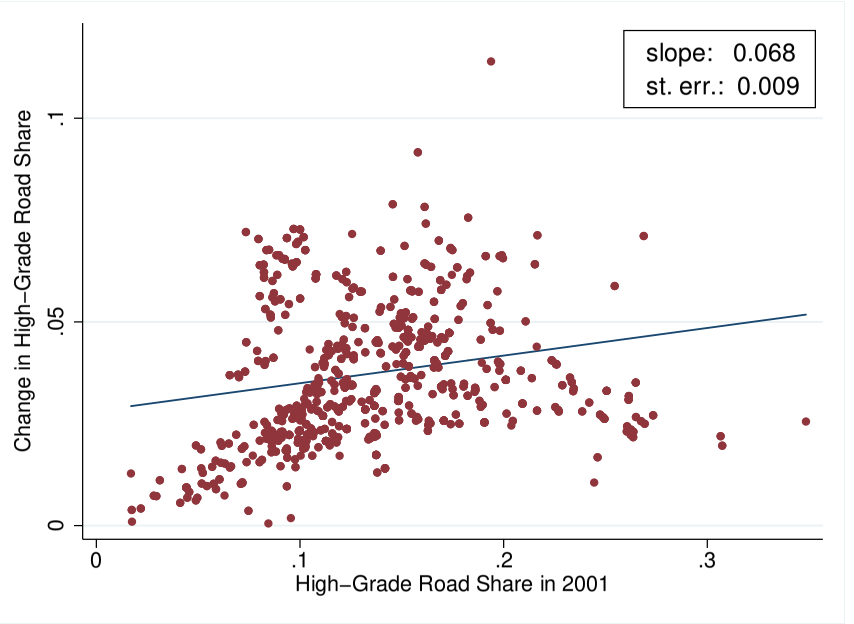
Source: 'China Statistical Yearbook of Communication and Transport (2001 and 2005)' National Bureau of Statistics of China

Figure 2.4: China's Route Network Expansion and Quality Improvement from 2001–2005

(a) Change in Route Road Density



(b) Change in Route High-Grade Road Share



Source: 'China Statistical Yearbook of Communication and Transport (2001 and 2005)' National Bureau of Statistics of China

2.3.2 Preliminary Analysis

The ideal dataset that could be used to study the relationship between domestic trade flow and overland transport system would include trade statistics between cities with details on transport modes and routes as well as clearly documented transport work programmes containing node to node information. Comprehensive information such as this, however, is typically not available for most countries. Examining internal segments of export and import shipments allows for an estimation of how trade flows are generally affected by ground transport infrastructure. In case of exports, the 31 regions can be treated as 'origins', and the 41 gateways as 'destinations'. For imports, the reverse is true. The trade data is adequate for a simple gravity model, which since its introduction in Tinbergen (1963), has been widely used in empirical work to estimate the impact on bilateral trade flows of a host of frictions.

The gravity model typically relies on three factors: origin specific variables that characterise the ability of all en route regions to produce or generate trade flow; destination-specific variables that capture the trading potential of destination locations; and a set of variables that reflect how the spatial separation of origins from destinations constrains or impedes trading interactions (M. M. Fischer and Wang 2011). In its simplest form, the gravity model assumes that bilateral trade is directly proportional to the economic size of both the origin and destination. Furthermore, it can be observed from the data that 'attraction' is negatively related to distance. Therefore, in the simple linearised gravity model adopted in this paper, trade flow between a region r and a gateway g at time t can be expressed as:

$$\ln T^f_{rgt} = \varphi^f_{rt} + \varphi^f_{gt} + \beta \ln d_{rg} + \epsilon_{rgt}, \tag{2.3}$$

where T represents trade flow in levels, $f \in \{e, i\}$ denotes whether the trade flow is outward (e for export) or inward (i for import), and φ^f_{rt} and φ^f_{gt} are time-variant region and gateway specific features concerning the demand and supply for trade products.

These location-specific features encompass various factors. For example, in the export scenario, these features would capture the origin's ability to create trade. Regional economic size and production specialisation pattern are among those factors. At the same time, accessibility to the rest of the world, and the trading potential with certain countries are incorporated into the specific features of the destination gateway. Most importantly, the factors vary over time. Developments in production technology, better facilitation of logistics chains, and seasonal or cyclical trend will all impact these factors. Therefore, the subscription t is included to indicate the timeliness of the features. The regional specific features are akin to their counterparts in international trade gravity model estimation. However, the decomposed effects of the numerous factors are not the focus of this study, therefore only the aggregated effects are considered. The distance variable d_{rg} as explained above, is the geographical distance between the region r and the gateway g.

Furthermore, the application of the gravity model must be able to to deal with multilateral resistance terms, which refer to the barriers each location faces in their trade with all their trading partners. Although multilateral resistance terms can-

not be observed directly, they can be estimated by including fixed effects. Feenstra (2015) expresses a preference for this method, as it is easy to implement and provides consistent estimates of the average effects. The inclusion of location specific features also serves this purpose. The coefficient β is associated with the distance elasticity of trade flows, revealing the extent to which geographical separation impedes trade.

There are 41 customs as gateways and 31 regions in total, so the potential data-point number regarding both imports and exports is 2542 for each year. However, not all regions and gateways 'trade' with each other during the study period. Nevertheless, many new trade links have been established, as the actual number of trade flow observations increases from 1647 in 2001 to 1845 in 2005, which is a manifestation of the extensive margin expansion. On the other hand, some regions and gateways ceased trading. Yunnan province serves as a good example to illustrate this range of scenarios. The province neither imported or exported goods from the Taiyuan gateway in Shanxi province from 2001 to 2005. It started to import from the Shijiazhuang gateway in Hebei province in 2005, while ceasing to importing from the Fuzhou gateway in Fujian province at the same time.

The conventional way to derive the distance elasticities of trade flows is to apply Ordinary Least Squares (OLS) estimation methods to a log-linearised gravity equation. However, only positive trade flows can be utilised. Taking logarithms of zero observations effectively removes them from the sample as the log of zero is undefined. The drop in observations leads to a loss of information. Furthermore, using the truncated samples in logarithms may sometimes yield misleading results. An alternative and theoretically sound approach to solving the zero trade problem could be the use

of a Pseudo Poisson Maximum Likelihood (PPML) estimator (Shepherd 2013). This method is applied to the levels of trade, and therefore estimates the non-linear form of the gravity model directly, avoiding the drop of zero trade. The dependent variable is the value of trade, while the explanatory variables remain in log forms. Silva and Tenreyro (2006) highlight the fact that under weak assumptions—essentially that the gravity model contains the correct set of explanatory variables—the PPML estimator provides consistent estimates of the original model. Moreover, they advise that in any case, PPML results should always be presented for comparative purposes or as a robustness check.

The distance elasticity of trade flows is estimated separately at the beginning (2001–2002) and at the end (2005–2006) of the period studied. Table 2.5 on the following page presents the results of the gravity estimates. Home shipments from the local gateways are also included, with the distance measure modified as one-half of the distance from the nearest neighbour, as noted previously. The first two columns in the table present the OLS estimates which are based on positive trade flows. The PPML method makes full use of the whole sample, and the results are given in column (3) and (4). As Table 2.5 shows, the OLS and PPML estimates generate similar numerical results for both samples. When comparing across the samples, the distance elasticity diminishes in absolute value over time, regardless of the estimation method adopted. More importantly, the OLS and PPML estimated coefficients are remarkably similar, implying that the adoption of OLS estimates does not result in a misleading interpretation.

The decreased magnitude of the distance elasticity over the years implies some

Table 2.5: Gravity Estimation Results

	(1) $\ln T^f_{rg}$	(2) $\ln T^f_{rg}$	(3) T^f_{rg}	(4) T^f_{rg}
$\ln d_{rg}$	-2.395^{***}	-2.386^{***}	-2.437^{***}	-2.365^{***}
	(0.070)	(0.071)	(0.083)	(0.082)
Regression	OLS	OLS	PPML	PPML
Observations	1647	1845	2542	2542
R^2	0.70	0.70	0.98	0.98
Fixed Effects	r-f, p-f	r-f, p-f	r-f, p-f	r-f, p-f
Period	2001—02	2005—06	2001—02	2005—06

Robust Standard errors in parentheses
Significance $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$
Notes: All regressions are estimated with region-flow(r-f) and gateway-flow(g-f) fixed effects, in which flow is either import (i) or export (e).

reduction in the domestic segment of trade costs as geographical distance is constant over time, despite the limited scope of this study such that the relationship between road congestion and road quality is not explicitly modelled. The upgraded road system may, on the one hand, reduces the travel time, however, if too many vehicles choose to take the route due to the anticipated shorter travel time, it may cause traffic jam and adversely affect the travel time. Indeed, the finding of relatively small reduction in the distance elasticity over time is in line with many results from gravity models applied to international trade. Nevertheless, the consistent result derived from two methods provides further reasons to investigate the relationship between the domestic road network, domestic overland transport costs, and international trade flow. The following section provides a more thorough exploration of this relationship by introducing a theoretical framework and adopting a richer set of control variables in the empirical analysis.

2.4 Empirical Analysis

2.4.1 Methodology

Firstly, due to the broad applicability of the gravity model, it is unnecessary to take a stand on the underlying source of trade generation. As noted by Head and Mayer (2014), various workhorse models of international trade comply with the general gravity specification. For this reason, a general gravity model set-up would be a good starting point, as the main interest of this study lies in estimating the impact of changes in transport cost on trade flows. The general outline of the model is as follow:

$$T^f_{rgt} = \Phi^f_{rt}\Phi^f_{gt}TC^{-\theta}_{rgt}, \tag{2.4}$$

where T represents trade flows in levels, and $f \in \{e, i\}$ indicates whether the trade flow is inward (i) or outward (e). The terms Φ^f_{rt} and Φ^f_{gt} capture specific time-varying factors at region r and gateway g that affect the trade flowing between them. TC_{rgt} stands for the cost of transport. θ should be a positive constant, which is related to the elasticity of trade flows in respect of transport cost. Based on different underlying international trade models, the structural interpretation of trade elasticity θ varies considerably.

As mentioned previously, since there is no detailed information regarding the foreign countries the gateways trade with, the international transport mode serves as the best approximate to the relative location of the gateway to the rest of the world.

The gravity model in Equation (2.4) is hence tailored with trade flows decomposed at a finer level, in respect of the chosen international transport mode, as well as gateway-specific factors. The adapted model is therefore given as:

$$T^{f}_{rgmt} = \Phi^{f}_{rt}\Phi^{f}_{gmt}TC^{-\theta}_{rgt}. \tag{2.5}$$

To this end, the transport cost has not been modelled explicitly with any functional form, despite references in the previous discussion to (i) the positive association with the distance between the origin and the destination and (ii) the negative association with the scale and quality of transport networks.

The road density measurement at route level P_{rgt} defined in Equation (2.1) on page 77 is used as a proxy to the accessibility and penetrability of the overland network. This adaptation is congruent with the 'shortest-path-problem' rationale, which is simply to find a route that minimises the distance between two geographical locations. Evidently, a denser road system implies a shorter traveling distance and time between any two random points, provided that the shortest path is always chosen. Moreover, the relationship is non-linear due to the randomness of the locations.

On the other hand, the cost of transport between region r and gateway g is an increasing function of distance. Distance in the gravity model can therefore be a multifaceted concept, and measurement and interpretation are subject to continuous debate and discussion. In this study, the distance measurement is limited to the static geographical distance as it represents an approximation of the physical disparity of two locations. The varying feature that affects the transport cost is that of distance

elasticity. As shown in Table 2.5 on page 86, distance elasticity reduces slightly over time. It is modelled in the form of a weighted mean, given the route level high-grade road share, which represents an approximation of road quality.

Therefore, putting all these factors together, the transport cost is specified as:

$$TC_{rgt} = (P_{rgt})^{-\kappa} \cdot (d_{rg})^{\tau_h HS_{rgt} + \tau_o (1 - HS_{rgt})}, \tag{2.6}$$

where P_{rgt}, is the route level road density over the route J_{rg} at time t. $-\kappa$ can be interpreted as the elasticity of transport costs regarding road density. As explained previously, road density is negatively associated with transport costs, $-\kappa$ is expected to be negative, hence $\kappa > 0$. The distance elasticity of transport cost is composed of high-grade and ordinary roads related elasticities with the corresponding shares used as the weights for the average. Namely, τ_h and τ_o are positive distance elasticities associated with high-grade roads and ordinary roads, respectively. Both τ_h and τ_o are assumed to be constant over time. The term HS_{rgt}, as in Equation (2.2), denotes the high-grade road share over the route J_{rg} at time t. Taking the logarithm of both sides, and denoting $\tau = \tau_o - \tau_h$, the transport cost is represented as follows:

$$\ln TC_{rgt} = -\kappa \ln P_{rgt} + \tau \left(1 - HS_{rgt}\right) \ln d_{rg} + \tau_h \ln d_{rg}. \tag{2.7}$$

In this equation, the first term on the right hand side captures the time variation in transport costs driven by enhanced road accessibility and penetrability. The second term accounts for the change in transport costs as a result of the road quality upgrade and capacity expansion. The final term is time invariant regardless of the

period investigated. Taking the logarithm of both sides of the Equation (2.5) and substituting $\ln TC_{rgt}$ with the derived representation in Equation (2.7), the linearised specification becomes:

$$\ln T^f_{rgmt} = \ln \Phi^f_{rt} + \ln \Phi^f_{gmt} + \theta\kappa \ln P_{rgt} - \theta\tau(1 - HS_{rgt}) \ln(d_{rg}) - \theta\tau_h \ln(d_{rg}). \quad (2.8)$$

To gauge the long-term effect of increasing P_{rgt} and HS_{rgt} on trade flows, first-order time differencing is applied to Equation 2.8:

$$\Delta \ln T^f_{rgm} = \Delta \ln \Phi^f_{r} + \Delta \ln \Phi^f_{gm} + \theta\kappa\Delta \ln P_{rg} - \theta\tau \left[\Delta(1 - HS_{rg})\right] \ln(d_{rg}), \quad (2.9)$$

In this specific equation, the sign Δ represents the difference between the 2005 and 2001 levels of a variable. The time invariant term is hence eliminated after this operation, which simplifies the estimation procedure. If the cost of transport on high-grade roads increases with distance at a smaller rate than it does on lower quality roads, that is, if $\tau > 0$, then an increase in HS_{rg} will reduce the transport costs given the specific route and hence promote trade flows. In this regard, an estimate of $\tau > 0$ is expected to comply with this relationship.

Mathematically, due to the equivalence between terms $\Delta(1-HS_{rg})$ and $-\Delta HS_{rg}$, the specification in Equation (2.9) can be further simplified. The baseline empirical model is therefore proposed as follows:

$$\Delta \ln T^f_{rgm} = \varphi^f_r + \varphi^f_{gm} + \beta_\rho \Delta \ln P_{rg} + \beta_q \triangle RC_{rg} + \epsilon_{rgm}, \tag{2.10}$$

where $\beta_\rho = \theta\kappa$ and $\beta_q = \theta\tau$. The previously defined region– and gateway–transport–flow fixed effects $\Delta \ln \Phi^f_r$ and $\Delta \ln \Phi^f_{gm}$ are used to account for location specific features, including multilateral resistance, are relabelled as φ^f_r and φ^f_{gm} respectively. Because data on both ΔHS_{rg} and $\ln d_{rg}$ are available, their multiplication generates a new explanatory variable, named as $\triangle RC_{rg}$ for convenience. Hence, $\triangle RC_{rg} = \triangle HS_{rg} \cdot \ln d_{rg}$ is known as the 'change of the route capacity'. As discussed above, the data suggests $\triangle \ln P_{rg}$ and $\triangle RC_{rg}$ are strictly positive for any possible route over the period, and the plausible estimates of both coefficients of β_ρ and β_q would both be positive, that is, $\theta > 0$, $\kappa > 0$, and $\tau > 0$. The regression disturbances are written as ϵ_{rgm}, which is unobservable.

Notably, while estimates of Equation (2.10) identify β_ρ and β_q, the underlying structural parameters of interest κ and τ cannot be separately identified from θ—the elasticity of trade flows concerning transport costs. As mentioned in J. E. Anderson and Van Wincoop (2004), such inseparability of structural parameters is standard in gravity literature, and often a pre-determined value is required. In the following section, coefficients of β_ρ and β_q estimated from the baseline model in Equation (2.10) are reported. Meanwhile, based on the study of Simonovska and Waugh (2014), θ is assumed to be 4.1, so that the structural parameters become identifiable after applying the delta method.

2.4.2 Baseline Results

Table 2.6 on the next page presents the regression results with OLS estimates. The individual effect of the change in high-grade road share (ΔHS_{rg}) as reported in column (1) is not significant. Such a result is not surprising as it does not account for the length of a particular route. After adding the control of the change in log-road density ($\Delta \ln P_{rg}$), both effects become significant, as shown in column (2). In the third column, the effect of the change in road capacity (ΔRC_{rg}) is investigated separately. It has a significance level of 0.06. The fourth column gives the estimates as specified in the baseline model (2.10) on the preceding page. The effects of both $\Delta \ln P_{rg}$ and ΔRC_{rg} gain their levels of significance, as the two coefficients have p-values lower than 0.009. The magnitude of the effects varies slightly when compared with the previous estimates. In the fifth column, all control variables are included for the purposes of comparison, and the coefficient of ΔHS_{rg} is, once again, not significant. The inclusion of the additional variable does not improve the fitness of the model. Moreover, the Bayesian information criterion (BIC) indicates that the specification in column (4) is preferred.

As mentioned above, $\beta_\rho = \theta\kappa$ and $\beta_q = \theta\tau$, where θ here is an estimate itself. Therefore, the multivariate extension of the delta method must be applied in this instance to disentangle the underlying structural parameters of interest. To be more specific, the random variable τ has the expected value $E(\tau) = E\left(\frac{\beta_q}{\theta}\right) \approx \frac{\mu_{\beta_q}}{\mu_\theta}$ and variance $Var(\tau) \approx \left(\frac{\mu_{\beta_q}}{\mu_\theta}\right)^2 \left(\frac{Var(\beta_q)}{\mu^2_{\beta_q}} + \frac{Var(\theta)}{\mu^2_\theta} - \frac{2Cov(\beta_q,\theta)}{\mu_{\beta_q}\mu_\theta}\right)$. The approximates for κ, $E(\kappa)$ and $Var(\kappa)$ can be represented in a similar manner. The expected value and

Table 2.6: Regression Results

	(1) $\Delta \ln T^f_{rgm}$	(2) $\Delta \ln T^f_{rgm}$	(3) $\Delta \ln T^f_{rgm}$	(4) $\Delta \ln T^f_{rgm}$	(5) $\Delta \ln T^f_{rgm}$	(6) $\Delta \ln T^f_{rgm}$
ΔHS_{rg}	4.305	8.507**			−0.870	
	(3.614)	(3.916)			(8.037)	
$\Delta \ln P_{rg}$		3.964***		3.761***	3.715***	3.734
		(1.432)		(1.376)	(1.444)	(3.329)
ΔRC_{rg}			0.930*	1.341***	1.443	1.704***
			(0.505)	(0.526)	(1.080)	(0.644)
Regression	OLS	OLS	OLS	OLS	OLS	IV
Observations	3074	3074	3074	3074	3074	3074
R^2	0.274	0.276	0.275	0.277	0.277	0.277
Fixed Effects	r-f, g-m-f	r-f, g-m-f	r-f, g-m-f	r-f, g-m-f	r-f, g-m-f	r-f, g-m-f
BIC	12228.87	12227.93	12226.56	12225.85	12233.87	14868.33
KP LM stat.						325.923
KP F stat.						98.977
DWH stat.						0.473

Robust Standard errors in parentheses
Significance $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$
Notes: All regressions are estimated with region-flow(r-f) and gateway-transport-flow(g-m-f) fixed effects, in which flow is either import or export.

the variance of θ are taken from Simonovska and Waugh (2014), that is, $\mu_\theta = 4.1$, $Var(\theta) = 0.0081$. Additionally, the co variances between β_p and θ, as well as β_q and θ are assumed to be zeros. Namely, $Cov(\beta_p, \theta) = Cov(\beta_q, \theta) = 0$. The results of the baseline specification in column (4) of Table 2.6 implies τ has the mean value 0.327 with a standard error of 0.128, while κ has the mean of 0.917 and a standard error of 0.336. The large magnitude of the elasticity of road density to transport costs κ signifies that the corresponding changing relationship between road density improvement and transport cost reduction would be virtually one-to-one. This indicates if the road network density is increased by 1%, the transport costs are expected to decrease by about 1%.

However, the reduction in transport costs induced by the upgraded road capacity requires further investigation. Therefore, the structural parameters τ, τ_h, and τ_o can

be more closely examined by considering the counterfactuals. The value of τ_o remains unknown, because it is only identifiable from the estimation of a sample where high-grade road shares for all the routes equal zeros, which is not true for the available dataset. Nevertheless, the route level in year 2000 has the smallest high-grade road shares for all the routes with the mean and median both below 0.1. Hence, for the sake of a back-of-the-envelope calculation, the value of τ_o is approximated by the distance elasticity estimated from the year 2000 sample using the specification in Equation (2.3) and PPML method. This estimate yields the approximation of τ_o, as 2.438, which implies $\tau_h = \tau_o - \tau = 2.111$.

Combing this information with the transport cost specification in Equation (2.6), the reduction in domestic transport segment cost can be quantified provided that the distance along the route is known. The mean route distance of 1374 km is used for the purpose of illustration. If such an average route is upgraded from an ordinary road to high quality, that is HS_{rg} changes from 0 to 1, the cost of shipping along that route would decrease by about 90%. Even without any expansion of the network scale, the fall in transport cost due to the improvement in road capacity is extremely significant.

Additionally, the value of 15-year discounted stream of trade flows is calculated with respect to each dollar invested in road quality improvement. The estimate uses the elasticities generated above and is based on a hypothetical route with a sample mean distance of 1374 km. To reduce transport costs by 1% on this specific route, 5.82 km of roads must be converted from ordinary to high quality, provided that no new roads are constructed. Based on past projects, the average cost of building the

highest quality expressways in China in the early 2000s was $5 million US Dollars per km. The construction costs for Class I and Class II roads were significantly lower. For instance, the average cost of building Class II roads was about $0.5 million per km. No reliable source regarding road upgrading costs was available as this was dependent on the original condition of the route, however the total cost should be cheaper as there is no need for route-planning or re-constructing road foundation. Therefore, as a back-of-the-envelope calculation, it is assumed that the total cost of upgrading 5.82 km of ordinary roads to a higher quality at the beginning of the 2000s in China was about $6 million. The gravity model in Equation (2.4) suggests that the total value of trade flows, including both exports and imports at the mean, generated by a 1% decrease in transport costs would be $24.4 million. For discount factors between 0.10 and 0.05, the present value of this 15-year stream of trade flows ranges from $5.84 to $11.74 million. This indicates that the annual value of trade flows generated by a one-dollar investment on road quality improvement is between $0.97 and $1.96. It is noteworthy that this calculation does not reflect the total rate of return to investment as it does not take into account stimulated domestic trade, which can be quite substantive. For instance, Allen and Arkolakis (2014) estimate a rate of return for the Interstate Highway System in the US to be 100% on intranational trade.

The results overall imply significant effects of road capacity expansion in terms of trade cost and the promotion of trade flows. There are several explanations as to the mechanism on how transport network related projects alleviate the adverse effects of geographical separation on trade. For instance, the reduced congestion of routes facilitates a higher travelling speed for all vehicles. Higher road penetrability

also connects smaller cities to international gateways. Furthermore, increased road capacity may be associated with an observed fall in road accidents. In 2001, there were 75, 4919 road accidents reported across China, a number that decreased by 40% to 45, 0254 in 2005. The reduction in the rate of road accidents reflects the direct benefits of smoother journeys and lower freight insurance costs. Meanwhile, the maintenance and depreciation costs of the logistics sector are lowered when operating on high-quality routes. These positive effects are likely to lead to the increased punctuality and predictability of deliveries and to generate freight on new routes that have previously cost too much to operate.

2.4.3 Instrumental Variables Estimation

As mentioned, Chinese central government's primary object of road investments was to ensure the integrity of the national network. This relieves the endogeneity concerns to some extent. Furthermore, the first-order differencing operation absorbs any route-level time invariant factors that might be correlated with the error term. However, it is never possible to be overcautious when trying to prevent the endogeneity problem. In an unlikely scenario, the building of some routes might be prioritised or others upgraded due to existing strong trade ties between regions and gateways connected by the routes. To address such potential issues, an instrumental variable model is therefore adopted in this section.

In standard econometric practice, valid instruments must satisfy two conditions, known as instrument relevance and instrument exogeneity. If an instrument is rel-

evant, then variation in the instrument is related to variation in the instrumented variable. If in addition, the instrument is exogenous, then the part of the variation of the instrumented variable that is captured by the instrument is exogenous. Precedent research has shown that the initial tariff levels are valid instruments to use in studying the impact of trade liberalisation (Goldberg and Pavcnik 2005; Amiti and Konings 2007; Edmonds, Pavcnik, and Topalova 2010). Similar logic is applicable in this context, where the initial high-grade road share is the candidate instrument for the change in road quality and, likewise, the beginning period of road density is the candidate instrument for road spreads. As illustrated in Figure 2.4 on page 81, there are some positive associations between the initial values of route density and quality indicators and their period changes. Further test statistics are examined later to justify the validity of the instruments.

The two-stage least squares (2SLS) technique has been developed to deal with the instrument variable. The two explanatory variables that are prone to the endogeneity problem and require instrumenting are $\Delta \ln P_{rg}$ and $\triangle RC_{rg}$, as shown in the baseline specification in Equation (2.10) on page 91. Some alterations to the initial values of route density and quality measurements need to be made, so that the instruments have the same format as the original variables. The instrumented variable is $\triangle RC_{rg} = \triangle HS_{rg} \cdot \ln d_{rg}$, which is a multiplication of the change in the route high-grade road share and the log of route distance. In alignment with this format, the instrument $RC_{rg,2001} = HS_{rg,2001} \cdot \ln d_{rg}$, is a product of the year 2001 route level high-grade road share and the log of the route distance. Additionally, the $\ln d_{rg}$ term will also be included, as it serves as an instrument given the structure of the instrumented

variable. The other variable to be instrumented, $\Delta \ln P_{rg}$, is a function of the change in route road length and the area covered. Likewise, the relevant additional instruments are $\ln P_{rg,2001}$ and $AREA_{rg}$. Thus Equation (2.10) is therefore estimated using the 2SLS method. In the first stage, the presumed endogenous variables are instrumented with all instruments and the exogenous variables then included. They are formulated as follows:

$$\begin{aligned}
\triangle RC_{rg} &= \varphi'_r + \varphi'_{gm} + \beta_{iv1} RC_{rg,2001} + \beta_{iv2} \ln d_{rg} \\
&\quad + \beta_{iv3} \ln P_{rg,2001} + \beta_{iv4} AREA_{rg} + \epsilon'_{rgm}, \\
\Delta \ln P_{rg} &= \varphi''_r + \varphi''_{gm} + \beta_{iv5} RC_{rg,2001} + \beta_{iv6} \ln d_{rg} \\
&\quad + \beta_{iv7} \ln P_{rg,2001} + \beta_{iv8} AREA_{rg} + \epsilon''_{rgm}.
\end{aligned}$$

In the second stage, the change in the trade flow is regressed on the predicted values from the first stage, hence:

$$\Delta \ln T^f_{rgm} = \varphi^f_r + \varphi^f_{gm} + \beta_\rho \widehat{\Delta \ln P_{rg}} + \beta_q \widehat{\triangle RC_{rg}} + \epsilon_{rgm}.$$

The IV results and test statistics are presented in column (6) of Table 2.6 on page 93. The under-identification test is conducted to check whether the instruments are correlated with the endogenous regressors. As the robust option is invoked in the estimation, the Kleibergen-Paap rk LM statistic is used and its value is 325.92, indicating no under-identification problem at any conventional significance level. How-

ever, the weak identification problem may still arise when the excluded instruments are correlated with the endogenous regressors, albeit only weakly. Estimators can perform poorly in a small sample when the instruments are weak. The Kleibergen-Paap Wald rk F statistic is used to identify this issue, and the test statistic is 98.98, suggesting that the IV estimates are very unlikely to suffer from bias due to weak instruments. The estimated coefficient on $\triangle RC_{rg}$ is still significant at the 1% level, while the coefficient on $\Delta \ln P_{rg}$ is no longer significant at the 10% level. The IV estimates in column (5) are slightly different from the OLS estimates in column (4). However, more importantly, the Durbin–Wu–Hausman test statistic is 0.47, with a p-value of 0.79, which suggest that the null hypothesis stating the specified endogenous explanatory variables can be treated as exogenous cannot be rejected at any conventional significance level. The OLS estimates are therefore consistent. Moreover, the high BIC of the IV model further suggests this method is not preferred. These results confirm the credibility of the exogeneity assumption. Hence, the OLS method is considered appropriate and will be used for further estimations.

2.4.4 Alternative Specifications and Additional Controls

Previously, geographical distance was used as the measure of regional access to gateways, mainly because it is constant over time and represents actual physical separation. However, distance in the gravity model is a multifaceted notion, and several candidate specifications can therefore be experimented with.

One alternative, the shortest road distance between a region and a gateway, can

be utilised on the grounds that the actual distance travelled by overland freight is via road. However, the shortest road distance changes from time to time when any shorter route in-between cities are newly built and historical statistics are not readily obtainable. Nevertheless, as mentioned in The World Bank (2007)'s report, while the major cities were linked up with road networks in the year 2000, the primary objectives of transport projects in the following years were to upgrade the existing network and extend the network to middle-sized cities. Thence, it can be safely assumed that the shortest road distances between major cities have not changed drastically from 2000 onwards; the numerous road construction projects that have taken place have mainly improved the existing network or set up new linkages among relatively smaller cities. Accordingly, the shortest road distance between a regional centre and a gateway can be treated as invariant and is approximated by the short road distance in 2011 during the study period. The shortest road distances used are extracted from Google Maps Distance Matrix API, given the coordinates of the regional centres and gateways. The within region shortest road distance is again approximated as half of that to the nearest neighbour.

Given this, the corresponding road condition variable is specified as $\Delta RC_{rg}^{road} = \triangle HS_{rg} \cdot \ln d_{rg}^{road}$. The result obtained from the alternative road distance measure is shown in Table 2.7 on the following page in column (2) with the baseline results given in column (1) for comparison. This shows that the coefficients display little variation between the two models.

The analysis is also subjected to the measurement method of road quality. Buys et al. (1990) used the distance-weighted average road quality index option to measure

Table 2.7: Regression Results: Alternative Specifications

	(1) Baseline $\Delta \ln T^f_{rgm}$	(2) $\Delta \ln T^f_{rgm}$	(3) $\Delta \ln T^f_{rgm}$	(4) $\Delta \ln T^f_{rgm}$	(5) $\Delta \ln T^f_{rgm}$
$\Delta \ln P_{rg}$	3.761***	3.802***	3.208**		
	(1.376)	(1.379)	(1.348)		
$\Delta \ln P^{between}_{rg}$				0.217	
				(0.508)	
ΔP^{semi}_{rg}					3.382*
					(1.849)
ΔRC_{rg}	1.341***				
	(0.526)				
ΔRC^{road}_{rg}		1.343***			
		(0.517)			
$\Delta RC^{distance}_{rg}$			0.812*		
			(0.493)		
$\Delta RC^{between}_{rg}$				0.234	
				(0.250)	
ΔRC^{semi}_{rg}					0.004***
					(0.001)
Regression	OLS	OLS	OLS	OLS	OLS
Observations	3074	3074	3074	3074	3074
R^2	0.277	0.277	0.276	0.274	0.277
Fixed Effects	r-f, g-m-f	r-f, g-m-f	r-f, g-m-f	r-f, g-m-f	r-f, g-m-f
BIC	12225.85	12225.57	12231.23	12236.78	12226.29

Robust Standard errors in parentheses
Significance $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$
Notes: All regressions are estimated with region-flow(r-f) and gateway-transport-flow(g-m-f) fixed effects, in which flow is either import or export.

the quality of the road links between city pairs when studying road network upgrading and overland trade expansion in sub-Saharan Africa. Like a measure that uses the regional area as the weight, the distance transited within a region can serve the same purpose. Column (3) of Table 2.7 displays the results with $\Delta RC_{rg}^{distance} = \triangle HS_{rg}^{distance} \cdot \ln d_{rg}$, such that $\triangle HS_{rg}^{distance}$ is the first-order difference of $HS_{rg,t}^{distance} = \sum_{i \in J_{rg}} (w_i^{distance} \times hs_{it})$, where $w_i^{distance} = \frac{d_i}{\sum_{i \in J_{rg}} d_i}$ as the weight. d_i denotes the geographical distance within region i, as a partial component of route J_{rg}.

Additionally, the in-between measurements are explored by excluding the origin and the destination information when constructing the changes in road capacity and density. Thus, the in-between high-grade road share for route J_{rg} is defined as $HS_{rg,t}^{between} = \sum_{i \in J_{rg} \& i \notin \{r,g\}} (w_i \times hs_{it})$ given J_{rg} contains more than two elements of the regions. $\Delta RC_{rg}^{between}$ is defined in a similar way. For any route J_{rg} that contains fewer than two elements, that is, routes within a region or connecting a gateway in the neighbouring region, $\triangle RC_{rg}^{between}$ is set to be zero. Similarly, the change of the road density $\Delta \ln P_{rg}^{between}$ excludes the the destination and origin and is set to zero provided that the routes pass through no region in between.

The results reported in column (4) of Table 2.7 indicate the explanatory power of measurements, which derives solely from the in-between variations. Both coefficients of the reconstructed measures are smaller and less significant than the baseline coefficients, implying the trade flows are affected not only by the within road network condition, but also the origin and destination factors. Moreover, the higher value of BIC indicates this specification is not preferred.

The trade cost can be further defined in a different functional form such that

$TC_{rgt} = \exp\left(-\kappa \cdot P_{rgt} + \tau_h \left[HS_{rgt} \cdot d_{rg}\right] + \tau_o \left[(1 - HS_{rgt}) \cdot d_{rg}\right]\right)$, where the coefficients of the parameters of interest can be interpreted as semi-elasticities, that is, the percentage change in value of trade flow with regard to an absolute level change in the network scale or road capacity. After making the appropriate substitutions, taking natural logarithms, and constructing first-order differencing, the explanatory variables become ΔP_{rg}^{semi} and $\Delta RC_{rg}^{semi} = \triangle HS_{rg} \cdot d_{rg}$. While the coefficients revealed in column (5) of Table 2.7 is no longer comparable to those of the baseline, the estimates nevertheless are of the expected signs and at sufficient levels of significance.

As well as trying alternative specifications, further robustness checks are carried out by adding extra control variables. Firstly, a distance-related dummy variable is included in the baseline specification to ascertain whether trade flows along longer routes exhibit different trends than those along shorter routes. The threshold is set as the median of all sampled route lengths. The results are shown in column (2) of Table 2.8 on page 105. The baseline results are displayed in the first column for comparison. The coefficient of the distance dummy variable estimated is insignificant and negligible while the coefficients of interest retain their significance and magnitude. Additionally, another dummy variable serving an analogue of 'home bias' in international trade is also examined. A dummy is generated based on whether the trade origin/destination is in the same region as the exporting/importing gateway. Based on the results in column (3) of Table 2.8, the coefficient is trivial and not significant, indicating that intra-regional trade does not exhibit a distinct evolving pattern in the way that inter-regional trade does. Given the inclusion of fixed effects in the gravity model, the above results are not surprising. The three additional factors

were examined are not time-invariant, therefore their impact on trade flow evolution should be mostly absorbed into the region- and gateway-specific effects.

Column (4) shows the results after controlling the period change in the log of per capita income along each route. The magnitude of the coefficient is relatively larger than those of the previous controls due to its time-varying nature. It also implies a positive association between the trend towards trade expansion and route per capita income growth. However, it does not appear to be significant at any conventional significance level. Finally, the proxies for market and supplier access, which estimate the proximity of the individual gateway and region to markets and suppliers, are examined together with the variables in the baseline specification. As an analogue to the definition given in Redding and Venables (2004), 'market access' is essentially a measure of market potential, measuring the export demand each gateway faces given its geographical position and that of its trading partners. Similarly, 'supplier access' is a counterpart measure on the import side and is an appropriately distance weighted measure of the location of import supply to each region. These measures are the estimated fixed effects recovered from the gravity estimation in Table 2.5 on page 86. The coefficient of the interaction term between market and supplier accessibility is presented in column (5) in Table 2.8. However, like the previous results, the estimators are insignificant and adding controls does not improve the fitness of the model.

Overall, although there are some variations in the point estimates of the explanatory variables that are of interest, the qualitative results comprehensively survive these checks. It can therefore be concluded that estimates of the intensive margin elasticities of trade flow with respect to road capacity and network scale are robust.

Table 2.8: Regression Results: Additional Controls

	(1) Baseline $\Delta \ln T^f_{rgm}$	(2) $\Delta \ln T^f_{rgm}$	(3) $\Delta \ln T^f_{rgm}$	(4) $\Delta \ln T^f_{rgm}$	(5) $\Delta \ln T^f_{rgm}$
$\Delta \ln P_{rg}$	3.761***	3.748***	3.901***	3.558***	3.823***
	(1.376)	(1.406)	(1.391)	(1.387)	(1.373)
ΔRC_{rg}	1.341***	1.325***	1.442***	1.307***	1.410***
	(0.526)	(0.626)	(0.544)	(0.527)	(0.524)
$I\{dist_{rg} > median\}$		0.005			
		(0.098)			
$Home$			0.100		
			(0.140)		
$\Delta \ln CGDP_{rg}$				2.069	
				(1.746)	
$MA_r \times SA_g$					−0.002
					(.001)
Regression	OLS	OLS	OLS	OLS	OLS
Observations	3074	3074	3074	3074	3074
R^2	0.277	0.277	0.277	0.276	0.275
Fixed Effects	r-f, g-m-f	r-f, g-m-f	r-f, g-m-f	r-f, g-m-f	r-f, g-m-f
BIC	12225.85	12233.88	12233.28	12430.9	12233.88

Robust Standard errors in parentheses
Significance $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$
Notes: All regressions are estimated with region-flow(r-f) and gateway-transport-flow(g-m-f) fixed effects, in which flow is either import or export.

2.4.5 Extensive Margin

Road network expansion and upgrading did not merely facilitate the established trade partnership between regions and gateways, it also simulated the generation of new trade linkages and created new trade partners. To further examine such expansion at the extensive margin, a conditional (fixed-effects) logistic regression method is employed. Although the linear probability model with fixed effects is qualitatively and quantitatively similar to the conditional logistic, model in that way suffers from several drawbacks, such as unbounded predicted probabilities. Hence, the conditional logistic model is preferred, despite the indirect interpretability of the coefficients. A binary variable New^{f}_{rgm} is generated, which takes the value of one if a new region-gateway trade linkage has been initiated for a specific transport mode from 2001 to 2005, and zero otherwise. Under the specification, the dependent variable is defined as $\log \frac{New^{f}_{rgm}}{1-New^{f}_{rgm}}$, known as the log of the odds ratio. Because different gateways have different accessibilities to transport mode due to various factors, such as geographical location and logistic infrastructure, it is inappropriate to examine all gateways with respect to six international transport modes. Therefore, the sample is restricted to region–gateway–transport mode combinations which include at least one record of observed trade flow during the period concerned. The whole sample comprises 4069 observations.

The results are presented in Table 2.9 on the next page. Column (1) presents the results that have the same explanatory variables as the intensive margin baseline model. According to the conditional logistic regression estimates, a one percent

Table 2.9: Regression Results: Extensive Margin

	(1) $\log \frac{Pr(New^f_{rgms}=1)}{1-Pr(New^f_{rgms}=1)}$	(2) $\log \frac{Pr(New^f_{rgms}=1)}{1-Pr(New^f_{rgms}=1)}$	(3) $\log \frac{Pr(New^f_{rgms}=1)}{1-Pr(New^f_{rgms}=1)}$	(4) $\log \frac{Pr(New^f_{rgms}=1)}{1-Pr(New^f_{rgms}=1)}$	(5) $\log \frac{Pr(New^f_{rgms}=1)}{1-Pr(New^f_{rgms}=1)}$	(6) $\log \frac{Pr(New^f_{rgms}=1)}{1-Pr(New^f_{rgms}=1)}$	(7) $\log \frac{Pr(New^f_{rgms}=1)}{1-Pr(New^f_{rgms}=1)}$
$\Delta \ln P_{rg}$	4.448***	4.560***	2.316	0.544	0.494	3.336**	5.192***
	(1.632)	(1.634)	(1.574)	(0.587)	(1.718)	(1.653)	(1.630)
ΔRC_{rg}	7.327***				3.561***	7.019***	7.319***
	(0.630)				(0.721)	(0.635)	(0.621)
ΔRC^{road}_{rg}		7.220***					
		(0.620)					
$\Delta RC^{distance}_{rg}$			5.731***				
			(0.574)				
$\Delta RC^{between}_{rg}$				1.611***			
				(0.290)			
$I\{dist_{rg} > median\}$					1.255***		
					(0.116)		
$\Delta \ln CGDP_{rg}$						7.600***	
						(1.824)	
$MA_r \times SA_g$							−13.873
							(11.092)
Regression	CLOGIT	CLOGIT	CLOGIT	CLOGIT	CLOGIT	CLOGIT	CLOGIT
Observations	4069	4069	4069	4069	4069	4069	4069
R^2	0.142	0.142	0.129	0.111	0.178	0.147	0.148
Fixed Effects	r-f, g-m-f	r-f, g-m-f	r-f, g-m-f	r-f, g-m-f	r-f, g-m-f	r-f, g-m-f	r-f, g-m-f
BIC	3358.43	3357.82	3400.491	3461.12	3243.79	3349.12	3517.81

Robust Standard errors in parentheses
Significance $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$
Notes: All regressions are estimated with region-flow(r-f) and gateway-flow(g-f) fixed effects, in which flow is either import or export.

increase in road density $\Delta \ln P_{rg}$ would result in a 1.045 level increase in the odds ratio of establishing a new trade link. Similarly, a one percent change in road capacity ΔRC_{rg} is associated with a 1.074 level change in the odds ratio. The impact of both road density and quality improvement on the propensity of creating new trade partnerships is substantial. Moreover, both point estimates are highly significant.

Meanwhile, several model variations have been tested, which are in line with the robustness checks used for the intensive margin model. The results are displayed in Table 2.9 from column (2) to (4). An alternative specification of road capacity with respect to road distance produces qualitatively and quantitatively similar results. The point estimates from the distance weighted and in between measures are relatively smaller and less significant, and hence less powerful in explaining the extensive margin expansion than the default specification. The BICs also indicate both models are not preferred in model selection.

Other control variables, such as the dummy for the longer route, change of the log of per capita income along each route, and the interaction term between market and supplier accessibility, are included in addition to the baseline explanatory variables. Because the extensive margin model is not estimated in differences, the location and route specific time-invariant factors would be more likely to exert an impact on trade creation propensity. In contrast to the growth of the intensive margin, the expansion at the extensive margin is associated with the length of the route. Routes longer than the median distance are more prone to establish new trade links. According to the results presented in column (5) in Table 2.9, a longer route increases the odds ratio of starting trade by 1.013. This is perhaps due to the fact that trade links along the

shorter routes have most been established in the beginning of the period. The results in column (6) show that the change in log per capita income along the route is also positively associated with trade creation. The odds ratio increases by 1.076 if the route-level change in log per capita income is 1%. The point estimates of the network scale and road density measurements change slightly but retain their significance. Finally, the proxies to market and supplier accessibility are also tested despite the insignificance of the interaction term. Overall, the results obtained from using the same explanatory variables as the intensive margin baseline mode are robust, although adding some relevant control variables would improve the performance of the model to some extent.

In addition to the investigation on the newly established trade partnership between regions and gateways, the components of the newly created trade flows can be used to provide further insights into the extensive margin expansion. As stipualted in standard international trade theory, all regions, gateways, and international trade partners have particular patterns of production specialisation. When a new trade link is created, it is always possible to track the specific categories of the traded products and their related sectors. In a similar manner, the trade flow for each sector's from and into a gateway can also be traced. Thence, the trade flows can be decomposed into the region–port–transport–sector level and reveal further implications concerning the initialisation and growth of trade. Using a method similar to that detailed in Broda and D. E. Weinstein (2006) for reporting trade elasticities and letting product parameters vary at the 3-digit HS classification level, the sampled trade flows are divided into 174 sectors.

Both margins with respect to sectors are estimated, and the results are presented in Table 2.10 on the following page. The first column replicates the baseline result, while column (2) and (3) feature the decomposition of the intensive-extensive margins. Regarding the dimension of change in trade values per sector, the coefficient for road capacity improvement is insignificant, despite having the right sign. However, the coefficient for the same parameter is significant at the level of 1% on the extensive marginwith the number of sectors that are traded in.

The coefficients of the change in network scale expansion are significant at the 5% level and have the right signs on both dimensions. Approximately, one-third (1.291/3.761) of the overall trade growth resulted from road network expansion which in turn resulted from the increased diversity of the sectors. In contrast, the intensive and extensive margin contributes 0.634 and 0.707, respectively to the trade growth stimulated by the improvement in road condition. By identifying the channels regarding trade sectors, these results complement the findings in the previous analysis in that improvements in road capacity and network expansion are associated with trade growth along the routes.

Given the fact that trade flows are composed of imports and exports, it is reasonable to ask whether road capacity and network scale exert similar effects on the flows in either direction. The analyses of intensive and extensive margins described previously are hence conducted on separate imports and exports samples rather than on the pooled sample to differentiate the effects. The results are presented in Table 2.11 on page 112. For consistency, the trade flows are decomposed at the region–port–transport level as before.

Table 2.10: Regression Results: Industry Margin

	(1) Baseline $\Delta \ln T^f_{rgm}$	(2) $\Delta \ln \left(\frac{T^f_{rgm}}{N^f_{rgm}}\right)$	(3) $\Delta \ln N^f_{rgm}$
$\Delta \ln P_{rg}$	3.761***	2.471**	1.291**
	(1.376)	(1.223)	(0.571)
ΔRC_{rg}	1.341***	0.634	0.707***
	(0.526)	(0.467)	(0.218)
Regression	OLS	OLS	OLS
Observations	3074	3074	3074
R^2	0.277	0.242	0.362
Fixed Effects	r-f, g-m-f	r-f, g-m-f	r-f, g-m-f

Robust Standard errors in parentheses
Significance $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$
Notes: All regressions are estimated with region-flow(r-f) and gateway-flow(g-f) fixed effects, in which flow is either import or export.

The results in column (1) and (4) of Table 2.11 are merely replications of previous results, generated from the baseline specifications for intensive and extensive margins. Comparing the results in column (2) and (3), it shows that, at the intensive margin, the imports are affected approximately 50% more due to the change in either road capacity or network scale. The estimates at the extensive margin, as reported in column (5) and (6), present a different picture. While the development of road capacity leads to the creation of new export and import links, the impact of results from the network scale expansion is much more profound on outward trade flows. The producers are thus more responsive then consumers in initiating trading and reaching new trade partners when the underlying driver of the reduction in transport costs is improved network accessibility and penetrability.

Table 2.11: Regression Results: Exports and Imports

	(1)	(2)	(3)	(4)	(5)	(6)
	Intensive Margin			Extensive Margin		
	$\Delta \ln trade^f_{rgm}$	$\Delta \ln trade^f_{rgm}$	$\Delta \ln trade^f_{rgm}$	$\log \frac{New^f_{rgm}}{1-New^f_{rgm}}$	$\log \frac{New^f_{rgm}}{1-New^f_{rgm}}$	$\log \frac{New^f_{rgm}}{1-New^f_{rgm}}$
$\Delta \ln P_{rg}$	3.761***	3.101*	4.702*	4.448***	6.769***	1.903
	(1.376)	(1.675)	(2.377)	(1.632)	(2.266)	(2.356)
ΔRC_{rg}	1.341***	1.127*	1.667*	7.327***	7.424***	7.248***
	(0.526)	(0.627)	(0.939)	(0.630)	(0.854)	(0.934)
Regression	OLS	OLS	OLS	CLOGIT	CLOGIT	CLOGIT
Flow	All	Export	Import	All	Export	Import
Observations	3074	1873	1201	4069	2381	1688
R^2	0.277	0.264	0.285	0.142	0.149	0.134
Fixed Effects	r-f, g-m-f	r-f, g-m-f	r-f, g-m-f	r-f, g-m-f	r-f, g-m-f	r-f, g-m-f

Robust Standard errors in parentheses
Significance $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$
Notes: All regressions are estimated with region-flow(r-f) and gateway-flow(g-f) fixed effects, in which flow is either import or export.

2.4.6 Impact Channels

After confirming the positive effects of overland network scale expansion and road capacity improvement on trade, it is also beneficial to explore the sectors through which the effect has been materialised. For consistency, the sector is defined by the 3-digit HS classification level as was the case in previous sector extensive margin analysis. The analysis is conducted at the level of region–gateway–sector–transport–year.

In general, sectors requiring transporting services more intensively are expected to be more responsive to the improved overland transport system. One of the common characteristics of these transport-intensive sectors is that their products are usually sensitive to duration and punctuality of the delivery time. For instance, some agricultural products are time-sensitive simply because they are perishable. Intermediate goods, such as steel used in producing cars and wood used in making furniture, are part of the international supply chains, and demand good timeliness and punctuality in shipping and delivery. Previous research studies have also identified some other causes of transport intensity in relation to goods. For instance, Evans and Harrigan (2005) claim that industries with a volatile demand for customised products require fast and frequent shipments of small volumes. Moreover, time-in-transit also constitutes a direct inventory-holding cost. Hummels and Schaur (2013) identified an *ad valorem* tariff of 0.6% to 2.3% for each day in transit, by exploiting the variation in the premium paid for air shipping and in the time delayed during ocean transit in the context of US imports. Thus, they have treated transit time as a trade cost, with the

above-mentioned arguments further suggesting that transport-intensive sectors are the impact channels in materialising the effects of overland transport upgrading on trade flows. Furthermore, the degree of 'heaviness' of sector products also determines the extent of usage of the transport facilities. For example, Duranton, Morrow, and Turner (2014) found that cities with more extensive highway networks specialise in sectors producing heavier goods by estimating the effect of the US highway system.

These shared characteristics have provided the guidelines to construct some proxies for measuring the transport intensity attribute of a sector. The first sector-specific parameter to be defined is the proportion of sector s' trade values transported by air in the international segment out of the total trade values, namely, $Air_s = \frac{Air_Val_s}{Total_Val_s}$. The trade flows are aggregated from all the international gateways, and both values are denominated in US Dollars. The air freight share is positively associated with the time-sensitiveness of the sector. Because air shipping is generally the fastest and most expensive shipment mode across countries, the shippers are willing to pay a premium in exchange for shorter transit time. Another proxy for sector time-sensitiveness is the 'heaviness' measure, defined as $Heavy_s = \ln \frac{Total_W_s}{Total_Val_s}$, in which $Total_W_s$ is the total volume of trade flows in sector s. If the shipment's documented unit is in weight, it is converted to kilogrammes for consistency. If the unit is in volume, then the volumetric weight is used. The default conversion factor for international shipment is 5000 between the volume measured in cm^3 and the weight in kg. $Total_Val_s$ is again the total trade value in US Dollars. As a matter of course, the higher the per dollar weight, the 'heavier' the product of the sector. To capture sector features across the period studied, both Air_s and $Heavy_s$ are treated as time-invariant, and

the averaged values from 2000 to 2006 are correspondingly used.

Another distinct feature of each sector is the substitutability of the sector's products by that of others, which is denoted as σ_s. The elasticity of substitution of the traded goods plays a crucial role in international trade theories. As justified by Arkolakis, Costinot, and Rodriguez-Clare (2012), the trade gains from varieties can be quantified by keeping track of only two factors: the elasticity of substitution among different varieties and shifts in expenditure shares among new, existing, and disappearing products, provided that the models specified incorporate the constant elasticity of substitution (CES) consumer preferences. The main intuition here is that increased diversity of goods does not increase productivity to a great extent if new varieties are close substitutes to existing varieties, or if the share of new varieties is small relative to existing ones. In this context, the elasticity of substitution governs the price elasticity of demand and trade elasticity. Hence, a higher σ_s indicates the higher elasticity of trade to transport costs. Nevertheless, estimating the elasticity of substitution is a challenging task in international trade. Broda, Greenfield, and D. Weinstein (2006) have estimated world trade elasticities using data from the COMTRADE database from 1994 to 2003. The methodology used is based on Feenstra (1994). The relevant estimations are available for China at a 3-digit HS classification level. The data are used as σ_s to quantify the substitutability of sectors' products.

To obtain an insight into variations among the sectors, the extreme values of air freight share, heaviness, and substitutability of sector products are briefly summarised in Table 2.12 on page 117, together with the Chapter name specified in HS. The upper panel contains the five maximal values arranging in descending order, and the bottom

panel gives the five minima in ascending order.

The HS Chapter names relevant to the sectors are reported in the second column. The Chapter at the 2-digit level is of higher hierarchy than the sector defined at the 3-digit level. Therefore, there are several sectors belonging to the same chapter. Unsurprisingly, products requiring a greater degree of manufacturing or more complex technology utilise air transport more intensively. In contrast, some animal and vegetable products are seldom shipped by air. Moreover, air freight share and heaviness are both negatively associated with the sample. This is justified by Harrigan (2010), in that the air transport mode is less suitable for goods with a high weight-to-value ratio. In this sense, the heaviness measure, aside from being an interested parameter itself, can be used as an additional control, and in conjunction with the air freight share, provide useful proxies to time-sensitivity. Regarding substitutability, the most elastic and most inelastic sectors both seem to be using more complex technologies in a more extensive degree of manufacturing.

The three additional variables of interest are incorporated in the baseline specification in the form of interaction terms. Adding the interaction terms enables the model to take account of the variations among sectors regarding the responsiveness of trade flow expansion to the improved road conditions. To facilitate the interpretability of the relevant coefficients, the variables Air_s, $Heavy_s$, and σ_s are redefined as dichotomous variables Air_s^d, $Heavy_s^d$, and σ_s^d respectively, based on the threshold of the respective median. If the sector's original Air_s value is larger than the median of all Air_s's, $Air_s^d = 1$. Otherwise, $Air_s^d = 0$. The same dummy generation method also

Table 2.12: Air Freight Shares, Heaviness, and Demand Elasticities of Industries

3-Digit HS	Chapter	Air_i
880	Aircraft, spacecraft, and parts thereof	0.87
930	Arms and ammunition; parts and accessories thereof	0.49
710	Natural or cultured pearls, precious or semi-precious stones, precious metals, metals clad with precious metal and articles thereof; imitation jewelry; coin	0.48
902	Optical, photographic, cinematographic, measuring, checking, precision, medical or surgical instruments and apparatus; parts and accessories thereof	0.48
854	Electrical machinery and equipment and parts thereof; sound recorders and reproducers, television image and sound recorders and reproducers, and parts and accessories of such articles	0.46
270	Mineral fuels, mineral oils and products of their distillation; bituminous substances; mineral waxes	3.46e-6
310	Fertilizers	7.21e-5
100	Cereals	8.69e-5
440	Wood and articles of wood; wood charcoal	2.55e-4
470	Pulp of wood or of other fibrous cellulosic material; waste and scrap of paper or paperboard	3.50e-4

3-Digit HS	Chapter	$Heavy_i$
250	Salt; sulfur; earths and stone; plastering materials, lime and cement	10.74
280	Inorganic chemicals; organic or inorganic compounds of precious metals, of rare-earth metals, of radioactive elements or of isotopes	10.36
252	Salt; sulfur; earths and stone; plastering materials, lime and cement	10.04
260	Ores, slag and ash	9.91
251	Salt; sulfur; earths and stone; plastering materials, lime and cement	9.87
880	Aircraft, spacecraft, and parts thereof	1.36
852	Electrical machinery and equipment and parts thereof; sound recorders and reproducers, television image and sound recorders and reproducers, and parts and accessories of such articles	3.17
980	Works of art, collectors' pieces and antiques	3.18
901	Optical, photographic, cinematographic, measuring, checking, precision, medical or surgical instruments and apparatus; parts and accessories thereof	3.19
903	Optical, photographic, cinematographic, measuring, checking, precision, medical or surgical instruments and apparatus; parts and accessories thereof	3.33

3-Digit HS	Chapter	θ_i
710	Natural or cultured pearls, precious or semi-precious stones, precious metals, metals clad with precious metal and articles thereof; imitation jewelry; coin	108.19
530	Other vegetable textile fibers; paper yarn and woven fabric of paper yarn	93.30
852	Electrical machinery and equipment and parts thereof; sound recorders and reproducers, television image and sound recorders and reproducers, and parts and accessories of such articles	39.28
850	Electrical machinery and equipment and parts thereof; sound recorders and reproducers, television image and sound recorders and reproducers, and parts and accessories of such articles	33.54
790	Zinc and articles thereof	32.27
854	Electrical machinery and equipment and parts thereof; sound recorders and reproducers, television image and sound recorders and reproducers, and parts and accessories of such articles	1.34
650	Headgear and parts thereof	1.34
870	Vehicles other than railway or tramway rolling stock, and parts and accessories thereof	1.34
281	Inorganic chemicals; organic or inorganic compounds of precious metals, of rare-earth metals, of radioactive elements or of isotopes	1.42
901	Optical, photographic, cinematographic, measuring, checking, precision, medical or surgical instruments and apparatus; parts and accessories thereof	1.45

applies to $Heavy_s^d$ and σ_s^d. The details of the model specification are as follows

$$\begin{aligned}\Delta \ln T_{rgms}^f = {} & \varphi_r^f + \varphi_{gm}^f + \beta_{\rho_0} \Delta \ln P_{rg} + \beta_{\rho_1} \Delta \ln P_{rg} \times Air_s^d \\ & + \beta_{\rho_2} \Delta \ln P_{rg} \times Heavy_s^d + \beta_{\rho_3} \Delta \ln P_{rg} \times \sigma_s^d \\ & + \beta_{q_0} \triangle RC_{rg} + \beta_{q_1} \triangle RC_{rg} \times Air_s^d + \beta_{q_2} \triangle RC_{rg} \times Heavy_s^d \\ & + \beta_{q_3} \triangle RC_{rg} \times \sigma_s^d + \epsilon_{rgms}. \end{aligned} \tag{2.11}$$

The first-order differencing eliminates the sector fixed effects which may drive the pattern in ways other than by the specified factors. Under this framework, if the trade flows of more time-sensitive and heavier sectors respond more strongly to improvements in road conditions, the point estimates of β_{ρ_1}, β_{ρ_2}, β_{q_1} and β_{q_2} are expected to be significant and positive.

The results are presented in Table 2.13 on the next page. In column (1), both coefficients of the interaction terms with air freight share are positive and significant at the 1% level. The trade flows respond positively to improved road accessibility and penetrability if the sector is characterised as heavy, while the sector's response to upgraded road capacity is negligible and insignificant. For the base category, where the sectors are neither shipped intensively using air freight nor heavy per dollar, their coefficients of change in network scale ($\Delta \ln P_{rg}$) and road capacity (ΔRC_{rg}) are not predicted to be significant at any conventional level. Column (2) shows the results after adding the substitutability related variables for each sector. However, the control of sector elasticities does not appear to make any substantial difference to the coefficients' magnitude nor significance. Furthermore, higher elasticity of a

Table 2.13: Regression Results: Transport Intensity and Impact Channel

	(1) $\Delta \ln T^f_{rgms}$	(2) $\Delta \ln T^f_{rgms}$	(3) $\log \frac{Pr(New^f_{rgms}=1)}{1-Pr(New^f_{rgms}=1)}$	(4) $\log \frac{Pr(New^f_{rgms}=1)}{1-Pr(New^f_{rgms}=1)}$
$\Delta \ln P_{rg}$	-0.378	-0.328	3.842^{***}	4.129^{***}
	(0.396)	(0.212)	(0.391)	(0.431)
$\Delta \ln P_{rg} \times Air_i$	0.730^{***}	0.741^{***}	0.894^{**}	0.824^{**}
	(0.229)	(0.230)	(0.361)	(0.364)
$\Delta \ln P_{rg} \times Heavy_i$	0.576^{**}	0.561^{**}	0.545	0.615^{*}
	(0.228)	(0.230)	(0.360)	(0.362)
$\Delta \ln P_{rg} \times \sigma_i$		-0.103		-0.520
		(0.209)		(0.330)
ΔRC_{rg}	-0.307	-0.300	5.913^{***}	5.759^{***}
	(0.202)	(0.212)	(0.190)	(0.210)
$\Delta RC_{rg} \times Air_i$	0.458^{***}	0.461^{***}	-0.025	0.014
	(0.147)	(0.148)	(0.186)	(0.187)
$\Delta RC_{rg} \times Heavy_i$	-0.000	–0.002	-0.019	-0.058
	(0.146)	(0.147)	(0.185)	(0.186)
$\Delta RC_{rg} \times \sigma_i$		-0.014		0.291^{*}
		(0.133)		(0.169)
Regression	OLS	OLS	OLS	OLS
Observations	61010	61010	121687	121687
R^2	0.066	0.066	0.117	0.117
Fixed Effects	r-f, g-f-m	r-f, g-f-m	r-f-s, g-f-m	r-f-s, g-f-m
BIC	274653.9	274674.9	113820.4	113837.4

Robust Standard errors in parentheses
Significance $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$
Notes: All regressions are estimated with region-flow(r-f) and gateway-flow(g-f) fixed effects, in which flow is either import or export.

sector could not be identified as one of the impact channels on trade expansion under this specification due to the insignificance of the relevant coefficients. The BIC also indicates that the model is inferior compared to the simpler specification.

A similar analysis is also conducted on the extensive margin to investigate how road condition enhancement induces transport costs reduction and trade initiation. In so doing, a binary variable New^{f}_{rgms} is created, which equals one if the region-gateway pair has newly established the trade linkage in sector s during the period studied, and zero if it does not. The specification in Equation (2.10) is then amended to a logistic model by changing the dependent variable to a log of the odds ratio for the binary variable New^{f}_{rgms}. The explanatory variables remain the same. Additionally, unlike the intensive margin difference in the differences analysis, the dependent variable is not in a differencing form. Therefore, sector-specific effects have to be considered if the regions are to account for regional production and demand specialisation patterns.

Column (3) and (4) in Table 2.13 present the results of the analysis. The conclusions are markedly different to those of the intensive margin. The road condition improvements benefit the base category in initiating new trade linkage the most and do not stimulate that of the transport intensive sectors. The network scale expansion, on the other hand, exerts a greater impact on time-sensitive sectors in creating new trade partnerships. Once again, the control of the sector's substitutability has little impact on the coefficients of interest. The BIC also indicates that the inclusion of additional controls is unnecessary.

The overall results have confirmed the hypothesis that in general time-sensitive and heavier sectors would benefit more from the expansion and improvement of the

overland transport system, especially on the intensive margin. To understand the economic significance of this estimate, taking two different sectors at above and below median air freight shares along the same route, the improvements in road quality would result in a difference in the trade increase ratio of approximately 60%, while that of road scale expansion is more than 70%. The evidence that more time-sensitive sectors are more likely to benefit from road development projects adds the credibility to the claim that the effect of reducing transport costs on trade has been identified. Moreover, the results provide further evidence to support the assertion that endogeneity is not a major concern in this regard, as central planners are highly unlikely to allocate and prioritise transport infrastructure investment merely because of the anticipated growth in a particular sector.

2.5 Conclusion

This paper examines the impact of China's nationwide investment in road transport networks on the level and composition of international trade. Transport cost reductions accomplished by the numerous investment projects have resulted in increased trade from regions whose connectivity and capacity to the international gateways have improved. The effects on trade stimulation came from increases in the extensive margins of trading sectors and industries, as well as the intensive margin of trading flows per province–gateway link. Noting that the analysis does not take account of traffic congestion induced by highway improvements. The overall results thus support the argument that internal transport infrastructure development plays an indispensable

role in facilitating access to international markets.

The specific impact channel for the regional trade flow response is estimated to be the increased trade of transport-intensive sectors, which have experienced the most significant reduction in transport costs. The products from these sectors are usually time-sensitive. This finding is in line with recent empirical literature emphasising time-related costs in international trade. While previous studies typically stress time in transit across borders or time lost in customs processing, the results of this study highlight the importance of domestic transport infrastructure in enabling the shipment of goods within a country in a timely and predictable fashion. Given the belief that efficient logistics enables countries to participate in global supply chains and exploit their comparative advantages, the findings have important implications for developmental policy.

Finally, by treating production locations as exogenous, the scope of the study is necessarily limited. In a more complex setting, the aggregate trade response of an industry or a sector is also associated with its initial location. This means that if the supply of and demand for transport-intensive products were initially agglomerated in regions with better market access, they would gain relatively less from transport cost reductions in the long run. Many economic geography models also suggest that the direction and degree of this change depends on the relative strength of agglomeration forces versus trade costs, which may be quite elusive. Nevertheless, this makes the long-term impact of large-scale infrastructure development projects on regional outcomes such as product specialisation patterns, employees' wages, and consumers' welfare fruitful fields for future research.

Chapter 3

The Economic Impacts Of Trade Sanctions: A Case Study of China–Japan Trade Ties

3.1 Introduction

Since the first Sino–Japanese war in 1895, tension has always been high between East Asian neighbours China and Japan. Diplomatic issues sometimes lead to economic fallout, with China calling for punitive economic sanctions against Japan for the purpose of gaining leverage in a diplomatic campaign.[1] The most recent example of this occurred in September 2012 as Japan nationalised a number of disputed islands in the East China Sea. These islands are known as the Diaoyu Islands to the Chinese and the Senkaku Islands to the Japanese. Some senior advisors to the Chinese government hinted at the possibility of trade sanctions against Japan as an instrument of foreign policy. 'Japan's economy would suffer severely if China impose sanctions on it. China's loss would be relatively small,' Jin (2012), a research analyst at China's

[1] Qiu (2006)discusses the role of history and collective historical memory in China–Japan relations and the interaction between public sentiment and government foreign policies. Burns (2000) discusses China and Japan's economics partnership for political ends from 1894 to 2000.

Ministry of Commerce, claimed in the China Daily. He argued that China could afford to sacrifice its 'low-value-added' exports to Japan at a small cost, while Japan, in contrast, relied on China's demand to keep its economy afloat. However, past evidence indicates that although economic sanctions are often threatened, the Chinese government has officially refused to admit any implemented economic sanctions as an instrument for bargaining with Japan during the past decade. Extensive empirical research has been done to understand China's strategy of putting forward economic sanctions but seldom launching them officially.[2] However, this strategy is often considered an issue of diplomacy and politics. Even in most prior economic studies focusing on the effects of economics sanctions, trade volume change has been considered the core issue, [3] and little is known about the potential welfare costs after the implementation of economic sanctions under a general equilibrium framework. Therefore, this paper aims to quantify the economic costs of China's unilateral sanctions against Japan, were they to be put into practice, and seeks an economic explanation of why such threats have remained rhetoric.

The economic sanctions most relevant in Sino–Japanese situations are principally trade sanctions. Lindsay (1986) defines trade sanctions as penalties in which one country (the initiator) publicly suspends a major portion of its trade with another country (the target) to attain political objectives. The use of unilateral economic pressure to advance strategic and diplomatic objectives is hardly unique internationally. For

[2]Reilly (2012) describes China as historically opposed to economic sanctions. However, over the past few years, Chinese policy makers began to resolve some of their legal, moral, ideological, and practical hurdles to using unilateral sanctions.

[3]Hufbauer, Oegg et al. (2003)adopt the gravity model to calculate the impact of economic sanctions on US trade flows; Hufbauer, Elliott et al. (1997) provide a brief analysis of the employment and wage effects of economic sanctions.

instance, the Commission et al. (1998) identified a total of 29 countries subject to unilateral economic sanctions for geopolitical considerations, national security concerns, human rights, democratisation issues, domestic politics and commercial interests. Nor is such a use of economic pressure to achieve political ends new in China's history. Since the founding of the People's Republic of China in 1949, Chinese policy makers have repeatedly politicised economic relations for strategic and ideological objectives. In recent years, for example, the Chinese government has mixed trade rewards and punishments to 'deter arms sales to Taiwan, isolate the Dalai Lama, eviscerate criticism of China's human rights policies, and defend its maritime claims'(Reilly 2012). Jian, a Chinese legal scholar (cited in Reilly (2012)) has emphasised that 'as China increases its international economic influence, China should increase its use of unilateral economic sanctions in order to maintain its legal international interests and achieve its foreign policy objectives. China should liberate its thinking, and fully utilise the important tool of unilateral sanctions.' Perhaps surprisingly, China has thus far not resorted to trade sanctions as a means of settling Sino–Japanese disputes. Despite the fact that the past decade has witnessed a marked deterioration in the relations of the two countries, both parties have usually found a way out of the resulting political and diplomatic impasse, even if they have not fully resolved their differences.

In fact, the term 'trade sanctions' is meant more as a threat signalling China's anti-Japanese sentiment than an actual policy instrument to be implemented against the Japanese. For instance, in the early 2000s, the islands territorial dispute escalated after boat collision incidents and Japan's detention of the crews. China has continued to assert its sovereignty with increased media coverage; a surge of anti-Japan protest

actions have been witnessed. However, the campaign to boycott Japanese products launched in some cities was at best a fringe attempt and was denounced by the authorities and the mainstream population (Liu 2006). As Reilly (2012) describes, 'China's sanctions are more bark than bite, signalling frustration.'

China's frequent threatening of, but constant balking at, the implementation of unilateral trade sanctions on Japan can be viewed as mainly an economic issue. As Eaton and Engers (1992) have concluded, the initiator's and the target's resolve largely depends on the extent to which they are likely to suffer from sanctions. The costs of implementing unilateral trade sanction against Japan shed light on the rationale of China's strategies. Most prior studies have focused on trade volume change after trade sanctions; however, although 'terms of trade' and 'trade volume' are important elements in describing countries' trade relations, they are not synonymous with social welfare. In that sense, the true economic costs of trade sanctions incurred towards both initiator and target have hitherto seldom been thoroughly calculated.

Economically, trade sanctions have double-edged effects on both sides. Depending on the balance of power between the nations involved and the nature of the countries' trade relations, the initiator may be able to depress the welfare level of the target country to an unacceptably low level if the sanctions are effective. To better describe the change of welfare, it is also necessary to consider the costs incurred via all channels. The costs of economic sanctions are often not exclusive. Tung (2003) claims: in terms of sensitivity interdependence, trade sanctions will bring for both parties an immediate loss of economic static allocative efficiency and reliability; in terms of vulnerability interdependence, the sanctions will reduce the base for future

economic growth by affecting dynamic efficiency and creating adjustment costs for the establishment of new trade patterns. In addition, as China and Japan also have substantial economic clout *vis-a'-vis* their smaller Asian neighbours, as well as some other remote but important trade partners, the impact of multilateral interactions should not be ignored.

The short run effects of trade sanctions are of most relevance in justifying China and Japan's strategy. Therefore, a static model of trade that incorporates the role of trade barriers under general equilibrium conditions is called for to quantify the effects. The theoretical approach adopted to analyse such an issue should be able to capture several key facts that define the Sino–Japanese trade pattern. Statistics from the Ministry of Commerce, People's Republic of China (2013) show that Japan is China's largest trade partner; Japan, trading extensively with China and running a trade deficit with it, listed China as its second largest trading partner in the early 2000s (ASEAN-Japan Centre 2013). Major Chinese exports to Japan include basic electric-mechanical products, textiles and raw materials, furniture, toys, base metals and chemicals. Japanese exports are of more technologically advanced and include electric-mechanical products, transport facilities, and optical, horological and medical products. As this suggests, Japan has a formidable lead in technology and provides much of the high-end production machinery in Chinese factories and many of the core components in China-made products (Ministry of Commerce, People's Republic of China 2013). China's rapidly growing economy seems to have an almost unquenchable thirst for high-end Japan-made products. In addition, the importation of lower-priced Chinese goods have become a significant part of low-end goods consumption

in economically stagnant Japan. In addition, China's full accession to the World Trade Organization (WTO) in 2001 has contributed to lower tariffs and the elimination of quotas, bringing Sino–Japanese trade barriers to a record low level and promoted bilateral trade relations (Blancher and Rumbaugh 2004). In terms of price level, the database Numbeo (2013) indicates that China enjoys a low-end product cost advantage absolutely and relatively, while Japan's high-end goods are cheaper than those in China, despite Japan's individual disposable income level being much higher than that of China's.

The Eaton and Kortum (2002) (EK henceforth) model, as the standard model for welfare analysis in trade, can be used as a guide for China–Japan trade sanctions. The model is developed and quantified as a tractable Ricardian model of international trade, which depart from Dornbusch, S. Fischer and Paul Anthony Samuelson (1977) and captures the competing forces of comparative advantage, as well as both natural and artificial geographic barriers inhibiting this. The model reflects many fundamental qualities of trade activities, which are: (i) trade diminishes with distance, (ii) prices vary across locations, (iii) factor rewards differ across countries, and (iv) relative productivities vary across industries. These facts are highly relevant to China and Japan's trade relationship as the first pair of facts indicates the role of geographical barriers in economic activity while the second pair suggests that the countries are at different technological levels. While the artificial geographic barriers, such as tariffs and quotas and negotiation problems, are interpreted as trade impediment factors, these variables can be manipulated for the purpose of conducting policy experiments. However, the EK model is believed to best describe trade in manufactured goods

among industrial countries, such as OECD countries. China, with an income per capita level only 12% of Japan's, is still a developing country on its path to stable and permanent industrialisation. Therefore, the EK model is unsuited to reconciling significant characteristics of China and Japan's trade activities. The major issue is that the EK model assumes that goods produced in different places differ only in quantity, but not in quality. Such an assumption would not be able to provide sufficient information for China and Japan's consumption and production activities, as well as the price discrepancy in high-end and low-end goods within a country and across different countries.

Fieler (2011) improved model, based on Eaton and Kortum's work as a prototype, is more applicable in this case, as it moves beyond the assumptions of homothetic preferences and uniform quality goods, which are inconsistent with micro-level evidences. To overcome the limitations, the goods are divided into types, which differ in two aspects: demand and quality. The model predicts that poor countries concentrate their spending on types of goods with low income elasticity, and rich ones on types with high income elasticity. As an analogue to product cycle theory, the model concludes that, under general equilibrium, countries in which overall productivity is low have low wages and produce less differentiated goods; technologically advanced countries have high wages and produce goods that require more variable technologies across countries. Such conclusions are in line with the empirical evidence on Japan and China and hence help to buttress the credibility of counterfactual simulations. Therefore, this paper adopts Fieler (2011)'s method and uses global bilateral merchandise trade flow data in 2000. The parameters included correspond to: (i) each

country's technology state, governing absolute advantage, (ii) the heterogeneity across goods of the same type, governing comparative advantage within each type, (iii) the heterogeneity across different types and the income elasticity of demand, and (iv) all countries' pair-wise trade barriers. Hence, Fieler (2011)'s model is one of the best currently available to tackle the principal problem of evaluating the economic costs of unilateral Chinese trade sanctions on Japan. The parameters estimated enable the quantification of the general equilibrium in the model and allow us to examine the counterfactual situations numerically, which is the focus of major interest.

Furthermore, overall welfare in a country has to be defined explicitly in order to quantify the policy impact. There are a number of different criteria available. In this study, as fairness of income distribution in a country is not the major concern, real GDP is hence adopted as the main welfare indicator. Moreover, since the population is fixed throughout in all scenarios, it is not necessary to distinguish between GDP and GDP per capita. The welfare is hence calculated by the summation of values generated from the per capita amount of each type of good consumed.

Counterfactual simulations illustrate China's and Japan's welfare consequences and the impact on the global economy numerically under a variety of unilateral Chinese trade sanctions:

1. Universal Japan-oriented boycotts or embargoes, or both from the Chinese side would impede both countries' access to trade, and would reduce both country's general welfare levels. Under all circumstances, China would suffer more in terms of drop in percentage of real GDP. Both country's consumption and

production patterns would be altered. Meanwhile, high-end products would become more expensive in China, hinting at a further divergence of comparative advantage. The changes of newly established equilibrium nominal wages do not show any conformity under different Chinese courses of action, although the change direction of rising or falling are always opposite for both countries.

2. Implementing partial restrictions of trade with Japan by imposing an import tariff or export tax would compensate China with additional revenue, but China would still be harmed more in percentage terms before the revenue redistributes throughout all levels of taxation. The changes in welfare, purchasing power, consumption and production patterns, and in bilateral trade volumes in both countries are much more drastic at low duty rates, and become steadier at a higher level, converging on the outcomes of comprehensive restrictions for both sides. Moreover, at a lower range of duty rates, and provided that revenues are distributed properly, China would suffer less than Japan, or even benefit marginally, although the distribution activity itself requires extra administrative costs.

3. The impact of China's unilateral trade sanctions would spread to other countries, even if they did not participate directly. Proximate countries having close but simpler trade relations with both China and Japan would react most responsively. The direction and magnitude of changes would depend on various factors, such as the countries' income level per capita, technology status, and balance of trade position. Furthermore, even for a single country, the con-

sequent welfare changes would vary according to different types of Chinese trade sanctions.

One caveat to avoid is to generalise the above counterfactual simulation results as the ultimate outcome of the corresponding policies. The model adopted in this study, however, does not take account of either the possibility of retaliation to Chinese trade policy by Japan nor the importance of intermediate goods in Chinese-Japanese trade. Those factors are more likely to adversely affect both countries' welfare. Due to the limited scope, the related impacts are not incorporated in this paper.

The rationale for China's frequent threatening of trade sanctions against Japan but unwillingness to implement them is well explained by the counterfactual simulation results as summarised. At the beginning of the twenty-first century, China has yet to implement trade sanctions, as most possible forms of such trade sanctions would be neither cost-efficient for its own economy nor punitively effective toward the target country, Japan. Furthermore, there would be an inevitable global spill-over as a result of such measures. The involuntary involvement of other countries in an economic conflict of this sort would likely complicate the issue even more for China as it may require further multilateral actions to restore the relations with its neighbours. Therefore, China has mainly used the threat of trade sanctions to signal its discontent and to exert some diplomatic pressure on Japan, as well as, perhaps even more importantly, to assuage the Chinese public's anti-Japan sentiments.

The paper is organised as follows. In Section 3.2, I present the theoretical framework of the model adopted. It delivers relationships connecting trade flows to bilateral

trade barriers, as well as technology, aggregate prices and nominal wages. This is followed by empirical specifications justifying its validity specifically in analysing the China–Japan case. Section 3.3 uses the qualified model to explore the counterfactual scenarios quantitatively deriving the main findings listed above. Section 3.4 provides some comments on the generated results. Section 3.5 concludes. The Appendices report the details of the data.

3.2 Theoretical Framework

Fieler (2011)'s work is a general equilibrium Ricardian model of trade. The essence of the model is that it allows for the divergence of the elasticity of trade with respect to income per capita, technology status and population. Traded goods are divided into various types according to the differences in income elasticity of demand. The model is originally meant to describe global bilateral trade patterns. Nevertheless, it is capable of capturing the basic features of China's and Japan's production, consumption and trade patterns, as well as providing adequate explanation of price discrepancy within and across countries. I believe the counterfactual simulations derived from the model are more representative and provide valuable insight into the welfare analysis.

The original model Fieler (2011) proposed divided goods into various types. However, a special case with two types of goods is adequate for this research for two reasons. As the database from the Ministry of Commerce, People's Republic of China (2013) shows, Chinese exports to Japan consist mostly of primary commodities compared to Japan's high-technology exports. The tradable products can hence be classi-

fied into two types based on the heterogeneity of production technology required. The goods that require more heterogeneous technology and are more differentiated are denoted type h, an analogue to high-end products. Rich households tend to concentrate spending on this type of good, and type h is hence more income-elastic in responses to demand. Moreover, due to the highly differentiated nature, type h goods cannot easily be substituted and have low elasticity of substitution. Likewise, the other group of goods denoted type l, also known as low-end products, can be produced by more homogeneous technology, are easily substitutable, and are less income-elastic. Normally, type h goods are high-value-added, while type l are equivalent to low-value-added goods.

To justify the coexistence of these two distinct types of goods and their roles in characterising the general trading products, the empirical specification of parameters must conform to the presumption of income and price elasticities mentioned above and, furthermore, must reflect the dominant production and consumption of low-end goods in China and high-end goods in Japan. Another reason for the division of goods into two types is that Fieler (2011) conducted robustness checks on dividing goods into more types and showed that the benefit would be marginal compared to the two-type case.

The model adopted is based on several assumptions similar to those commonly applied in the theory of trade. It is assumed that sanctions are expected to impact the target country immediately once implemented. However, the time-consuming decision-making process gives the target the opportunity to organise and evaluate the effect in quick responses. Therefore, although the punishment of sanctions is in-

evitable provided that the initiator acts, the effect of such actions will be mitigated by the target's reaction by establishing new trade relations or intensifying existing ones. Moreover, the model assumes the balance of trade for each country in aggregation.

I introduce the basic settings of the model in Section 3.2.1. Section 3.2.2 closes up the model under the general equilibrium. The estimated parameter values are provided in Section 3.2.3, together with a validation of the model and an explanation of its workings.

3.2.1 Basic Settings

The total number of countries in the world is denoted by N. The goods, as justified above, are divided into two types $\tau \in \{h, l\}$, such that type h goods demand more heterogeneous production technologies than type l ones. Each type of goods follows the Dornbusch, S. Fischer and Paul Anthony Samuelson (1977) model of Ricardian trade with a continuum of goods. Type τ goods are denoted by $j_\tau \in [0, 1]$. All consumers have a heterogeneous preference towards different types of goods. A representative consumer purchase of type τ goods in amounts $q(j_\tau)$ to maximise the utility function,

$$U = \sum_{\tau \in \{h,l\}} \left\{ (\alpha_\tau)^{1/\sigma_\tau} \left(\frac{\sigma_\tau}{\sigma_\tau - 1} \right) \int_0^1 [q\,(j_\tau)^{(\sigma_\tau - 1)/\sigma_\tau}] dj_\tau \right\}, \tag{3.1}$$

where $\alpha_\tau > 0$ are weights and $\sigma_\tau > 1$ for all τ. The weights are normalised to $\sum_{\tau \in \{h,l\}} (\alpha_\tau)^{1/\sigma_\tau} = 1$. Parameter σ_τ is not only associated with the elasticity to substitution, but more importantly with the income elasticity of demand. Denote x_τ

to be the total spending on type τ goods. The first-order conditions for the utility maximisation problem illustrates that

$$\frac{x_h}{x_l} = \lambda^{\sigma_l - \sigma_h} \left(\frac{\alpha_h P_h^{1-\sigma_h}}{\alpha_l P_l^{1-\sigma_l}} \right), \tag{3.2}$$

where P_τ is the constant elasticity of substitution price index of type τ goods and $\lambda > 0$ is the Lagrange multiplier associated with the consumer's maximisation problem, which can be interpreted as the marginal utility of income showing strictly decreasing monotonicity in a consumer's total income. As the income elasticity of demand of type τ is $\frac{w}{x_\tau}\frac{dx_\tau}{dw} = -\sigma_\tau w \frac{d\lambda}{dw}$, where w is a consumer's income, the relative income elasticity of demand for type h goods to that of type l equals $\frac{\sigma_h}{\sigma_l}$. Accordingly, with a one-to-one relation between w and λ, Equation (3.2) implies that consumers with different income levels allocate their spending on different types of goods to maximise their utility.

As in the Ricardian model, due to the perfect mobility of production factors across types and goods but strict immobility across countries, the cost of the inputs bundle is treated the same across commodities within a country, as the EK model also suggests. Denoting that input cost in country i as c_i, with a constant returns scale, the cost of producing a unit of good j_τ in country i is then $\frac{c_i}{z_i(j_\tau)}$, where $z_i(j_\tau)$ represents the efficiency level in producing good j_τ. For the sake of conciseness, wage analysis is focused, so labour is considered as the only factor of production. Therefore, the unit cost becomes $\frac{w_i}{z_i(j_\tau)}$, where w_i is the wage in country i.

Based on Paul A Samuelson (1954) standard 'iceberg costs' assumption, trans-

porting one unit of good j_τ from country i to country n requires producing d_{ni} units in i. d_{ii} for all i is normalised to one, while with positive cross-border trade barriers, $d_{ni} > 1$ for $n \neq i$. The triangle inequality holds for all i, k and n, such that $d_{ni} \leq d_{nk} d_{ki}$, eliminating the possibility of arbitrage. Hence, the total costs of delivering one unit of good j_τ produced in country i to country j is

$$p_{ni}\left(j_\tau\right) = \frac{d_{ni} w_i}{z_i\left(j_\tau\right)}.$$

Assuming perfect competition in the goods markets, the price of good j_τ faced by consumers in country n is

$$p_n\left(j_\tau\right) = \min\left\{p_{ni}\left(j_\tau\right) : i = 1, \ldots, N\right\}.$$

As in the classic EK model, the technologies are followed by a probabilistic representation. For any $z \geqslant 0$, the measure of the set of good $j_\tau \in [0, 1]$ such that $z_i\left(j_\tau\right) \leq z$ is of the country and good-specific probability distribution $F_{i\tau}\left(z\right) \leq z$. By the law of large numbers, $F_i\left(z\right)$ is also the fraction of type τ goods for which country i's efficiency is below z. The probability theory of extremes provides a form for $F_{i\tau}\left(z\right)$ equalling to the cumulative distribution function of a Fréchet random variable

$$F_{i\tau}\left(z\right) = \exp\left(-T_i z^{-\theta_\tau}\right), \tag{3.3}$$

where $T_i > 0$ for all countries $i = 1, \ldots, N$, and $\theta_\tau > 1$ for all types. These distributions are treated as independent across countries and types.

Crucially, the parameters T_i and θ_τ capture the concepts of absolute and comparative advantage across a continuum of goods. T_i defines country i's overall state of technology. The assumption that T_i does not depend on the type of good types implies absolute advantage in the manufacture of all types of goods. Parameters θ_τ regulate heterogeneity across goods in countries' relative efficiencies. They have a dual role in the model. Firstly, the variability of technologies across goods governs comparative advantage within types. The smaller θ_τ, the larger the dispersion in labour efficiencies. Consequently, the price differences of the same type of good would be greater, leading to more intensive trading of such goods. Secondly, the variability of labour efficiencies across countries governs the comparative advantage across types. The expectation of the relative cost of importing good j_τ from country i to producing it domestically in country n equals

$$\frac{E\left(p_{ni}\left(j_\tau\right)\right)}{E\left(p_{nn}\left(j_\tau\right)\right)} = \left(\frac{T_i}{T_n}\right)^{-1/\theta_\tau} \frac{d_{ni} w_i}{w_n}, \tag{3.4}$$

which implies that, with a greater θ_τ, the relative effective wages dominate the level of technology in determining the relative price, while when θ_τ decreases, the ratio of the technology parameters becomes more deterministic. Therefore, to accommodate the presumptions of a discrepancy between type h and type l goods, the specified value of θ_h must be lower than θ_l, while the income effect parameter must be $\sigma_h > \sigma_l$. The difference between the two countries should be captured by lower wage and technology levels in China.

3.2.2 Equilibrium

The model is closed under general equilibrium conditions. Briefly, again, the economy is defined by a set of N countries, with each country i's population L_i, technology parameter T_i, and trade costs $\{d_{ni}\}_{n,i\leqslant N}$, where n represents the importer and i the exporter. The goods are divided into two types: $\tau \in \{h, l\}$. Each good has the technology parameter θ_τ and preference parameters α_τ and σ_τ. Following the previous literature, population and labour force are not distinguished. All countries have a continuum of individuals who supply inelastically one unit of labour. The EK model has provided the necessary condition for a finite solution, which is $(\theta_\tau + 1) > \sigma_\tau$ for $\tau \in \{h, l\}$. An individual consumer's demand function of a country is derived from the distribution of technologies, which yields the distribution of prices, together with the utility function. The spending of a typical consumer in country n on goods of type τ is

$$x_{n\tau} = \lambda_n^{-\sigma_\tau} \alpha_\tau P_{n\tau}^{1-\sigma_\tau}. \tag{3.5}$$

where $\lambda_n > 0$ is the Lagrange multiplier corresponding to the consumer's problem. $P_{n\tau}$ is country n's price index of type τ goods. As in the EK model, the price index is

$$P_{n\tau} = \left[\Gamma\left(\frac{\theta_\tau + 1 - \sigma_\tau}{\theta_\tau}\right)\right]^{1/(1-\sigma_\tau)} (\Phi_{n\tau})^{-1/\theta_\tau}, \tag{3.6}$$

where Γ is the gamma function and $\Phi_{n\tau} = \sum_{i=1}^{N} T_i \left(d_{ni} w_i\right)^{-\theta_\tau}$. Using the property of the price distributions, the probability that country i provides a good τ at the lowest

price in country n is

$$\pi_{ni} = \frac{T_i \left(d_{ni} w_i\right)^{-\theta_\tau}}{\Phi_{n\tau}}. \tag{3.7}$$

Since the goods are perceived as a continuum, this probability can also be viewed as the fraction of goods τ that country n imports from county i. The spending of a consumer in country n on goods of type τ from country i is

$$x_{ni\tau} = \frac{T_i \left(d_{ni} w_i\right)^{-\theta_\tau}}{\Phi_{n\tau}} x_{n\tau}. \tag{3.8}$$

Aggregately, country n's imports from country i is

$$X_{ni} = L_n \left(\sum_{\tau \in \{h,l\}} x_{ni\tau} \right). \tag{3.9}$$

Since the supply of goods equals demand, the labour market clearing conditions are as follows:

$$L_i w_i = \sum_{i=1}^{N} X_{ni} \quad \text{for } i = 1, \ldots, N. \tag{3.10}$$

The equilibrium is thus a set of wages $w \in \Delta\left(N-1\right)$ that satisfies the market clearing conditions.

Moreover, when the equilibrium conditions hold, it is straightforward to denote country i's per capita type τ goods production level per capita in country i to

$$s_{i\tau} = \frac{1}{L_i} \sum_{n=1}^{N} L_n x_{ni\tau}. \tag{3.11}$$

3.2.3 Empirical Specification

Based on Fieler (2011), the bilateral merchandise trade flows data is obtained from UN Comtrade (2010). Data on population L and national income w come from the The World Bank (2011) provides observations from 162 countries. (A comprehensive country list is included in Appendix C.) The data specific to pairs of countries is taken from Mayer and Zignago (2011). The parameter estimates are identified simultaneously from the supply and demand side in the efficient way described as in Fieler (2011).

3.2.3.1 System of Trade Flows

For the entire N countries, individual population L_i, wage w_i, technology parameter T_i and trade costs d_{ni} determine the trade flows. The good's technology parameters θ_h and θ_l govern the distribution of technology; utility parameters σ_h and σ_l control the income elasticity of demand; the expenditure weights of type h and type l goods are α_h and α_l, respectively. Referring to the database, N, L_i, w_i are treated as known, where N equals the number of countries, which is 162; L_i is approximated by the country's total population, while income per capita is used as a proxy for wage w_i.[4] The parameters: $\{d_{ni}\}_{n,i=1}^{N}$, $\{T_i\}_{i=1}^{N}$, θ_h, θ_l, α_h, α_l, σ_h, and σ_l are unknown parameters which need to be identified.

Identification of σ and θ Fieler (2011) has experimented with several values for θ_h and σ_h, and concluded that neither the objective function nor the interpretation of

[4]Fieler (2011) has argued that although there are ways to distinguish population and labour force, the modification only complicates the notation and exerts nil impact on the empirical results.

the parameters estimated and the results would change under different combinations. Hence, in order to recover the remaining parameters, θ_h is fixed as 8.28, the median estimate of manufactured goods in OECD countries, which can represents high-end good in our setting. $\sigma_h = 5$ is set arbitrarily to meet the condition that $\sigma_h \leq \theta_h + 1$.

Trade Barriers d_{ni} Anderson and Wincoop (2004) have pointed out that since direct measures of trade costs are remarkably sparse and inaccurate, theory-based equations provide better inferences about unobservable trade costs. As in Fieler (2011), the trade costs are simplified from the traditional exponential functional form to the following:

$$d_{ni} = \begin{cases} 1 & \text{for } n = i \\ 1 + (\gamma_1 + \gamma_2 D_{ni} + \gamma_3 D_{ni}^2) \cdot \gamma_{border} \cdot \gamma_{language} \cdot \gamma_{agreement} & \text{for } n \neq i \end{cases}. \quad (3.12)$$

where $\gamma_{border} = 1$, if country n is contiguous to country i, and it is a parameter to be estimated otherwise. Similarly, $\gamma_{language}$ and $\gamma_{agreement}$ refer respectively to whether countries n and i share a common language, and whether they have a trade agreement.[5] Variable D_{ni} is the distance (in thousands of kilometres) between countries n and i. γ_1, γ_2, γ_3 lay out the effect of physical distance on the trade barrier. Denote the set of trade cost parameters to $\Upsilon = \{\gamma_1, \gamma_2, \gamma_3, \gamma_{border}, \gamma_{language}, \gamma_{agreement}\}$ and the pairwise data set of distance, common border, language and trade agreement to $\tilde{\Upsilon}$.

[5]The trade agreements are listed by the World Trade Organization (2011b).

Technology Parameters T_i With parameters $\{\Upsilon,\ \theta_h,\ \theta_l,\ \alpha_h,\ \alpha_l,\ \sigma_h,\ \sigma_l\}$, data $\left\{L,\ w,\ \tilde{\Upsilon}\right\}$, equilibrium conditions (3.10) pin down the technology parameters $\{T_i\}_{i=1}^{N}$, which clear the global market. In that sense, the number of parameters to be estimated is reduced to N, which equals 162.

Trade Flows z_{ni} The trade flow from country n to i is denoted as z_{ni}, and z is the corresponding vector. To account for country size and gain estimation efficiency, Fieler (2011) has suggested the normalisation of trade flows in the such a way that $z_{ni} = \frac{X_{ni}}{X_n X_i}$, whereas the trade flows are divided by the importer's product and the exporter's total income. By substituting the trade costs as given in Equation (3.12) and the implicit solutions for technology parameters T_i, the vector of trade flows becomes a function of the data $\left\{L,\ w,\ \tilde{\Upsilon}\right\}$ and parameters $\{\Upsilon,\ \theta_h,\ \theta_l,\ \alpha_h,\ \alpha_l,\ \sigma_h,\ \sigma_l\}$, plus the error term ϵ :

$$z = f\left(w,\ L,\ \tilde{\Upsilon};\ \Upsilon,\ \theta_h,\ \theta_l,\ \alpha_h,\ \alpha_l,\ \sigma_h,\ \sigma_l\right) + \epsilon. \tag{3.13}$$

Fieler (2011) estimates the equation using non-linear least squares (NLLS). Following the remark on J. E. Anderson and Van Wincoop (2003)'s discussion on error terms, the estimator is unbiased if ϵ is uncorrelated with the derivative of f with respect to $\left\{L,\ w,\ \tilde{\Upsilon}\right\}$. This assumption holds if the error term is interpreted as a measurement error. Although the error term can enter the model in other ways, Fieler (2011) has simulated several situations that indicate that the effects of structural errors in trade costs are likely to be small on wages, which is our main focus.

Table 3.1: Summary of Parameters and Estimation Results

Parameter	Implication	Value	S.E.
Normalised			
θ_h	Distribution of technology in Type h	8.28	–
σ_h	Income elasticity of demand in Type h	5.00	–
Estimated			
$(\alpha_h)^{1/\sigma_n}$	expenditure share in Type h	0.82	0.03
θ_l	Distribution of technology in Type l	14.34	0.95
σ_l	Income elasticity of demand in Type l	1.29	0.10
γ_1	Trade barriers parameter - interception	1.38	0.04
γ_2	Trade barriers parameter - distance	0.20	0.03
γ_3	Trade barriers parameter - distance square	-0.01	0.00
γ_{border}	Trade barriers parameter - border sharing	0.99	0.07
$\gamma_{language}$	Trade barriers parameter - common language	0.93	0.05
$\gamma_{agreement}$	Trade barriers parameter - trade agreement	1.22	0.12

Notes: It is not intuitive that the trade agreement among countries would increase the trade costs by 22% from the specification. Moreover, Promfret and Patricia (2009) concludes the Asian trade agreements have helped to reduce the related trade costs. The misspecification might be a hidden problem here, since the construction of the trade barrier is not comprehensive and so calls for further work.

3.2.3.2 Estimation of Results

This paper reproduces the estimation parameter values. They are presented in Table 3.1. This model confirms the coexistence of two types of goods in the economy as claimed, because $(\alpha_h)^{1/\sigma_h} \in (0, 1)$. Type h has a higher income elasticity of demand, $\sigma_h > \sigma_l$ ($\sigma_h = 5$ and $\sigma_l = 1.29$), and presents more heterogeneous production technologies, $\theta_h < \theta_l$ ($\theta_h = 8.28$ and $\theta_l = 14.34$). The hypothesis is that $\sigma_h > \sigma_l$ and $\theta_h < \theta_l$ cannot be rejected at a 0.1% significance level. Hence, type h is confirmed to be relevant to the high-end goods and type l to the low-end goods in trading between China and Japan. To illustrate the global trade pattern, Figures 3.1 and 3.2 plot

the production, [6] demand, and net exports of type h and l goods respectively, as a fraction of GDP, against income per capita. Both demand and production curves are upward sloping in Figure 3.1, since, generally, rich countries produce and consume relatively more goods that require heterogeneous technologies, that is, high-end goods, in accordance with empirical evidences. The net exports of type h form a V-shaped curve concentrated on the two ends, indicating a small balance of trade for low- and high-income countries, while the trade deficits of middle-income countries are significantly larger, implying that middle-income countries consume more type h goods than they produce. Figure 3.2 shows that low-income countries produce mostly type l goods, while middle-income countries are large net exporters of such products.

More detailed results for China and Japan from the predictions of the model are given in the following tables. In Table 3.2 on page 147, the variable 'Wage' is calculated as the relative value to the U.S.'s individual income level. Accordingly, the other variables, 'Price Level', 'Real Wage', and 'Consumption/Production Per Capita' can be viewed as relative values corresponding to the U.S.'s initial wage normalisation. A representative consumer utility is derived directly from the utility function of Equation (3.1) after the substitution of the optimal consumption bundle in the equilibrium. As suggested in the EK model, one of the welfare measures is

[6] The calculation of production is flawed in Fieler (2011). The type τ goods production level per capita in country i is $\frac{1}{L_i}\sum_{n=1}^{N} L_n x_{ni\tau}$. However, in Fieler's (2011) replication package it has been mistaken as $\sum_{n=1}^{N} x_{ni\tau}$, which tends to overestimate individual production level for countries with large populations while to underestimate it for smaller ones. Therefore, the exact share of type h goods $\frac{\sum_{n=1}^{N} L_n x_{nih}}{\sum_{n=1}^{N} L_n x_{nih}+\sum_{n=1}^{N} L_n x_{nil}}$ is substituted to $\frac{\sum_{n=1}^{N} x_{nih}}{\sum_{n=1}^{N} x_{nih}+\sum_{n=1}^{N} x_{nil}}$ in country n, which are not equivalent. Nevertheless, the alternative way of calculating production generates little adjustment to the production share of each type of goods; Figure 1 shows almost identical picture as in Fieler's (2011) Figure 7.

captured by $W_{n\tau} = {}^{w_n}/_{P n\tau}$, an analogue to the real wage in country n in terms of obtaining goods of type τ.[7] Combining the Equations (3.6) and (3.7) and setting $i = n$ delivers an expression relating $W_{n\tau}$ and share of domestic supply π_{nn} in the country n:

$$W_{n\tau} = \left(\frac{T_n}{\pi_{nn}}\right)^{1/\theta_\tau} \left[\Gamma\left(\frac{\theta_\tau + 1 - \sigma_\tau}{\theta_\tau}\right)^{-1/(1-\sigma_\tau)}\right]. \tag{3.14}$$

Since the autarky indicates $\pi_{nn} = 1$, from the expression, we can infer the gains from trade from the share of domestic supply, since such a ratio is negatively correlated with the real wage. The Chinese market of type h goods benefits extensively from the trade, as their share of supply is as low as $1.38 \times 10^{-4}\%$. Type l goods in China and type h goods in Japan are more self-sufficient within their own countries and, hence, do not gain as much from trading. The price ratio indicates that low-end goods are much cheaper than high-end goods in China, implying that type l goods' have a comparative advantage in China; in fact, such goods also have an absolute advantage compared to those in Japan and worldwide. Japan, identified as a natural manufacturer owing to its technological edge, in contrast, enjoys both comparative and absolute advantage in type h goods. Reasoning in a similar way, the consumption of type h takes 88.28% of Japan's gross domestic product (GDP), while China's consumption of type l is the dominant expenditure with a share of 99.04%. Correspondingly, Japan produces most type h goods (90.39% of the country's GDP), while Chinese production of type l is negligible.

[7]The model is constructed with uniform nominal wage in producing different types of goods within a country; however, the purchasing power of the wage in obtaining various goods can still be captured by the conventional real wage.

Table 3.2: China and Japan's Key Variables: Modelled Results Under Baseline

		China		**Japan**	
Wage	(w_n)	0.0274		1.0592	
Utility Per Capita	(U_n)	0.3768		1.5472	
Price Ratio	(P_{nh}/P_{nl})	2.0282		0.9146	
Real Wage Ratio	(W_{nh}/W_{nl})	0.4931		1.0934	
Consumption Share of Type h	(x_{nh}/w_n)	0.96%		88.28%	
Production Share of Type h	(s_{nh}/w_n)	1.72×10^{-6}%		90.39%	
		Type h	Type l	Type h	Type l
Price Level	$(P_{n\tau})$	1.4752	0.7273	0.9056	0.9902
Real Wage	$(W_{n\tau})$	0.0186	0.0377	1.1696	1.0697
Consumption Per Capita	$(x_{n\tau})$	2.6285×10^{-4}	0.0272	0.9351	0.1241
Production Per Capita	$(s_{n\tau})$	4.7136×10^{-10}	0.0274	0.9574	0.1018
Share of Domestic Supply	(π_{nn})	1.38×10^{-4}%	99.70%	99.43%	82.05%

Notes: The wages here are calculated as the relative values to the initial U.S. wage, that is, the U.S. wage is normalised to 1. Henceforth, other non-ratio/share variables are subject to such normalisation. The ratio/share variables are the quotients of relevant variables.

Table 3.3 on the following page shows the China–Japan bilateral trade flow and indicates the quantity that each country imports from its counterpart, both at per capita and aggregate level. The figures capture the key features of China and Japan's bilateral trade relations. China mainly exports low-end goods to Japan, while the imports from Japan are mainly of a higher standard. Notwithstanding the fact that per capita consumption level of high-end goods is negligible in China, the huge population makes the country a major exporting partner for Japan. Aggregately Japan has a large trade deficit with China.

Table 3.3: China–Japan Bilateral Importing Flows

	China		**Japan**	
	Type h	Type l	Type h	Type l
Per Capita	1.3434×10^{-4}	7.7012×10^{-8}	2.0503×10^{-10}	0.0030
Aggregate	1.6968×10^{5}	97.2663	0.0260	3.7833×10^{5}
Bilateral Net	1.6968×10^{5}	-3.78234×10^{5}	-1.6968×10^{5}	3.7823×10^{5}
Total Net	-2.0856×10^{5}		2.0856×10^{5}	

Notes: The per capita volume is subject to the normalisation with respect to the initial U.S. wage; the aggregate are the multiplication of per capita volumes and the country's population.

The two countries' top five trading partners for both types of goods, as recovered from the model, are listed in Table 3.4. Perhaps due to the highly stylised set-up of the specification of trade barriers (for example, the symmetric bilateral barriers), the model underestimates the trade volumes of both countries with some distant countries, such as the United States and Germany. Qualitatively, these predicted results manage to recover the general picture of China and Japan's trading pattern to a reasonable degree of accuracy. Japan tops the list as China's type h goods importer and type l goods exporter, while China plays a significant role in Japan's type l goods market. According to the empirical evidence, in the early 2000s, China's most active trading partners were Japan, the United States and other Asian countries and regions. Japan's leading trading partners were the United States, China and other nearby Asian countries and regions as well (UN Comtrade 2010). Table 3.4 also show that China and Japan share a number of mutual trade partners particularly in Asia, such as South Korea, Taiwan, Hong Kong, Malaysia. Such facts would imply that the impact of Chinese unilateral trade sanctions would be very extensive due to the existing multilateral close trade ties. In any case, because the main trade

patterns of both China and Japan are well captured in the model, in so far as they correspond to the empirical evidence, the model is hence validated for the numerical analysis of the economic effects of trade sanctions. Additionally, as some variables can be manually adjusted, applying the model is a practical means of providing the numerical evaluations to counterfactual simulations of various possible Chinese trade sanctions against Japan.

Table 3.4: China and Japan's Top 5 Trading Partners Recovered From The Model

	China				
	Type h			Type l	
	Importing	**Exporting**		**Importing**	**Exporting**
1	Japan	South Korea	1	South Korea	Japan
2	Taiwan	Japan	2	Taiwan	Hong Kong, China
3	South Korea	Taiwan	3	Malaysia	South Korea
4	Hong Kong, China	Hong Kong, China	4	Thailand	Taiwan
5	United States	Malaysia	5	Brazil	United States
	Japan				
	Type h			Type l	
	Importing	**Exporting**		**Importing**	**Exporting**
1	South Korea	South Korea	1	South Korea	China
2	Taiwan	Taiwan	2	China	Hong Kong, China
3	Hong Kong, China	China	3	Taiwan	South Korea
4	United States	Hong Kong, China	4	Brazil	Taiwan
5	Germany	Brazil	5	Malaysia	United States

Figure 3.1: Production, Demand, and Net Exports of Type h Goods

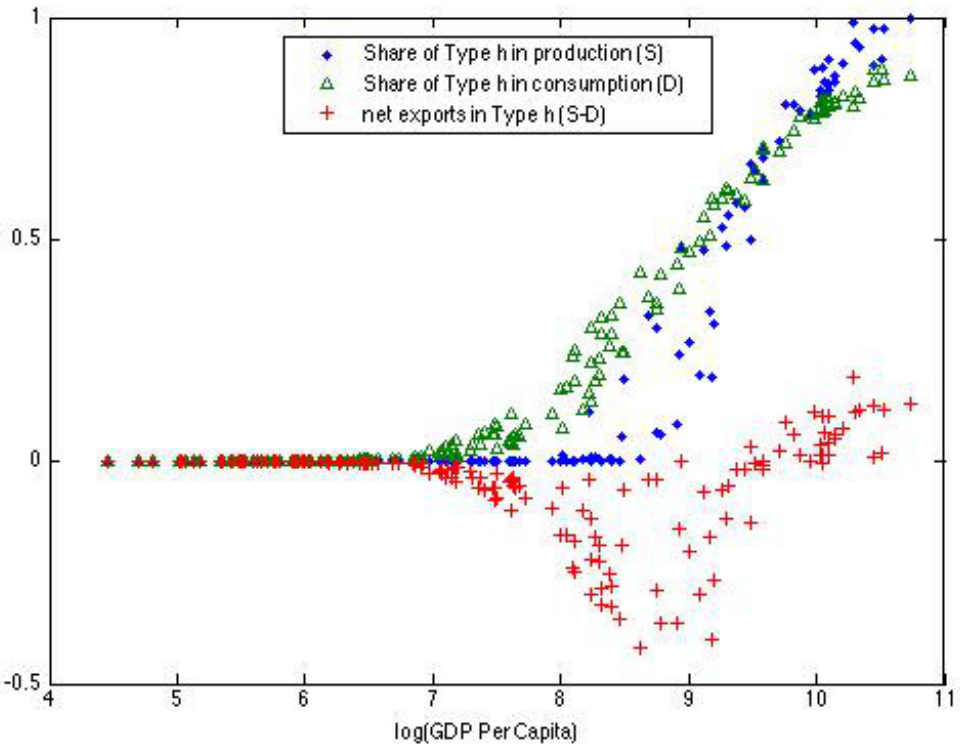
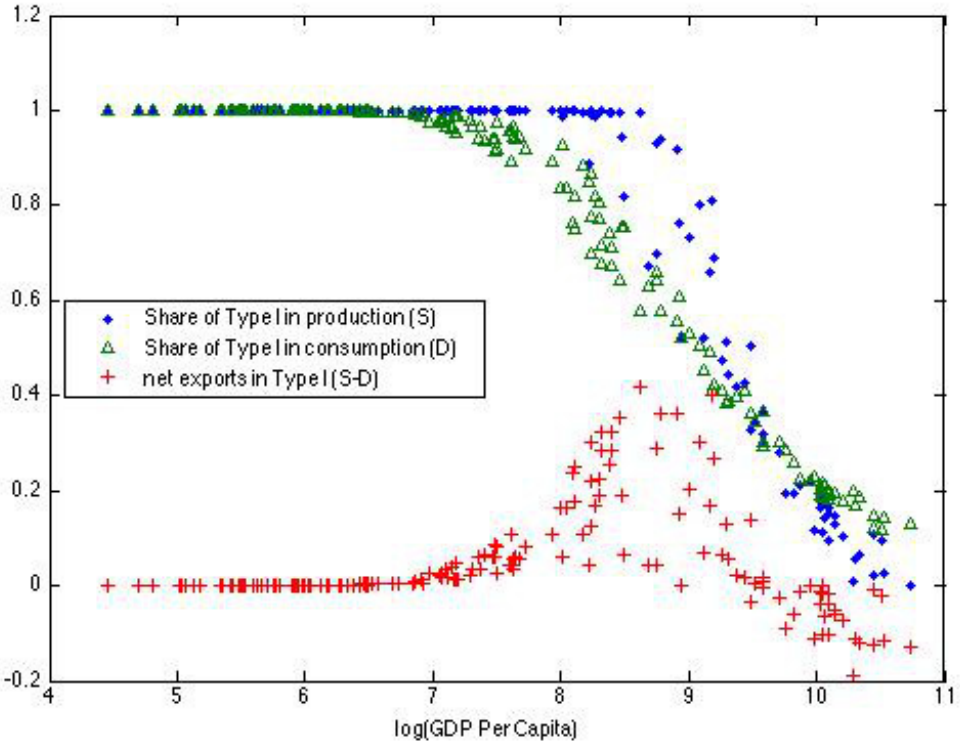


Figure 3.2: Production, Demand, and Net Exports of Type l Goods



3.3 Counterfactuals

Partial Equilibrium Analysis

This section approaches the problem from a simplified approach by modelling China's trade sanction policy as an exogenous change in trade costs in a partial equilibrium framework. The comparative statics are derived under the assumptions such that the global wage as well as every individual's import demand are fixed after the exogenous change. With such assumptions, the partial equilibrium analysis focuses on the goods market and provides the insights on how that market react in very short run.

According to Equation (3.8), an individual Chinese consumer's spending on goods of type τ from Japan is denoted as:

$$x_{(China,Japan)\tau} = \frac{T_{Japan}\left(d_{China,Japan}w_{Japan}\right)^{-\theta_\tau}}{\Phi_{China,\tau}}x_{China,\tau}.$$

China's trade policy of levying Japanese imports tariff can be modelled as an increase in the parameter $d_{(China,Japan)}$. By taking the first order derivation with respect to $d_{(China,Japan)}$, the change of a China consumer's spending on Japanese goods can be approximated as:

$$\Delta x_{(China,Japan)\tau} \approx -\frac{\theta_\tau \pi_{(China,Japan)\tau}(1-\pi_{(China,Japan)\tau})}{d_{(China,Japan)}w_{Japan}}x_{China,\tau},$$

where $\pi_{(China,Japan)\tau}$ is the fraction of goods τ that China imports from Japan. Hence,

the aggregated import change is:

$$-L_{China} \times \sum_{\tau \in \{h,l\}} \frac{\theta_\tau \pi_{(China,Japan)\tau}(1 - \pi_{(China,Japan)\tau})}{d_{(China,Japan)} w_{Japan}} x_{China,\tau}.$$

From the approximation, an increase in China's cost of importing from Japan, the aggregated change is always negative, as $\pi_{(China,Japan)\tau} \leq 1$ for both h and l. In addition, the total change is positively correlated with the country's labour market size, but negatively correlated with the initial trade costs and the trading partner's wage level. Other types of trade policy can be modelling in similar ways. However, the partial equilibrium analysis will lose its accuracy if the policy change is drastic, that is, the change of trade cost becomes very large. Additionally, the change in the trade costs will also trigger changes in the trade demand as well as the wage level. Therefore, general equilibrium analysis has to be adopted to provide a more comprehensive picture of the trade policy's after-effects.

General Equilibrium Analysis

The estimation of parameter values presented in Table on page 144 has quantified the adopted model and allowed for experiments of counterfactual situations involving China's implementation of trade sanctions. The numerical results of the counterfactuals should not be considered definite as a quantitative guiding line for policy analysis because the model itself is highly stylised. However, since the model captures the basic features of China and Japan's trade, regardless of the accuracy of the values of

the specific variables, the relative changes do provide some insight into the ordinal analysis of China's unilateral trade sanctions.

The fit of the model cannot be perfect because of its stylised nature. For example, the heterogeneity of geographic barriers across different types of goods are suppressed. Nevertheless, the effects of any of the counterfactuals can still be distinguished from the initial misfit of the model. Therefore, given actual GDP and population as in the database, the new equilibrium wages are derived from Equations (3.5) to (3.10) and they are compared with a baseline considered as the status quo.

The counterfactuals can be analysed according to a number of different criteria. The most important one among them is overall welfare in the country, measured by real GDP. As the population is held fixed throughout in each country, it is not necessary to distinguish between GDP and GDP per capita. The real GDPs of the counterfactuals are calculated by the summation of values generated from the per capita amount of each type of good consumed in the situation multiplied by the relevant baseline price. Mathematically, it takes the form $\frac{x'_{nh}}{P'_{nh}} p_{nh} + \frac{x'_{nl}}{p'_{nl}} P_{nl}$. The percentage change in welfare is hence calculated by the difference of counterfactual to baseline divided by baseline value. By way of the construction of welfare measure, the change in real GDPs is hence a composition of both income and price effects. Aside from evaluating welfare, other indicators, such as representative consumer utility, goods prices, consumption and production structures, are also examined. Moreover, because the aggregate balance of trade is established in the model for each country, the welfare implications drawn from either the consumption or production side would be equivalent for a country. I also investigate the corresponding changes of multilateral

trade flows.

In order to explore the numerical results of trade sanctions, China's actions should be quantified as the manipulated trade costs in different values. In cases of extreme excision of the trade sanctions, such that (i) China boycotts all Japanese imports; (ii) China embargoes all products to Japan; and (iii) China suspends all trade activities with Japan, the relevant trade barrier is set to infinity, resulting in a zero trade flow. When considering the effects of partial restrictions of trade activities by the means of tariffs, quotas and so on, the trade barriers are proportionally increased against the initial level, which would not completely eliminate the flows of trade. The entire economy is described by each country's population taken from the data and by the estimates of parameters T, θ_h, θ_l, α_h, α_l, σ_h, σ_l and of trade costs matrix d_{ni} through the estimates of Υ. The global wages taken from the data initially clear the global market. In performing the simulation of trade sanctions, the procedure is as follows: the relevant trade barrier value is modified, so that the general equilibrium is resolved, obtaining counterfactual wages under the adjusted trade barriers, and consequentially regenerating other variables' values for both sides. The multilateral spillover results affecting uninvolved countries are also derived from the newly established general equilibrium.

3.3.1 Counterfactuals of Boycotts and Embargoes

This part discusses the counterfactuals of China's universal restrictions of trade with Japan via boycotts and embargoes and both and provides an alternative perspective

on the situation of a complete suspension of trade activity. The conclusion arrived at from consideration of the evidence is that China would have been proportionally more impaired than Japan if these kinds of trade sanctions had been implemented in the early 2000s.

3.3.1.1 China Boycotts All Imports From Japan

A survey carried out by Japan Times (2013) suggested that over two-thirds of Chinese citizens would refrain from buying Japanese products as a result of the Senkaku/Diaoyu Islands spat of September 2012. With such lasting universal anti-Japan sentiment, the banning of Japanese imports seems to be a practical and opportune policy if the Chinese government aims to make use of its economic strength against Japan at any point of time. To simulate the extreme scenario of China blocking all Japanese imports, the trade barrier parameter is modified as $d_{China,Japan} \to \infty$, indicating that China initiatively makes the import trade costs from Japan infinite, resulting in a zero import trade flow from Japan. Intuitively, as the trade costs becomes significantly large, the unit costs of all products would be affected and would increase accordingly. The exporter loses absolute advantage in product prices, and the importer would hence refrain from buying from the initial partner and seek other alternatives that, though slightly more expensive than the original price, would still be cheaper than the cost of continuing to trade with the initial partner. Mathematically, from Equation (3.7), the spending of a consumer in country n on goods of type τ from country i becomes zero when $d_{ni} \to \infty$, given $\theta_\tau > 0$. Setting $d_{China,Japan} \to \infty$, and solving for the new market clearing wages, the results are presented in Table 3.5.

Based on the model and evaluated parameter values, together with the data from 2000, the simulation results indicate that China would lose more in terms of welfare percentage drop and consumer utility deprivation as an immediate effect of its unilateral boycott sanction. However, if the sanctions are prolonged, Japan would need to bear more costs to adjust its industrial structure to move away from its comparatively advantaged industry. Nevertheless, the likelihood of the long-term implementation of such sanctions is slim, unless the Chinese are willing to, and would be able to, afford such a substantial welfare loss perpetually. Such counterfactuals shed light on the claim that, in aggregate, Japan had a greater influence on China's import sectors than China had on Japan's export sectors in the early 2000s.

Table 3.5: Imports Boycott: China and Japan's Key Variables' Percentage Change (%)

	China		**Japan**	
Welfare	-4.94×10^{-2}		-7.35×10^{-3}	
Wage	0.89		-0.32	
Utility Per Capita	-1.38×10^{-2}		-4.85×10^{-3}	
Price Ratio	16.25		-4.65×10^{-2}	
Real Wage Ratio	-3.66×10^{-2}		0.18	
Consumption Share of Type h	-0.25		1.53×10^{-5}	
Production Share of Type h	4.96×10^{-9}		-7.10×10^{-4}	
	Type h	Type l	Type h	Type l
Price Level	8.97	0.88	-0.32	-0.27
Real Wage	-7.41	3.31×10^{-3}	-1.39×10^{-3}	-5.23×10^{-2}
Consumption Per Capita	-25.15	1.14	-0.32	-0.34
Production Per Capita	30.03	0.89	-0.40	0.41
Share of Domestic Supply	89.23	-0.05	0.01	0.75

Notes: All percentage changes of non-ratio/share variables are calculated as $100\left(\frac{x'-x}{|x|}\right)$, where x' is the value under $d_{China,Japan} \to \infty$ and x is the value in the baseline. The changes of ratio/share variables are calculated by direct subtraction: $(x' - x)$. For all ratios, the base category is Type l, the low value-added product sector.

a) Consumption, Production and Welfare Change in China

The nominal wage, rise in China and fall in Japan following an embargo of Japanese imports by China. As the analysis is medium-run in nature, the trade balance is assumed to be fixed multilaterally with existing trade partners in general. In this case, excessive Japanese goods produced, which originally aiming at selling in China, would have to be absorbed in the global market, hence, a cut in exports price, induced by cost reduction is as anticipated to stimulate the demand from Japan's other trading partners.

Meanwhile, with the absence of imports from Japan, China would have to seek alternative trading partners to meet internal demand, enhance existing trade relations and attempt to produce more by itself. However, such a deviation from the initial behaviour would nevertheless push up the country's costs in general. Hence, a ban on Japanese imports would lead to higher price levels of both types of goods in China. The real wage, equivalent to purchasing power in obtaining China's type h goods, would fall by 7.41%, which is much more rapid than for type l goods. Such a change has widened the gap between type l and type h industry even more; low-end goods, in which China specialises, would be more dominant in the whole economy.

The prediction of real wage change is essentially in line with the implication of the Factor Price Equalisation Theorem (Paul A Samuelson 1949), despite the fact that the model's set-up is quite different. The original version of the theorem states that, as a result of international trade in commodities, the real wage rate for identical jobs will tend to be equalised across countries. Unequivocally, the converse negative proposition of the theorem predicts that, with no Japanese imports, the real wage for

type l goods in China would tend to fall. Facing higher prices and lower purchasing power in the type h goods market, China would have more restricted access to the high-end goods, which are already rarely consumed. On the other hand, on the premise of China would be more self-sufficient in the type l goods market, the changes in that sector would be marginal compared to the drastic variations in the type h market. The purchasing power of type l goods would almost be maintained at the initial level. This situation would give rise to the shift in China's consumption pattern, with the share of consumption of type l goods increasing.

On the production side, both sectors would expand production to compensate for the internal demand left unmet by the absence of imports from Japan. The previously more Japan-dependent goods market h would be stimulated more and so would contribute a higher proportion to total productive activity after the boycott sanctions. From the dynamic point of view, such a change would help the development of China's heterogeneous sector through involuntary expansion, although the benefit would be marginal and constrained in the short run. Since the general wage level would be pushed up in the new equilibrium, China would suffer an overall loss in exporting, with weakened absolute cost advantage and more domestically oriented production. The total gain from trade would henceforth be abated. However, the damage would still be masked in the type l market due to its enhanced comparative advantage. The ratios of domestic supply as welfare indicators affirm the large harm in the type h goods market and the marginal benefit in type l. Nevertheless, China's general welfare level and the utility level of its representative consumer would suffer from the combined effect of price and income.

b) Consumption, Production and Welfare Change in Japan

In contrast, after being banned from exporting to China, Japan would face excessive supply, especially in the more trade-active goods market type h, which produces more goods originally intended for sales to China. As a result, the consumption bundle would be adjusted towards a more type h goods inclination, as the domestic market reacted to absorb the excessive supply of major high-end exports. However, the slashed real wages in obtaining both types of goods would inevitably lead to a shrinkage in Japanese consumption. In addition, the higher absolute and relative real wages in obtaining type h goods confirms the Factor Price Equalisation Theorem (Paul A Samuelson 1949), in that the higher real wage sector tends to offer even higher wages relatively, responding to the lack of exports to China, as evidence of wage divergence.

The new equilibrium wage level has to be reduced to provide Japan with an enhanced edge on absolute cost advantage and to expand overseas markets in order to keep its economy afloat. The production of type l goods improves, indicating dominance of the price substitution effect to help stimulate outside demand as well as to supply internal needs, while its production of its traditional strongholds, type h goods, declines because of more serious negative income effects resulting from China's boycotts. The production share of type h goods would decrease slightly, but the whole economy would nevertheless still remain dominated by the production of type h goods. Meanwhile, Japan's moving away from its more advantaged type h goods production would incur industrial adjustment costs and impair development pillars in the long run, although the cost would be subtle and difficult to analyse on the spot. Self-

fulfilment shares of both types of goods would rise after sanctions, suggesting the loss of welfare in both goods' markets, although Japan's specialised heterogeneous technological market would experience less harm due to its traditional dominance.

c) Trade Pattern Change

The bilateral importing flows changes are reported in Table 3.6. Although the boycott sanction would not directly target Japanese imports from China, China's banning of Japanese products would simultaneously reduce Japan's imports from China. The sector producing type l goods in Japan would respond more negatively than that producing type h goods due to Japan's closer relations with China in importing low-end products. Aggregately, China's reduction in imports from Japan would be much greater than that of Japan's from China, and the sanction would therefore put Japan into a further widened trade deficit with China.

Both countries' global trade flow changes with respect to the baseline per capita trade volume are depicted in Figures 3.3 and 3.4 on page 162. With an increased nominal wage in China compared to rest of the world, the imports would be expanded while the exports would shrink. For Japan, as nominal wage decreased relatively to baseline, the situation would be the reverse. (Both Countries' detailed import/export change patterns are included in Appendix D.) A strong positive correlation is identified between the trade volumes in the baseline and the magnitudes of changes after the imposition of the sanctions, indicating that countries that initially have closer trade ties would react more in the counterfactuals. The net exports are derived by deducting imports from exports in each country. Due to the inevitable consequence of

increases in production costs, China's net exports would be reduced, with especially significant declines in South Korea, Hong Kong, Taiwan, Malaysia, and the United States. These would also be the countries that would react most to Japan's nominal wage cut, with their response of a fall in gross barter terms of trade.

Figure 3.3: Imports Boycott: China Global Net Exports Pattern Change

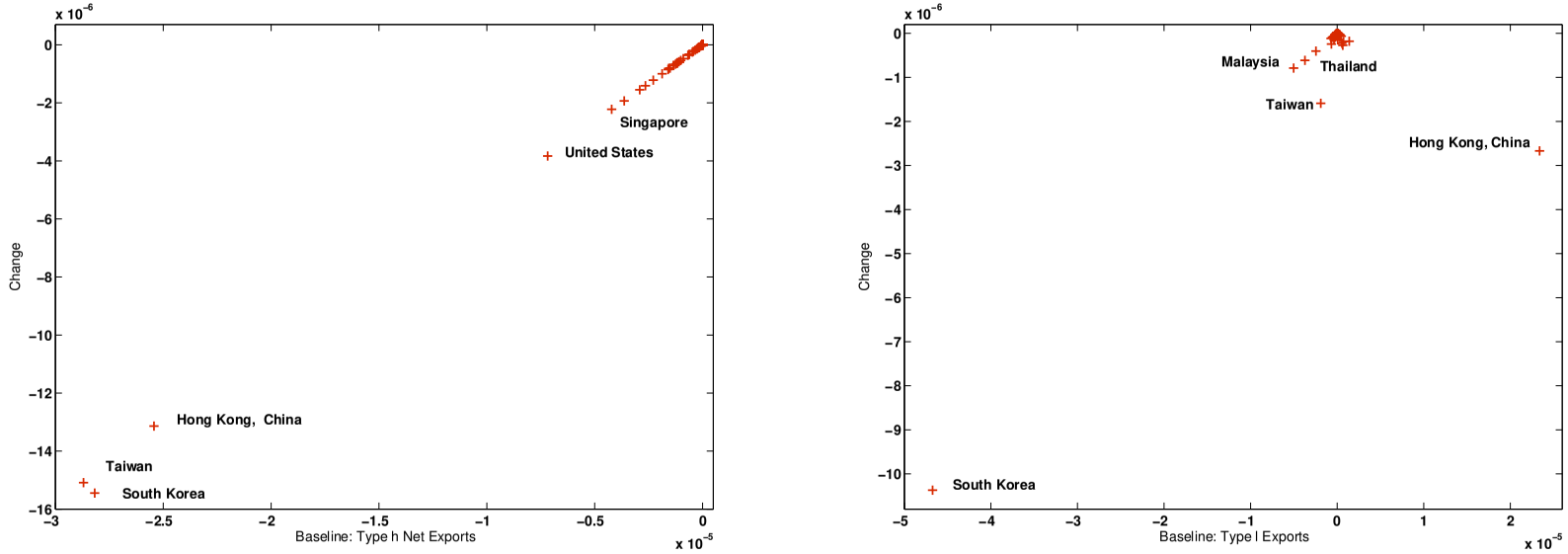
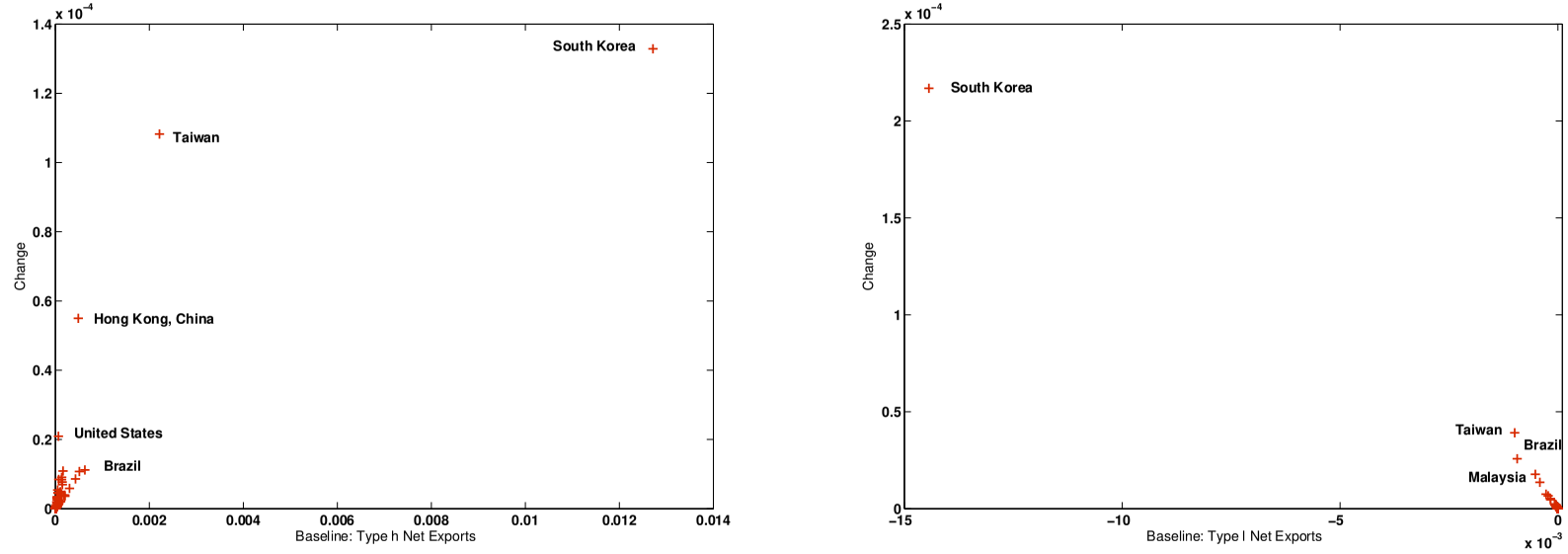


Figure 3.4: Imports Boycott: Japan Net Exports Trade Pattern Change



Notes: China and Japan's data are excluded here as most of them are outliers in the figures. They are better described in the bilateral trade pattern tables.

3.3.1.2 China Bans All Exports to Japan

In September 2010, the Chinese government was accused of blocking exports to Japan of a crucial category of rare earth minerals, used extensively in producing cars and electrical devices, in response to a dispute over Japan's detention of the captain of a Chinese fishing trawler (Bradsher 2010). Although the action was officially denied, such an event provides evidence for the possibility that China could use export prohibition as a method of trade sanctions against Japan. In the extreme eventuality that China halts all exports to Japan, the parameter of China's export barrier to Japan is manipulated to infinity, that is, $d_{Japan,China} \to \infty$, indicating that Japan would be passively confronted with infinitely large import costs from China and there would not be any trade flow from China to Japan. The simulated counterfactuals of this scenario are summarised in Table 3.7 on page 167.

It is unequivocally clear that limited trade activities would impair the country's well-being as a whole. In addition to a diminution in consumer utility, the unevenly increased trade costs in different markets would bring about the potential expense of industrial structure adjustment. In either country, relative price, real wages, consumption and production pattern would qualitatively change in the same direction as presented in Section 3.3.1.1, though dissimilarity is revealed in terms of absolute variation magnitude. The enlarged magnitude of change in this situation sheds light on the claim that China's exports to Japan exerts a larger impact than Japan's exporting to China in both the domestic and international markets. Furthermore, it substantiates the claim that, in the early 2000s, China relied more on Japanese demand to

keep its economy afloat than the other way around.

In the short run, China would still cause itself greater harm in terms of welfare as well as individual consumer utility levels by implementing a ban on Japanese exports. The embargo action hence appears even less effective than that of a boycott, as the real GDP drop in China is more than seven times that in Japan. However, Japan would be obliged to bear higher industrial structure adjustment costs and greater impairment to high-technology pillar if the trade sanctions were prolonged. With such a result, it is asserted that, aggregately, Japan had a greater influence on China's exporting sectors than China did on Japan's import markets at the beginning of the 21st century.

a) Consumption, Production and Welfare Change in China

Since China is more self-sufficient in low-end goods, the price of type l goods would fall accordingly to mitigate the nominal wage reduction, masking a larger welfare change. In contrast, high-end goods h, which have mainly relied on Japanese exports, would experience a much lower price drop even through nominal wage would be slashed; despite the effect of the enlarged absolute advantage for domestic supply, the real wage in obtaining type h goods would hence drop much more, by 9.86%. With the relative price rise of type h goods, it would become more preferable to spend on low-end goods and the consumption bundle is altered toward more bias on spending on type l goods. The intuition behind the consumption bundle shift would be that the excessive supply that was previously intended for export to Japan would be more easily absorbed domestically, while it is always more difficult to seek

alternative sources of acquiring type h goods.

On halting all exports to Japan, China would have to expand its production to other overseas markets in order to mitigate the negative income effect. This involuntary export expansion could only be attained by undercutting the production costs via the reduction of wages. Therefore, in contrast to the previous case, China's nominal wage would drop in the new equilibrium. On the production side, due to the slashed real wage in obtaining type h goods from outside, domestic production would increase by as much as 52.98% and improve the fraction of self-supplement even more, by 136.20%. Nevertheless, the insignificant baseline value implies that the sector that produces more heterogeneous goods would play a more marginal role in the whole economy than before, while the industrial pattern would remain more or less the same. The sector that produces homogeneous technological goods would not escape from the damage in this case, as the improved absolute and comparative advantage could not compensate fully for the income loss after the voiding of exports to Japan. Nevertheless, its share of domestic supply would increase little, by 0.23%, implying a much smaller welfare loss in the specialised industry.

b) Consumption, Production and Welfare Change in Japan

Japan would ultimately face higher importing costs if it needed to seek alternative importing substitutions besides China. The price levels of both types of goods would increase and lead to imminent supply shocks. However, since initially Chinese products with fewer technological requirements make up a substantial proportion of Japan's Chinese imports, China's suspended export activity would impact Japanese

market of type l goods more severely than its more self-sufficient market of type h goods. Therefore, the price of type l goods would rise more to the nominal wage, so the purchasing power of such goods would drop, resulting in lower expenditure on the low-end goods.

Triggered by the shrink in exports due to the loss in absolute advantage, the production sector of type h goods would stagnate, as prices would rise but output would fall. The embargoes would create a negative supply shock to Japanese markets, although the effect might be masked in type l goods by the increased demand from the international markets. Type l goods production, as well as the ratio of domestic supplement, on the other hand, would increase to satisfy the domestic demand. Nevertheless, the whole economy would still be mainly oriented to high technology goods as its comparative advantage is preserved, even exhibiting a weak improvement after the sanctions, conforming to the converse negative proposition to the Factor Price Equalisation Theorem (Paul A Samuelson 1949). Together with the positive effect on Japanese goods' enhanced absolute cost advantage, its high-technology pillar industry would be able to gain marginally, as inferred from the slightly decreased domestic supply share after China's embargoes. However, the increased proportion of type l goods in the production suggests that the economy would have to bear a potential cost from producing more of its comparative disadvantaged goods l and downsizing its more advanced technological sector.

Table 3.6: Imports Boycott: China–Japan Bilateral Importing Flows Change

	China		**Japan**	
	Type h	Type l	Type h	Type l
Per Capita	-1.3434×10^{-4}	-7.7012×10^{-8}	-2.0093×10^{-11}	-4.6393×10^{-4}
Aggregate	-1.6968×10^{5}	-97.2663	-0.0025	-5.8872×10^{4}
Percentage	-100%	-100%	-9.80%	-15.56%

Notes: The per capita/ aggregate changes are obtained from direct subtraction $(x' - x)$, where x' is the value under $d_{China,Japan} \to \infty$ and x is the value in the baseline. The percentage changes are calculated as $\frac{x'-x}{|x|}$.

Table 3.7: Exports Embargo: China and Japan's Key Variables' Percentage Change (%)

	China		**Japan**	
Welfare	-7.93×10^{-2}		-1.08×10^{-2}	
Wage	-10.02		0.12	
Utility Per Capita	-2.24×10^{-2}		-7.00×10^{-3}	
Price Ratio	0.22		-1.11×10^{-3}	
Real Wage Ratio	-4.85×10^{-2}		1.30×10^{-3}	
Consumption Share of Type h	-3.20×10^{-3}		4.16×10^{-5}	
Production Share of Type h	1.20×10^{-8}		-1.60×10^{-3}	
	Type h	Type l	Type h	Type l
Price	-0.18	-10.01	0.12	0.24
Real Wage	-9.86	-1.63×10^{-2}	3.10×10^{-3}	-0.12
Consumption Per Capita	-39.85	-9.73	0.13	8.64×10^{-2}
Production Per Capita	52.98	-10.02	-5.21×10^{-2}	1.76
Share of Domestic Supply	136.20	0.23	-2.56×10^{-2}	1.68

Notes: All percentage changes of non-ratio/share variables are calculated as $100\left(\frac{x'-x}{|x|}\right)$, where x' is the value under $d_{Japan,China} \to \infty$ and x is the value in the baseline. The changes of ratio/share variables are calculated by direct subtraction: $(x' - x)$. For all ratios, the base category is Type l, the low value-added product sector.

Table 3.8: Exports Embargo: China–Japan Bilateral Importing Flows Change

	China		**Japan**	
	Type h	Type l	Type h	Type l
Per Capita	-5.5539×10^{-5}	-6.1960×10^{-8}	-2.0503×10^{-10}	-0.0030
Aggregate	-7.0145×10^{5}	-97.2663	-0.0025	-3.7833×10^{5}
Percentage	-41.34%	-80.46%	-100%	-100%

Notes: The per capita/ aggregate changes are obtained from direct subtraction $(x' - x)$, where x' is the value under $d_{Japan,China} \to \infty$ and x is the value in the baseline. The percentage changes are calculated as $\frac{x'-x}{|x|}$.

Table 3.9: Trade Suspension: China and Japan's Key Variables' Percentage Change (%)

	China		**Japan**	
Wage	-7.94		0.69	
Welfare	-9.25×10^{-2}		-1.44×10^{-2}	
Utility Per Capita	-3.08×10^{-2}		-9.23×10^{-3}	
Price Ratio	0.38		-1.31×10^{-3}	
Real Wage Ratio	-4.85×10^{-2}		1.52×10^{-3}	
Consumption Share of Type h	-3.20×10^{-3}		4.72×10^{-5}	
Production Share of Type h	1.20×10^{-8}		-1.87×10^{-3}	
	Type h	Type l	Type h	Type l
Price	9.38	-7.92	0.69	0.83
Real Wage	-15.83	-1.51×10^{-2}	1.83×10^{-3}	-0.14
Consumption Per Capita	-52.93	-7.50	0.70	0.65
Production Per Capita	89.45	-7.94	0.49	2.65
Share of Domestic Supply	316.60	0.22	-1.51×10^{-2}	1.99

Notes: All percentage changes of non-ratio/share variables are calculated as $100\left(\frac{x'-x}{|x|}\right)$, where x' is the value under $d_{Japan,China} \to \infty$ and $d_{China,Japan} \to \infty$, and x is the value in the baseline. The changes of ratio/share variables are calculated by direct subtraction: $(x' - x)$. For all ratios, the base category is Type l, the low value-added product sector.

Table 3.10: Trade Suspension: China–Japan Bilateral Importing Flows Change

	China		**Japan**	
	Type h	Type l	Type h	Type l
Per Capita	-1.3434×10^{-4}	-7.7012×10^{-8}	-2.0503×10^{-10}	-0.0030
Aggregate	-1.6968×10^{5}	-97.2663	-0.0025	-3.7833×10^{5}
Percentage	-100%	-100%	-100%	-100%

Notes: The per capita/ aggregate changes are obtained from direct subtraction $(x' - x)$, where x' is the value under $d_{Japan,China} \to \infty$ and x is the value in the baseline. The percentage changes are calculated as $\frac{x'-x}{|x|}$.

c) Trade Pattern Change

Although China's embargo sanctions would not aim at reducing China's imports from Japan, the negative effects of China's embargoes on Japan would spread to China's import sectors. Table 3.8 on the preceding page presents the changes of bilateral importing flows. With China's domestic nominal wage slashed much more than Japan's, the Japanese products would become too expensive for China. China would move away from Japanese products, and both its markets would experience a drastic downturn in imports from Japan. The embargoes would create a trade deficit with Japan. The changes in China would be proportionally much larger than the change of its counterpart, as based on the case discussed in Section 3.3.1.1. This hints at the fact that Japan is more intertwined in China's economy than *vice versa*.

The movements of trade pattern, which again show a strong correlation between baseline trade volume and the absolute change magnitude, as shown in Figures 3.5 and 3.6 on page 174, suggests that both countries' close trading partners would be more distorted after China's embargoes. (The detailed import/export volume changes

are depicted in Appendix D.) China, with its more reduced wage to rest of the world, would reduce its imports while experiencing nominal expansion in exporting, while Japan would experience the opposite situation. Bilateral net exports from China to rest of the world would increase, in contrast to the downturn of those in Japan, especially towards proximate and remote, but large economics.

3.3.1.3 China Cuts All Trade Relations With Japan

The most stringent unilateral trade sanction that the Chinese side is able to implement would be cutting all trade relations with Japan. In this case, both trade barriers of $d_{China,Japan}$ and $d_{Japan,China}$ would become infinite, generating nil bilateral trade flow. Such extreme action would compel both countries to divert trade relations elsewhere and cause more extensive shocks to both economies. The simulated counterfactuals are discussed in the Table 3.9 on page 168.

Unsurprisingly, with the absence of mutual trade activities, both countries would *ipso facto* suffer a larger reduction of the general welfare level than would be the case under the void of either way trade flow, as presented in Sections 3.3.1.1 and 3.3.1.2. Such a sanction would again cause greater harm to China's economy in terms welfare loss and consumer utility drop in percentage terms. Dynamically, Japan would have to move further away from the production of type h goods as its production would fall in both absolute and relative values in the new equilibrium, resulting in adjustment costs and dynamic inefficiency.

a) Consumption, Production and Welfare Change in China and Japan

Qualitatively, the changes exhibit similar patterns to the outcomes discussed in Section 3.3.1.2, implying the more influential role of the Chinese trade outflow to Japan, or equivalently, Japan's trade inflow from China. The change to either country's dominant domestic industry would be much more moderate, while the damage to the unspecialised industry would be more significant compared with previous numerical results. These results are in line with the further implications of Factor Price Equalisation Theorem (Paul A Samuelson 1949), since it can be inferred that a further movement away from free trade would induce a larger discrepancy between factor prices. Noticeably, Japan's high-end goods sector would be sheltered from damage from the trade sanction because of its overall strong comparative as well as absolute advantage.

The new equilibrium wage in China would fall, in contrast to a moderate rise in the Japanese wage. In both countries, relatively expensive goods would become even more expensive while the relevant real wages of obtaining them would fall, resulting in a shift of consumption bundles' bias towards the relatively cheaper goods. The production bundles, however, would change in the other direction, as the the leftover demand for less specialised products would need to be fulfilled domestically. The shares of domestic supply would report significant losses in the high-end goods market while the damage to China's specialised industry would be much smaller. Japan's low-end market would suffer unequivocally. Noticeably, Japan's heterogeneous technological goods market would be sheltered from a negative income effect, as its ratio of domestic supply would decrease slightly, indicating that it manages to gain

more from expanding trades with rest of the world. The strong absolute as well as comparative advantage of Japan's high-end production is reaffirmed. The welfare loss stems from the combined effects for both sides. Once more, individuals in China are hurt more than their counterparts in Japan, in terms of percentage deterioration of welfare and utility.

An alternative perspective worth mentioning here is that the complete discontinuation of trade relations can be viewed as a form of revenge from Japan's side, provided that China uses a one-way trade blockage as the sanction method: Japan would be able to initiate blockage of trade the other way and hence increase the welfare impairment to China at its own cost. This retaliation would put both sides into an even worse situations since the above discussion has shown that the welfare loss and utility deprivation of suspending bilateral trade would be more severe than either one-way trade blockage. However, whether such retaliation is worth implementation is an open question that depends on Japan's primary objective. The complete termination of trade relations would protect Japan's priority high-technology industries, though the drawback would be the further decline of its unspecialised industries.

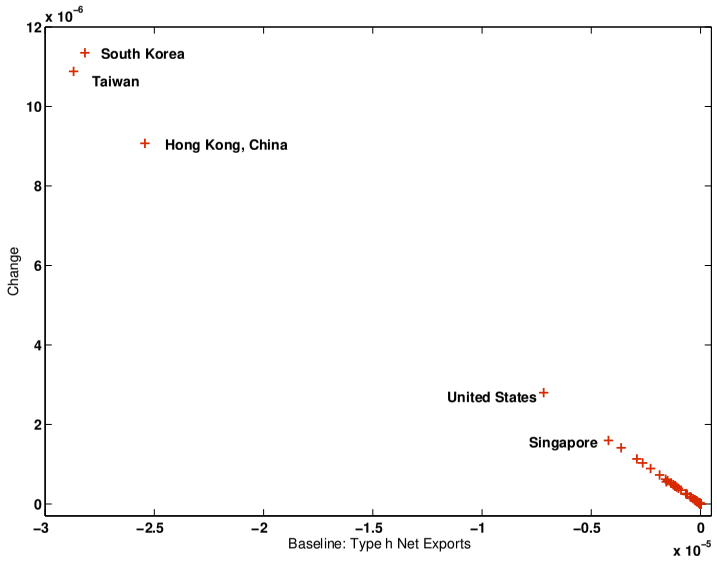
b) Trade Pattern Change

The complete break down of Sino–Japanese trade ties would result in zero trade flow from either direction, as shown in Table 3.10. As the effects of such sanctions on other countries becomes more complicated, the correlation between baseline trade volume and the magnitude of change becomes less significant than in the previous two situations. (The complete trade volume changes are provided in Appendix D.) The net

exports change patterns are shown in Figures 3.7 and 3.8 on page 175. Nevertheless, both countries' neighbours, such as Hong Kong, Taiwan, and South Korea, as well as their large trading partners, such as the United States and Germany would still react more in terms of changes in both inflow and outflow. The gross barter terms of trade would improve in China and become worse in Japan. The most active trade patterns would not change in order.

Based on evidence of the economic strength of each country, as well the trade dependent relations in the early 2000s, the model predicts that China would have been more vulnerable than Japan if it had implemented unilateral trade sanctions taking the form of boycotts, embargoes or both, even though the nominal variables differ in change directions. Furthermore, taking the fact that China's population is nearly ten times of that in Japan, it is indisputable that China, as a whole would suffer much more than Japan would. Such consequences implies that sanctions taking up the forms discussed would neither be brutal enough for Japan nor cost efficient for China. On the basis of this, the next step is to analyse the consequences of less extreme trade sanction measures as partial restrictions on bilateral trade.

Figure 3.5: Exports Embargo: China Global Net Exports Pattern Change



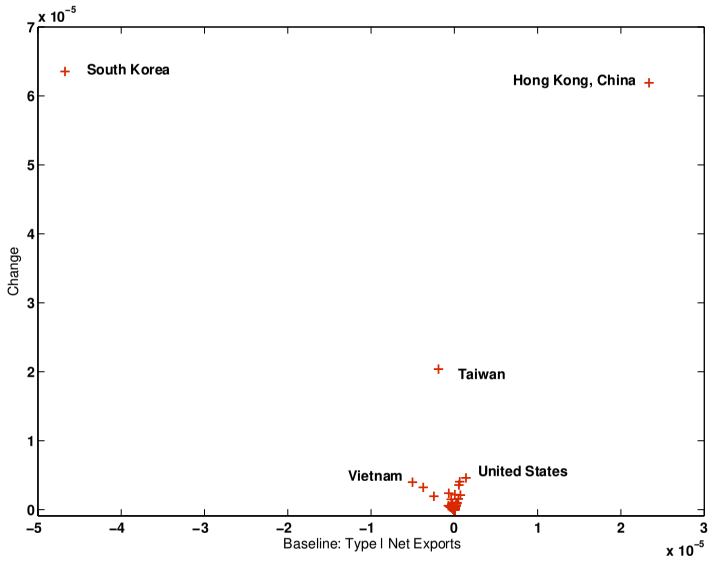
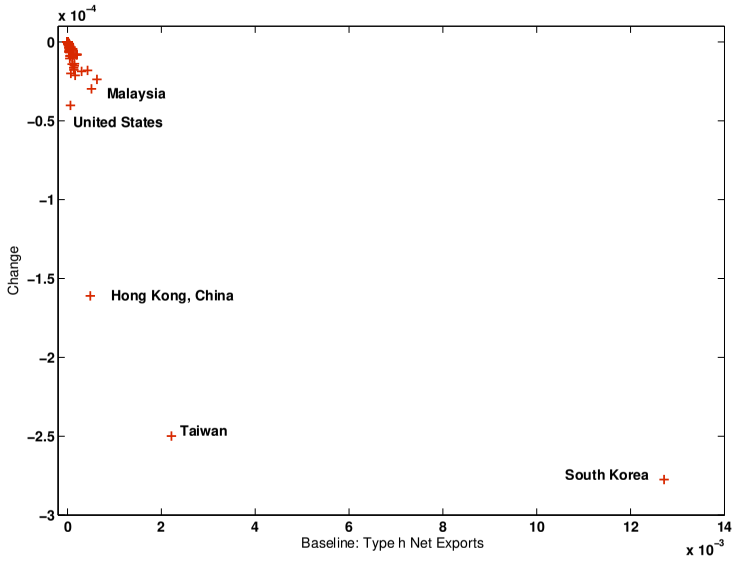
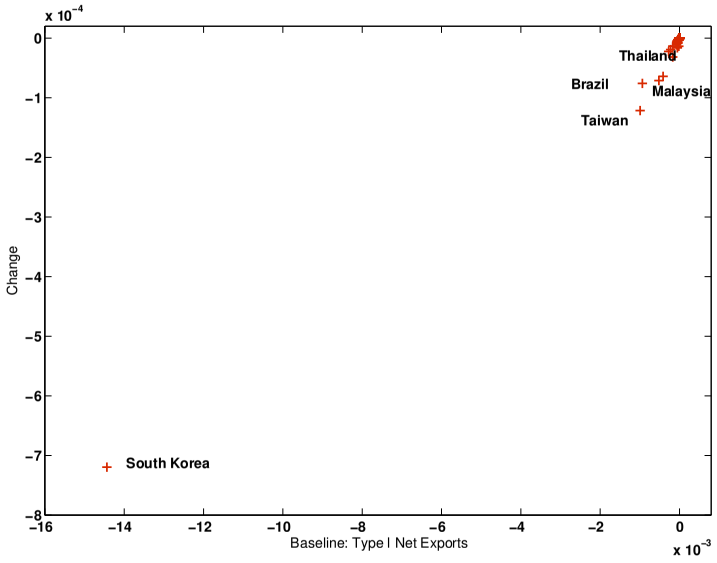


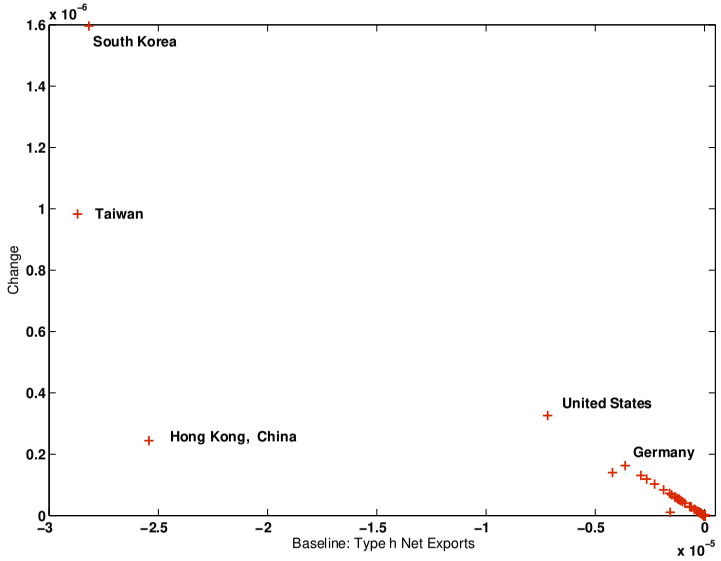
Figure 3.6: Exports Embargo: Japan Global Net Exports Pattern Change





Notes: China and Japan's data are excluded here as most of them are outliers in the figures. They are better described in the bilateral trade pattern tables.

Figure 3.7: Trade Suspension: China Global Net Exports Pattern Change



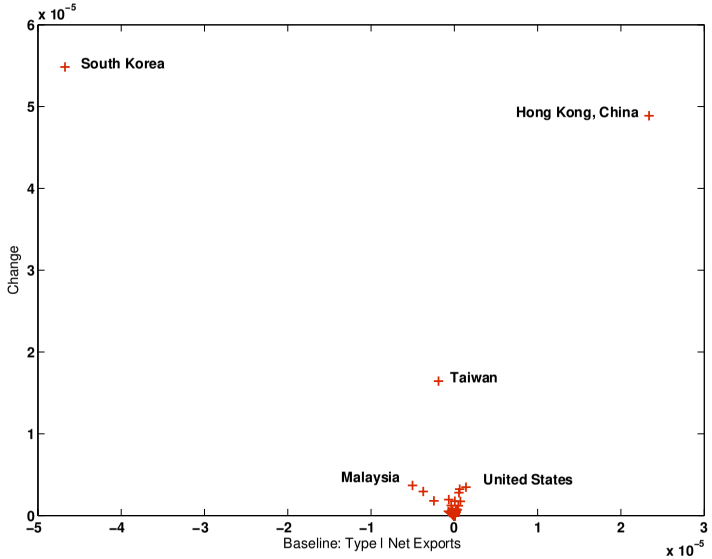
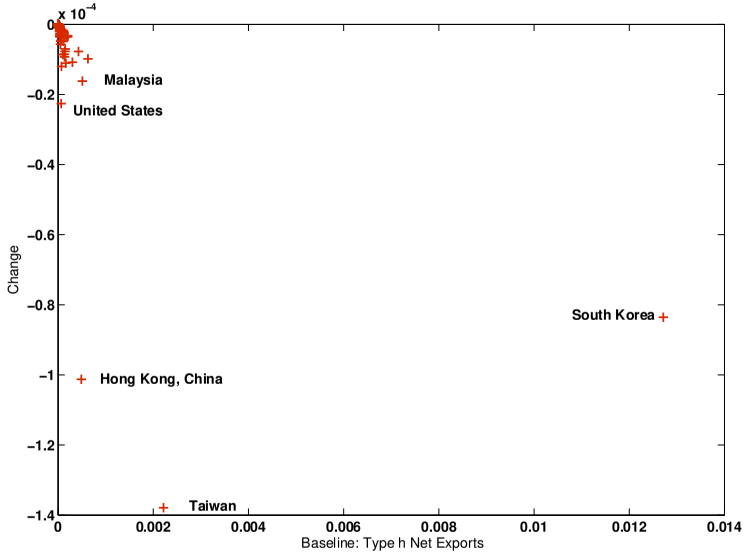
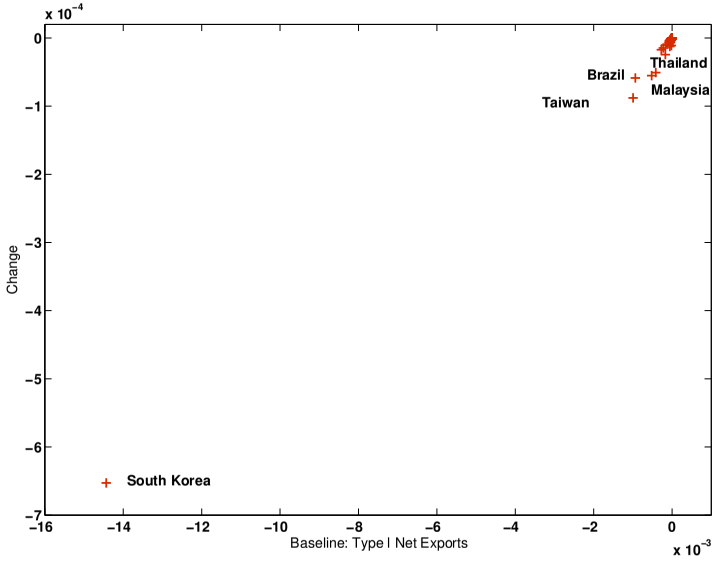


Figure 3.8: Trade Suspension: Japan Global Net Exports Pattern Change





Notes: China and Japan's data are excluded here as most of them are outliers in the figures. They are better described in the bilateral trade pattern tables.

3.3.2 Counterfactuals of Partial Trade Restrictions

Full-range products boycotts and embargoes are ways of implementing trade sanctions to fully interrupt economic ties between China and Japan. However, as China has been a member of WTO since 2001, such actions would run counter to the fundamental principles that WTO insistently defends, and the organisation would actively discourage these actions if the issue were to be submitted for settlement (Smeets 2000). Therefore, partially limiting the trade activities seems to be more applicable for China in order to avoid legal problems. Such trade restrictions can be achieved by applying the direct restrictions through import quotas and export restraints, as well by the imposition of tariffs and taxes, which are not prohibited by WTO.

Bhagwati (1965) has demonstrated that if perfect competition prevails in all markets, tariffs and import quotas are equivalent, in the sense that an explicit tariff reproduces an import level that, if set alternatively as a quota, produces an implicit tariff equal to the explicit tariff, and *vice versa*. Since all markets are assumed to be perfectly competitive, the tariff-quota equivalence holds in our model. Symmetrically, the export tax would be equivalent to voluntary export restraints in our setting. Hence, the outcomes of China's imposition of an import tariff and export tax are examined in this section to derive the economic effects of China's trade sanction deterrent against Japan as if enacted in the early 21st century.

The framework that has been used throughout this paper can readily incorporate the tariff and tax barriers. The geographic barriers d_{ni}, studied before, are viewed here as a composition of natural trade barrier d^*_{ni} and the part relating to the tariff/tax

component. In the case that China implements an *ad valorem* import tariff $t_{China,Japan}$ on CIF (cost, insurance and freight) prices of all goods from Japan, the trade barrier becomes $d_{China,Japan} = (1 + t_{China,Japan})d^*_{China,Japan}$ and the tariff revenue generated for the Chinese government would be:

$$TR_{China} = \frac{t_{China,Japan}}{1 + t_{China,Japan}} X_{China,Japan} = \frac{t_{China,Japan}}{1 + t_{China,Japan}} L_{China} \cdot \sum_{\tau \in \{h,l\}} x_{(China,Japan)\tau}. \tag{3.15}$$

In parallel, if the export tax t'_{ni} on FOB (free on board) prices of goods from China to Japan is adopted, then $d_{Japan,China} = (1+t'_{China,Japan})d^*_{Japan,China}$ and the tax revenue received by the Chinese government is augmented to be:

$$TR'_{China} = \frac{t'_{China,Japan}}{1 + t'_{China,Japan}} X_{Japan,China} = \frac{t'_{China,Japan}}{1 + t'_{China,Japan}} L_{Japan} \cdot \sum_{\tau \in \{h,l\}} x_{(Japan,China)\tau}. \tag{3.16}$$

[8]The status quo is taken as the baseline case and the current trade barriers $d^*_{China,Japan} = d^*_{Japan,China} = 1.7652$ are identified as natural trade barriers. In that sense, the tariff/tax rate would instead be considered as the increased percentage on the current tariff/tax. We then ask what happens when: (i) China imposes import tariffs on products from Japan varying from 0 to 100 percent, and (ii) China levies export taxes on products to Japan varying from 0 to 100 percent. The global equilibrium

[8]Furthermore, for the case of double-taxation on both Chinese imports and exports, the duty revenue equals $TR_{China} + TR'_{China}$, the importing tariff and the exporting tax rates can be varied. This action seems to be less practical in reality and as using too many forms of tax would repel the public and cause domestic instability. Moreover, as shown in Section 3.3.1.3, the outflow from China to Japan seems to be the guiding force in deciding the pattern of change after the combined effect. Therefore, it is expected that the patterns after double-taxation would strongly resemble that of exporting tax. As the combinations are numerous, the diagrammatic illustration would be too tedious to be included.

wages and the consequential changes to welfare and trade patterns are recalculated under the counterfactual trade barriers. Percentage change of real GDP is again identified as the major indicator of welfare measure.

The results confirm that the changes of all variables would monotonically increase in tariff/tax rate, implying that higher duty rate would have a greater impact on both countries' economies. The effects are more substantial at the lower rates of duties but becomes marginal at higher levels. The crucial distinction between boycott/embargo and duty policy is that the latter generates revenue for the government. This is the major difference that affects evaluation of the costs after duty policy trade sanctions. Since government revenue does not enter the expression of real GDP and consumer utility in our model, the critical issue lies in the way in which this revenue would be of benefit the whole economy. For the sake of simplicity, from here on the revenue is assumed to be distributed evenly across the whole population in the form of consumable goods; and each individual would receive a goods subsidy in proportion to the relevant optimal consumption bundle on both types of goods. Furthermore, the increment of demand is completely absorbed by internal supply, and hence no additional international trade activities would be raised as the revenue distribution and price level would remain the same. With such revenue distribution, the counterfactual results imply that China would be in the dominant position at some lower duty rates regarding the real GDP change, although Japan's economy would not be severely jeopardised.

3.3.2.1 China Imposing Import Tariffs on Imports From Japan

Qualitatively, the counterfactuals of the boycott situation discussed in Section 3.3.1.1 resemble the outcomes after imposition of import tariff at every single level of tariff rate for both China's and Japan's variables of consumption, production and welfare, although the magnitude of changes is smaller for the lower tariff rate. The binary relationship between the degree of changes in China and Japan is also consistent throughout. This is essentially because, before the distribution of the tariff revenue, all changes are initiated from the lifted Chinese import barrier from Japan and the mechanisms involved are exactly the same as in the infinite trade barrier case, despite the differences in variation degree. One point worth mentioning is that the changes to both economies are more drastic at lower levels of tariff rate and soon become steadier and approach the extreme situation as if the imports are completely banned. Such patterns can be explained by the concavity of the demand with respect to trade barriers in the model set-up; as for variables expressed in Equation (3.5) to (3.8), they all have negative second derivatives with respect to d_{ni}, implying that their responsiveness to trade barrier change decreases with larger trade barriers, or, equivalently, the tariff rate in this scenario. Nevertheless, we reach the same conclusion as in all previous cases: before the tariff revenue distribution, China would lose more than Japan by imposing import tariff, regardless of the tariff rates. (For the purpose of conciseness, the complete set of diagrammatic illustrations is attached in Appendix D.)

The revenue varies with the rate of the tariff. The pattern is depicted in Figure 3.9

on page 187. The total revenue peaks with a tariff rate of about 15% and decreases with higher tariff rates. The revenue distribution would not cause any extra distortion to Japan's economy based on the assumption of revenue distribution. The pattern indicates that Chinese consumers would be able to enjoy a welfare gain at a very low tariff rate, but that the benefit would diminish dramatically with increases in the tariff rate, although the redistribution would always be superior to the prior state. Such findings are well justified by the Theory of Optimal Tariff (Johnson 1953). It is claimed that, in a large country, due to the tariff's effect on the terms of trade, the country's welfare is maximised at a positive rate of the tariff. Although the tariff would increase the price levels and discourage consumption and production, it generates government revenue. Provided that the revenue is properly distributed and utilised, the overall benefits would outweigh the distortions at some specific rate. From Figure 3.10, China's real GDP is maximised at the tariff rate of around 5%, [9] and it would have greater benefits than Japan as long as the rate is below 13%. Nevertheless, the feasibility of equal distribution of tariff revenue and the method of satisfying increased domestic demand, is another problem. The gain would not come easily, unless some other hidden issues are solved. For example, the government may incur administration costs whilst the production sectors undergo transformation and expansion. Given the weak advantage that China would have at lower tariff rates,

[9]However, at this point, it is still not conclusive that 5% is the optimal tariff rate for China. Ogawa (2007) demonstrates that optimal tariffs rates are not uniform across types of goods as it depends on the compensated excess demand elasticity of the foreign countries's exports with respect to the price of foreign countries' imports. Hence, as the heterogeneity of trade barriers is suppressed in the model, it is still not possible to evaluate the outcomes of non-uniform tariff rates on different types of goods. Nevertheless, the model provides the optimal uniform tariff rate for China. Similar argument also applies in the discussion of export taxes.

such action would still seem infelicitous for China.

3.3.2.2 China Levying Export Taxes on Products To Japan

With the sole change of export barriers from China to Japan without tax revenue distribution, the counterfactual simulations at each level of export tax rate are again the same as the embargo situations discussed in Section 3.3.1.2, despite the degree of variation. The binary relation of change magnitude between China and Japan is also maintained at every rate, showing the consistency as in the extreme embargoes case. The results emphasise that, before tax revenue distribution, China would lose out more than Japan in terms of welfare after the levy of Japanese export taxes, regardless of the rate of tax. Moreover, in accordance with the results in Section 3.3.1.2 clarifying the more influential role of China's exports to Japan, the magnitude of changes would be amplified for each variable as in Section 3.3.2.1, with the relevant duty level. (The complete set of diagrammatic illustrations is included in Appendix C.)

The total tax revenue in this case is more responsive to the tax rate and it starts to drop at a lower rate compared with the situation for the tariff revenue. Figure 3.11 on page 187 shows that the tax revenue peaks at about 10% and becomes negligibly small when the rate is higher than 80%, indicating that Japan's drastic cut in import volumes cannot be compensated for by higher revenue from each unit. Noticeably, the highest export tax revenue is almost twice as much as that of import tariff. The tax revenue is distributed and utilised as assumed. The economy of Japan would again be unaffected by China's revenue distribution. The Optimal Tax Theory (Boskin and Sheshinski 1978) is applicable here in explaining the gain of China's welfare at

the initial stages, as shown in Figure 3.12. As with the presence of the externality, a certain level of positive tax rate will internalise its effects and optimising welfare. The optimal tax rate is identified as being around 5%. For taxation beyond the optimal level, China's real GDP would shrink rapidly and drops below the baseline once the tax rate is greater than 12%. For taxation below 20%, China would be in a more advanced position than Japan, but its welfare would plunge at a higher rate with less to be gained from the tax revenue. The best improvement of welfare in China is more significant than the case of import tariff and China would possess the dominance with a wider range of dominant tax rates zone. This suggests that China's levy of export taxes on production to Japan would have been a more worthwhile action than the imposition of import tariffs, provided that China had been deterministic in implementing trade sanctions.

3.3.3 The Extensive Global Impact of China's Sanctions

Under the framework of general equilibrium, China's unilateral trade sanctions would not exert economic effects on the initiator and the target alone. Although other countries' populations, geographical barriers and technology statuses would remain throughout, they would not be excluded from economic shocks once China would launch such measures. Figures 3.13 and 3.14 on page 188 present the ultimate situation of global welfare would change if (i) China boycotts all Japanese imports, and (ii) China bans all exports to Japan. (The comprehensive list of all countries and their indices are attached in the Appendix C.) The patterns indicate that the welfare effect

varies not only across different countries but differs also for a given country depending on China's level of trade sanctions. The two patterns do reveal some similarities. Both Japan's and China's proximity exhibit the largest welfare variation, regardless of their income level and economic size; however, the peripheral large economies also demonstrate responsiveness to China's actions to some extent, while the low-income and remote countries have the least sensitivity to the situational variations.

Following this glimpse of the extensive global results effected by China, I take a closer look at some typical countries' welfare variation outcomes with regard to different actions from the Chinese side. The welfare change of twelve representative countries has been selected for analysis. The countries are categorised into three different groups based on the characteristics of their economies sizes and their geographic relations to China and Japan. The first group is identified as both countries' higher income neighbours, which are South Korea, Taiwan, Macao and Hong Kong. They share the closet trade relations and interact most responsively with China and Japan. The second group of countries, Thailand, Malaysia, Vietnam and Mongolia, are also located close to both countries, but have relatively lower real GDP per capita than those in the first group. The United States, the United Kingdom, Germany and Australia, belonging to the third group, are all remote, high-income countries. They have quite close trade relations to both countries, though their trade ties are very widespread. The baseline case is again specified as current trade barriers $d^*_{China,Japan} = d^*_{Japan,China} = 1.7652$. The real GDP changes are depicted against the increase in the relevant trade barrier from 0 to 100 percent. Each group responds differently to China's raising of importing or exporting barriers to Japan. The patterns,

varying within and across the group, are illustrated in the follow sections.

3.3.3.1 Spillover Effect of Increasing China–Japan Import Barrier

The resolved general equilibrium conditions conclude that, as the China–Japan import barrier increases, the nominal wage in China would increase, while that in Japan would drop. Consequently, Japanese export would have improved in absolute terms while China's would have declined. The relative price of type h increases in China but decreases in Japan, indicating that both countries' comparative advantages are enhanced and that the specialised industry would be in a better position than minor ones. Such changes are the main source of spillover effect. Figure 3.15 on page 189 illustrates what would happen to welfare in different countries of the world as a percentage change to the baseline as a result of the proportional increase of the China–Japan import barrier. For all countries, the impact on welfare remains qualitatively the same at each level of the China–Japan import barrier, though the effect amplifies at a lower rate than the growth of the barrier.

For both countries' high-income neighbours, the increase in a Chinese barrier to imports from Japan would be a benefit. The counterfactual equilibrium shows that these four countries' nominal wage relative to Japan would increase while that to China's would decrease at different levels. Furthermore, the model predicts that all four of those countries would have trade deficits with Japan in type h, which is their main type of consumption. Therefore, the benefit of China's action is achieved via the consumption channel, with Japanese products diverted from China to them at a lower price. Meanwhile, with improved trade surplus positions with respect to China

in type h goods, the increased prices of Japanese products to China would also help them in exporting type h goods at a slightly higher price than the baseline, resulting in improved terms of trade in their preponderant type h goods. The country pairwise counterfactuals report increases in the quantity of type h goods exported to China from all four of these countries. However, due to Japan's slashed costs of production, these countries would lose part of their absolute advantage in the global market, resulting in loosened trade ties among themselves, as well as with other parts of the world. Nevertheless, the unfilled demand from China after such trade sanctions would be large enough to enable them to experience a welfare gain in aggregate.

The spillover effects illustrated within the second group are not uniform. The middle-income neighbours Malaysia and Thailand, who compete directly with China in low-end goods, would benefit from their lower equilibrium wages relative to China's. The gains occur especially in the type l goods market, which they are specialised in. The country pairwise counterfactuals indicate that their export to most countries within the Asian-Pacific region would be increased. Meanwhile, as large net importers of high-tech goods, the increase in overall price relative to their nominal wages would diminish the benefits. Hence, although they would still benefit, the extent of this would not be as large as that of their high-income neighbours. In contrast, the poorer countries Vietnam and Mongolia, being major net importers of low-end Chinese goods, would be harmed as a result of the higher import costs and lower net import volume from China, leading to a increase in domestic price of type l goods . Noticeably, Mongolia would suffer the most due to shrinking exports as well as the deterioration of trade. This change primarily hurts the poor countries whose minor

sector of type h goods and lack of intensive trade would benefit little from the drop in price of Japanese high-end goods, while also losing competence substantially in the welfare of type l goods.

The third group of countries have more diversified trade relations with the rest of the world. Their trade pattern changes appear to be more complicated than that of the previous two groups. Being the largest net exporters of type h goods, these countries benefit as China's actions would increase the price of type h goods relative to type l in many middle income countries, the largest net importers of high-end goods. However, as they also compete with Japan in terms of the heterogeneous technological goods in the global market, Japan's slashed type h goods price would improve its absolute advantage, and hence affect these rich countries adversely. Nevertheless, being the largest and most powerful economic entities in the world, the slightly improved welfare would be marginal.

Figure 3.9: Import Tariff: China's Total Tariff Revenue

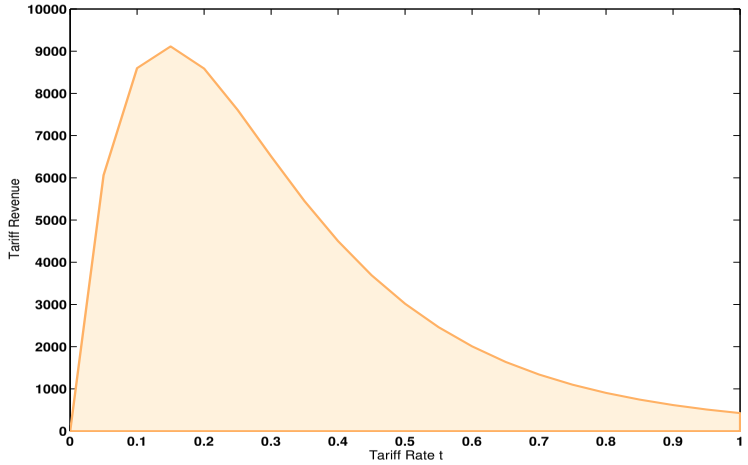


Figure 3.10: Tariff Revenue Distribution: Real GDP Change

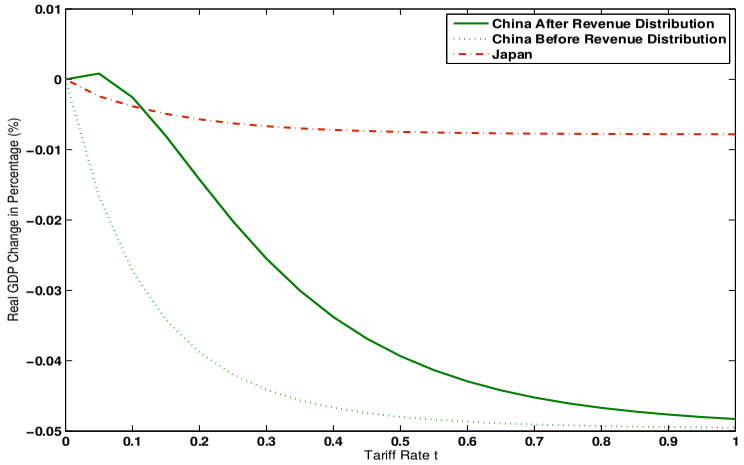


Figure 3.11: Export Tax: China's Total Tax Revenue

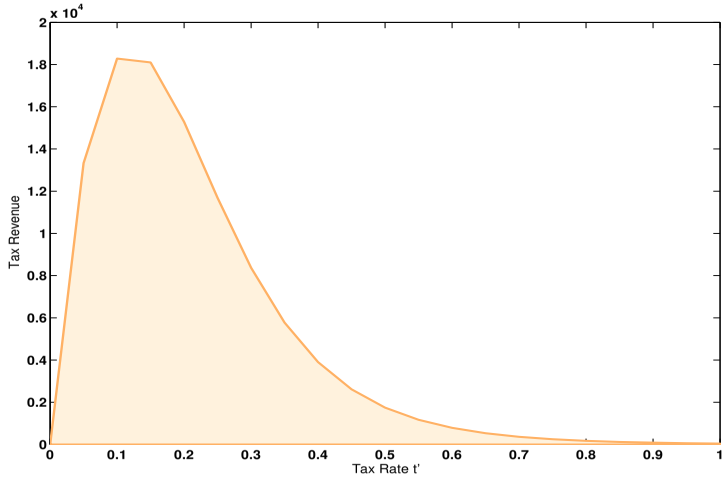
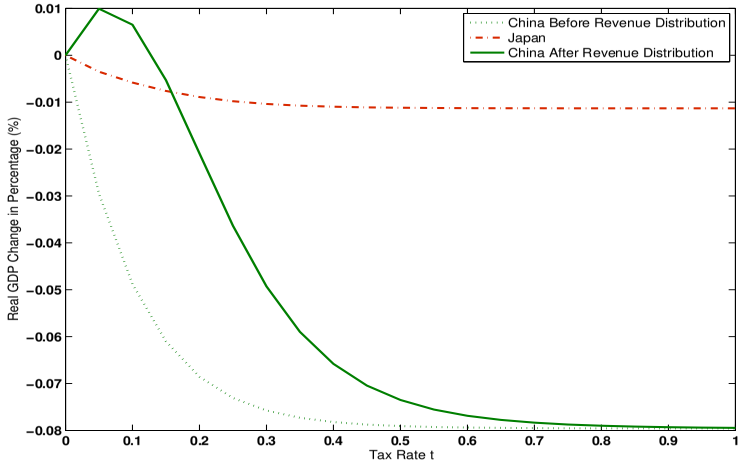


Figure 3.12: Tax Revenue Distribution: Real GDP Change



Notes: The tariff/tax revenue is subject to normalisation with respect to initial U. S. wage.

Figure 3.13: Imports Boycott: Global Welfare Change

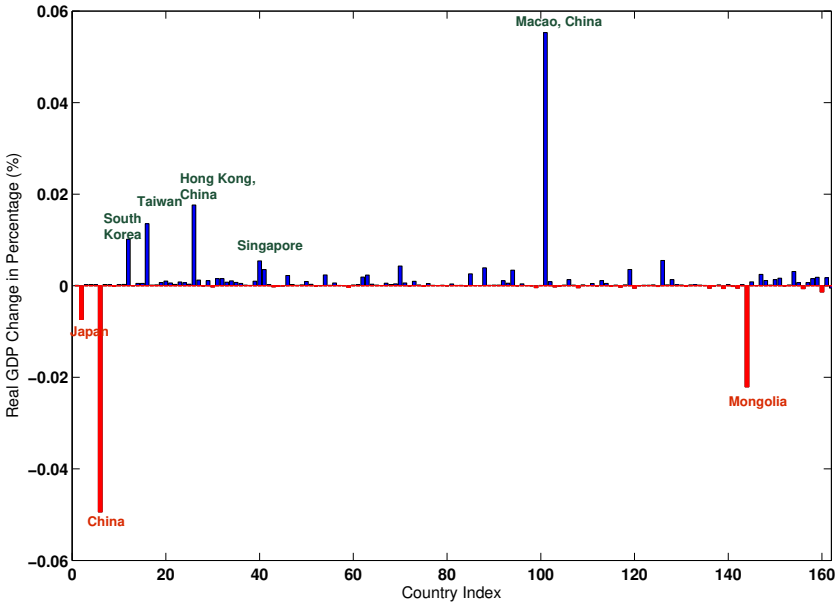


Figure 3.14: Exports Embargo: Global Welfare Change

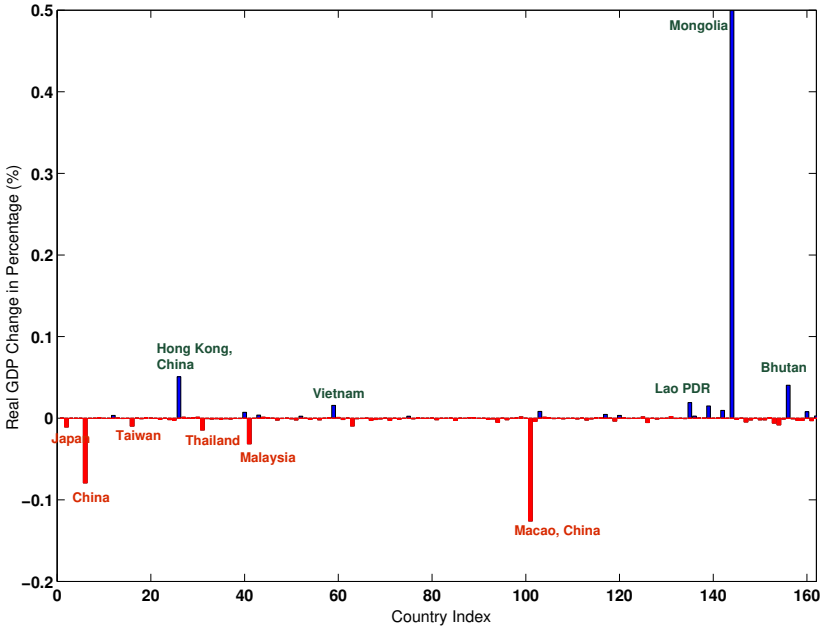
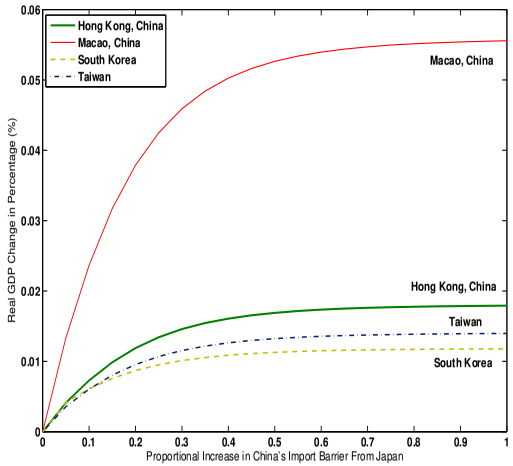
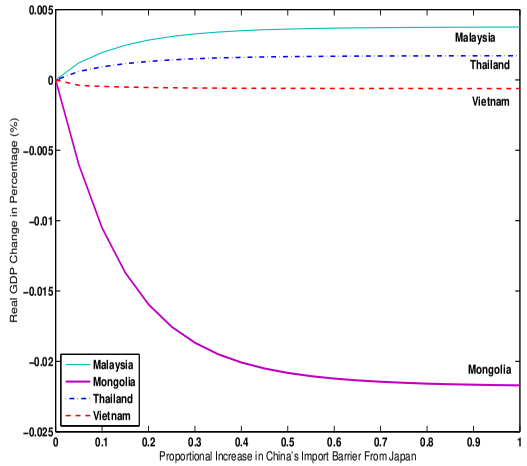


Figure 3.15: Increasing China's Import Barrier Towards Japan: Spillover Effects





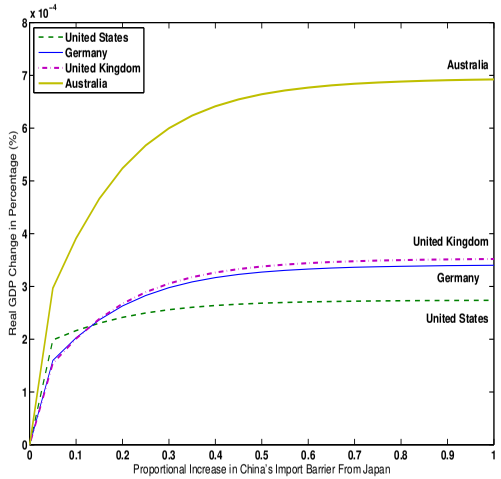
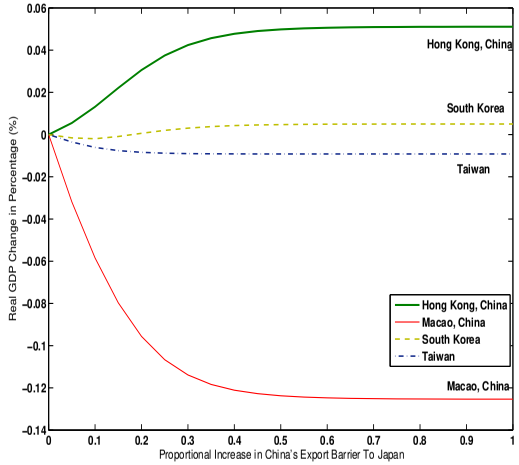
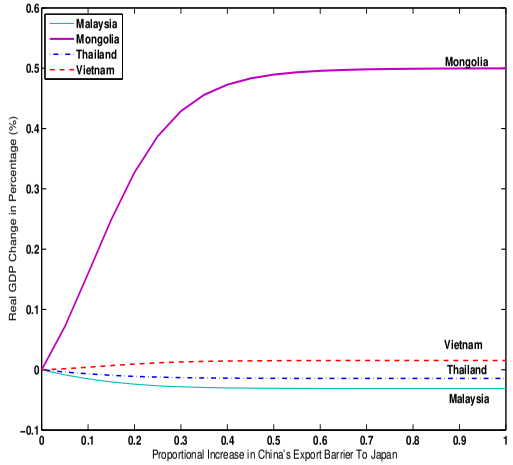
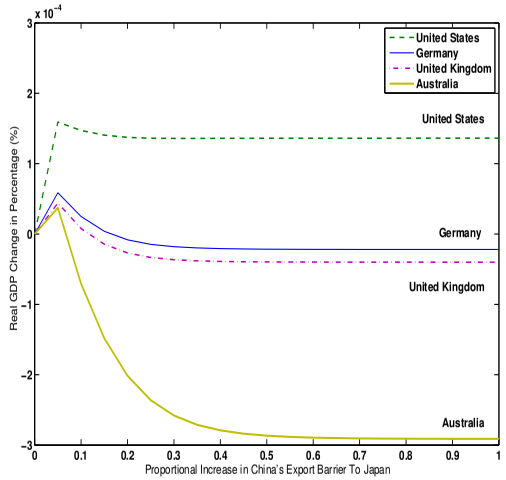


Figure 3.16: Increasing China's Export Barrier Towards Japan: Spillover Effects







3.3.3.2 Spillover Effect of Increasing China–Japan Export Barrier

The increased China–Japan export barrier would lead to reduced market clearing wage in China, while Japan's nominal wage would increase. Therefore, China's low-cost edge on exporting, especially in their specialised type l goods, would be enhanced, while Japan would lose some of its absolute advantage. The comparatively advantaged sector in each country would again be more advantageous with lowered relative prices. The global effects stem from the new equilibria. Figure 3.16 on the preceding page depicts the consequent changes, showing that the sanctions intended to increase China's export barrier to Japan would exert a different impact on global economy. For the first two groups, the welfare effect remains consistent throughout the increase of the export barrier, although the effects diminish at a higher level. The pattern in the third group is more complicated. All curves show an initial impact effect on welfare with slightly higher export barriers, then drop rapidly after the peak and then decrease.

Macao, with its surge in wage relative to China and decrease relative to Japan, would lose out in type l exporting market, seeing a drastic shrinkage of trading with proximate Asian countries as a consequence of an attenuated absolute advantage. Such loss could not be compensated for by the gain from improved type h goods sales, as Macao does not have a dominant position in heterogeneous technological goods. Therefore, Macao's welfare would be mostly impaired after China's trade sanctions of such kinds. South Korea and Taiwan, whose markets consuming type h goods are larger, would be negatively impacted due to decreased purchasing power in obtaining

Japanese high-end goods. However, as they hold tighter trade ties with Japan, their supplement in response to excessive demand from Japan's domestic market would mitigate the negative effect. South Korea, with particularly close trading relations with Japan, would even be able to gain slightly from stimulated outputs because of Japanese-oriented products. The large welfare gain in Hong Kong would arise from a different source, however, being the only net exporter of type h goods among the first group, Hong Kong's main industry would be more competitive in the global market and would hence enjoy globally boosted sales of high-end goods.

Interestingly, the pattern of the second group's welfare change is almost symmetrically obverse to the zero-change axis in the previous section. The wages of Thailand and Malaysia would be increased sightly relative to China's, leading to weakened competitiveness in the global type l market. Malaysia, which would benefit more under the previous scenario, would be hurt more than Thailand, indicating a larger contribution and responsiveness to change of type l goods trading in Malaysia's economy. Mongolia, with especially great reliance on importing China's low-end goods and limited trade activities of other sorts, would enjoy the largest welfare gain because of the slashed importing costs as well as expanded consumption quantity of type l goods.

The magnitude of welfare change for the large economies in the third group would be extremely small compared to the first two groups and, again, they would be less responsive to China's action in increasing export barriers to Japan. The figure indicates that all countries would have an initial welfare increment as a response to a minor increase in the China–Japan export barrier. Such benefits comes from consum-

ing more cheaper Chinese type l products. However, because of the limited roles of low-end goods in these high-income countries, the boon would not be maintained if higher barriers were put in place. The United States stands out from the pattern. Its nominal wage rises is much more moderate than that of Japan's, and it would hence be able to improve its edge on type h goods and experience welfare gain throughout, irrespective of the level of the trade barrier.

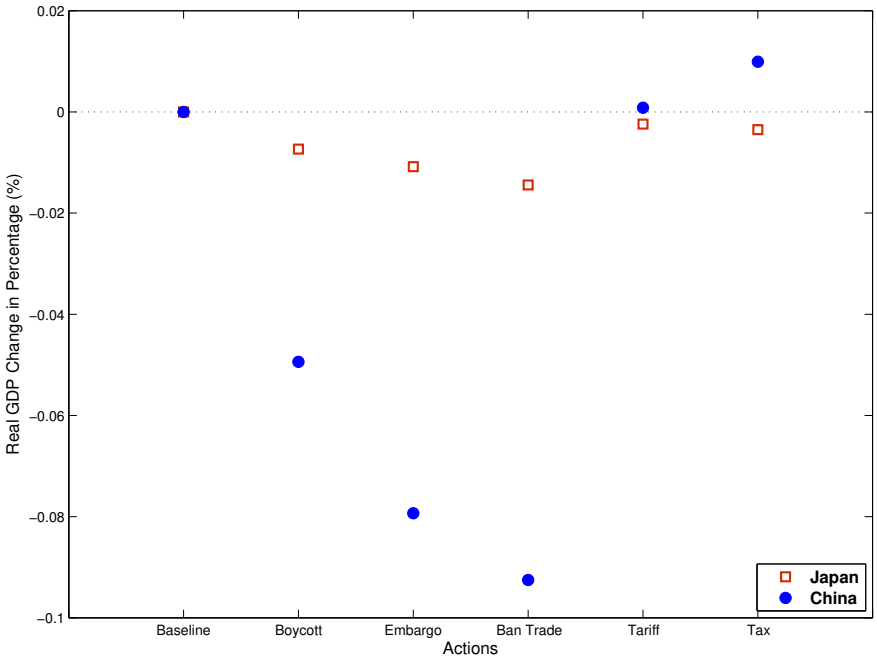
A final note at this section is that Hong Kong would benefit in all situations regardless of the specific trade sanction method, due to its close trade relations with both China and Japan and its unique edge in manufacturing. As a special administrative region of the People's Republic of China, Hong Kong maintains highly a consistent political stance with China against Japan in claiming sovereignty over the Senkaku/Diaoyu Islands (Broadhead 2012). Despite Hong Kong civilians' nationalism ties with China, the positive spillover effect after any form of China's unilateral sanctions might be a subtle but noteworthy reason for the government support.

3.4 Comments on Costs and Strategies

Following the analysis presented above, the outcomes of various actions of China's unilateral sanction are summarised in Figure 3.17 on the next page. China's blocking of both directions of trade with Japan would be the most severe trade sanction of Japan in terms of the real GDP percentage change. Correspondingly, the cost incurred to itself would be significant. China's unilateral export embargoes would lead to a more substantial impairment of both countries' welfare than import boycotts would

do, while the change in China would be more drastic. All such evidence disproves the claim that Japan's economy would suffer severely if China were to impose sanctions on it under the conditions prevailing at the beginning of the twenty-first century. Moreover, it indicates that the trade flow from China to Japan contributes more and interacts more deeply with both country's economies than does the trade flow from Japan to China.

Figure 3.17: China's Unilateral Trade Sanctions Against Japan: Graphic Representation



The best outcomes that China can achieve, with partial trade restrictions at optimal duty rates, seem to be more promising. With proper revenue distribution after the imposition of either an import tariff or an export tax, China would benefit slightly in terms of a small improvement of welfare, while Japan would be harmed with its real GDP decrease, although the the cost is not significant. The export tax seems

to be more effective as Japan would suffer more in contrast to China's larger gain. Such results reinforce the previous comment and evidence that both economic entities are more responsive to Japanese imports from China, or, from another perspective, China's exports to Japan.

China's dominant position in sanctioning Japan with tariff and tax does not necessarily mean it would achieve a sufficient level of intimidation. Firstly, the procedure of revenue distribution and additional goods production would be costly. Such costs would dampen, or even exceed, the welfare gain. More importantly, China's dominant position is very fragile. The minor advantage would be diminished once Japan retaliated. Take the example of China's levying of export tax: if Japan immediately responded to China with a 5% export tax on products shipped to China, the dominant position would immediately be reversed after Japan's revenge. China's welfare gain would not only be eliminated, but the country would also incur a fall in real GDP fall of 0.0047%. China would again lose out more because Japan would experience only a 0.0012% drop in welfare. Therefore, China's improvement in welfare would happen only if other countries did not retaliate by raising taxes or tariffs themselves. Even in such a case, such a sanction is a 'beggar thy neighbour' policy (Johnson 1953), since it lowers welfare in some other neighbouring countries as discussed in Section 3.3.3. China has endeavoured to ease fear of the "China threat" especially among its Asian neighbours. The implementation of unilateral trade sanctions would risk ruining its reputation.

Therefore, the general conclusion reached is that China would lose more in terms of general welfare if it implemented a unilateral trade sanction against Japan in

the 2000s, provided that Japan took appropriate actions to cope with it. In fact, Reilly (2012) international relations study concludes that we cannot overestimate China's capacity to use economic pressure should not be overestimated, even though its economic threats seem to have become more effective recently.

To evaluate the effectiveness of sanctions, Eaton and Engers (1992) developed a model of sanctions for a discrete concession and reached the basic conclusion that if the sanctions are incredibly costly for the initiator or/and not brutally effective in harming the target, the only equilibrium consists in threats of sanctions if the targeted country does not comply with demands. With the costs as evaluated, such that Japan's economy would not be undermined while the impairment to China would be more significant, both countries' strategies seem to be in compliance with this conclusion. The prolonged Sino–Japanese disputes, with China's frequent threatening of economic sanctions against Japan and Japan's noncompliance with China's political requests, represents such an equilibrium outcome under the economic situation at the beginning of the twenty-first century.

3.5 Conclusion

In summary, this paper evaluates the economic costs of unilateral trade sanctions in the case of China and Japan. An improved version of EK model, which differentiates trade product as either high-value added, or low-value added type is adopted. The model is based on Fieler (2011)'s work which incorporates the role of trade barriers in international trade and accommodates the nonhomotheticity of traded goods un-

der the general equilibrium is adopted. With the estimated parameters' values, the model has recovered the key features of China–Japan trade ties, and hence its ability to tackle the problem has been validated. I have experimented with counterfactual simulations and explored the economic costs on China, Japan and other countries of Chinese unilateral boycotts, embargoes, two-way blockages, import tariffs and export taxes. The main conclusion that requires further emphasis here is that, in the early 2000s, China does not yet have the economic strength to punish Japan by levering trade sanctions. Regardless of the form of the sanction, China would incur greater harm than Japan in terms of percentage drop in welfare if Japan reacted promptly to the sanction. Such a conclusion, combined with Eaton and Engers (1992) sanction model, provides a partial economic explanation for China's reluctance to actually implement trade sanctions, and Japan's continuous resistance in return as an equilibrium. Moreover, other countries uninvolved in the direct trade sanctions would not be unaffected by the fallout. The neighbouring countries would be affected the most, though the specific benefit or loss depend on many factors, such as the form of trade sanction, the income level of the country and its trade relations with China and Japan.

Some issues that have not been addressed in this study represent potentially valuable directions for future research. First, the modelling of trade barriers in this study is highly stylised. For example, the heterogeneity in trade barriers across different types of goods and the asymmetry of bilateral trade barriers are suppressed in the model. Further relaxations may promote a better working of the model and improve its robustness. Secondly, the model does not account for the trade flows beyond 100%

of a country's GDP, although the data up to date show that several countries trade more than their GDPs. Hence, a model with a role of intermediate inputs is called for to accommodate such a feature. Last but not least, the dynamic effect of trade sanctions is discussed in the cost analysis but cannot be specifically quantified at this point. As the data are available for several years' span, a dynamic version of the model may be developed to incorporate the role of dynamic efficiency, as well as the trade evolution and growth for evaluating the long-term impacts of unilateral trade sanctions.

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Appendix A

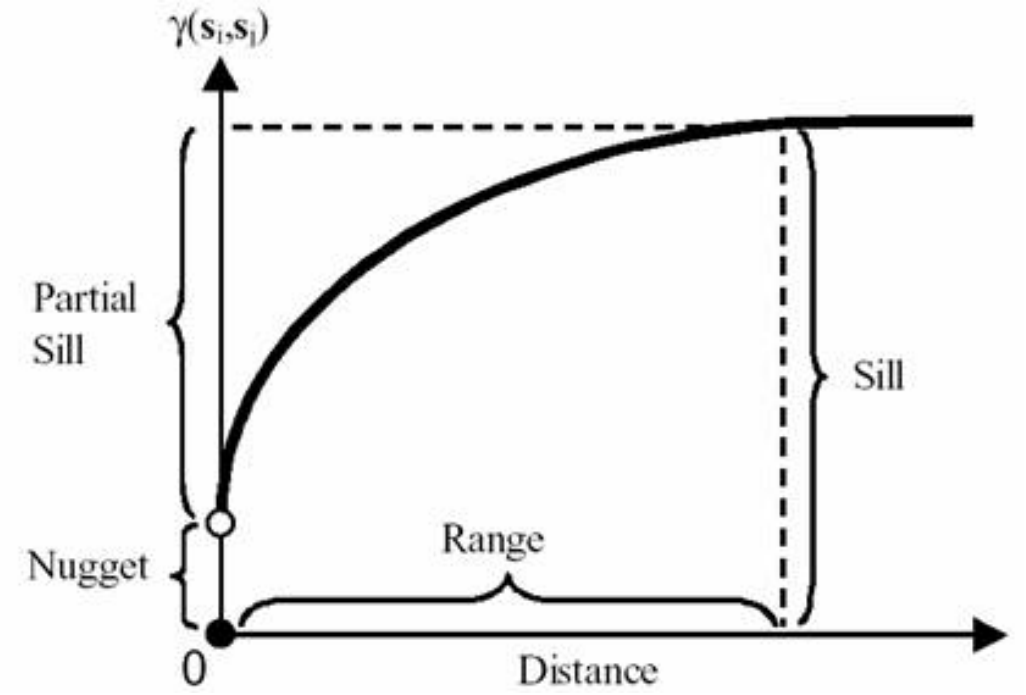
Semi-variogram

Range, Sill, and Nugget

The semi-variogram depicts the spatial autocorrelation of the measured sample points. Because of a basic principle of geography – things that are closer are more alike, measured points that are close will generally have a smaller difference squared than those father apart. Once each pair of locations is plotted after being binned, a model is fit through them. There are certain characteristics that are commonly used to describe these models.

For a semi-variogram, at a certain distance, the model begins to level out. The distance where the model first flattens out is known as the range. Whilst, the value at which the semi-variogram model attains the range is called the sill. Moreover, at an infinitely small separation distance, the semi-variogram often exhibits a nugget effect, which is some value greater than zero. The nugget effect can be attributed to measurement errors or spatial sources of variation at distances smaller than the

Figure A.1: Semi-variogram: range, sill, and nugget



sampling interval (or both). The partial sill is defined as the sill minus the nugget.

Spherical Semi-variogram Model

There are multiple semi-variogram functions to model the empirical semi-variogram, such as: circular, spherical, tetraspherical, exponential, and Gaussian. The selected model influences the prediction of the unknown values, particularly when the shape of the curve near the origin differs significantly. The steeper the curve near the origin, the more influence the closest neighbors will have on the prediction.

The one adopted in this study is the standard spherical semi-variogram model.

The formula of the spherical model is: $\gamma(d) = \begin{cases} 0, & d = 0 \\ C_o + C(\frac{3d}{2a} - \frac{d^3}{2a^3}), & 0 < d \leq a \\ C_0 + C, & d > a \end{cases}$,

where C_0 is the nugget constant, $C + C_0$ is the sill, the value at which the model first flattens out. C is the structure variance. The effective range, that is, the distance at which the model first flattens out is captured by a. According to the best fitted model, the effect range in this context is 3.3.

The slope rate at the point of origin is $\frac{3C}{2a}$, and the intersection between the sill value and x-axis is $\frac{2a}{3}$. The spherical model is the most common model in geostatistics. Its features are that it has a linear growth when the distance between two points are short (and closer to the point of origin); however, and for larger distances beyond a certain range, it levels off.

Appendix B

Summary Table to Spatial Weights

There are 3142 paris of filling stations located within 3.3 km. The spatial weight of each pair, deriving by the adaptive LASSO method is summarised in Table B.1. Among all the coefficients, there are 380 having nonzero values, indicating 380 pairs of comptiton relation, such that the reactor would response materially to any price change of its paired initiator. The values of nonzero spatial weights are summarised in Table B.2.

Table B.1: Summary to All w_{ij}'s (Including 0's)

Min.	1st Qu.	Median	Mean	3rd Qu.	Max.	# of Pairs	Std.
0	0	0	0.021	0	0.213	3142	0.058

Table B.2: Summary to Identified w_{ij}'s (Excluding 0's)

Min.	1st Qu.	Median	Mean	3rd Qu.	Max	# of Pairs	Std.
0.145	0.175	0.176	0.177	0.180	0.213	380	0.007

Appendix C

Data and Countries

The data on bilateral merchandise trade flows in 2000 is taken from the U.N. Comtrade data abase (United Nations (2011)). Therefore, of all possible importer-exporter pairs, there are 272 ($= 17^2 - 17$) missing. The missing data are completed with data from the World Bank World Development Indicators Data Set (2011) as suggested in Fieler (2011).

Table C.1: List of Countries

	Country		Country		Country		Country
1	United States	42	Colombia	83	Cameroon	124	Guinea
2	Japan	43	Philippines	84	Yemen, Rep.*	125	Turkmenistan
3	Germany	44	Chile	85	Cyprus	126	New Caledonia
4	United Kingdom	45	Pakistan	86	Angola*	127	Burkina Faso
5	France	46	United Arab Emirates	87	Tanzania	128	Barbados
6	China	47	Czech Republic	88	Iceland	129	Mali
7	Italy	48	Algeria	89	Serbia and Montenegro	130	Benin
8	Canada	49	Peru	90	Jordan	131	Armenia
9	Brazil	50	New Zealand	91	Bolivia	132	Rwanda*
10	Mexico	51	Hungary	92	Trinidad and Tobago	133	Niger
11	Spain	52	Bangladesh	93	Jamaica	134	Malawi
12	South Korea	53	Nigeria	94	Bahrain	135	Lao PDR*
13	India	54	Kuwait	95	Ethiopia	136	Fiji
14	Australia	55	Romania	96	Latvia	137	Swaziland
15	Netherlands	56	Libya*	97	Zimbabwe	138	Chad*
16	Taiwan*	57	Morocco	98	Paraguay	139	Kyrgyz Republic
17	Argentina	58	Ukraine	99	Botswana	140	Togo
18	Russian Federation	59	Vietnam	100	Uganda	141	Equatorial Guinea*
19	Switzerland	60	Uruguay	101	Macao, China	142	Tajikistan
20	Sweden	61	Slovak Republic	102	Estonia	143	Central African Republic
21	Belgium	62	Luxembourg	103	Nepal	144	Mongolia
22	Turkey	63	Oman	104	Azerbaijan	145	Suriname
23	Austria	64	Dominican Republic	105	Bosnia and Herzegovina*	146	Lesotho
24	Saudi Arabia	65	Tunisia	106	Bahamas, The	147	Belize
25	Poland	66	Syrian Arab Republic	107	Ghana	148	Guyana
26	Hong Kong, China	67	Slovenia	108	Mauritius	149	Burundi
27	Norway	68	Croatia	109	Senegal	150	St. Lucia
28	Indonesia	69	Kazakhstan	110	Congo, Dem. Rep.*	151	Antigua and Barbuda
29	Denmark	70	Qatar	111	Nicaragua	152	Eritrea
30	South Africa	71	Lebanon	112	Madagascar	153	Maldives
31	Thailand	72	Sri Lanka*	113	Malta	154	Seychelles*
32	Finland	73	Costa Rica	114	Haiti*	155	Cape Verde
33	Venezuela, RB	74	Ecuador	115	Mozambique	156	Bhutan*
34	Israel	75	Uzbekistan*	116	Albania	157	Gambia, The
35	Greece	76	El Salvador	117	Cambodia	158	Grenada
36	Portugal	77	Belarus	118	Macedonia, FYR	159	St. Kitts and Nevis
37	Iran, Islamic Rep.	78	Kenya	119	French Polynesia	160	Solomon Islands*
38	Egypt, Arab Rep.	79	Bulgaria	120	Papua New Guinea	161	Dominica
39	Ireland	80	Sudan	121	Namibia	162	Tonga
40	Singapore	81	Lithuania	122	Zambia		
41	Malaysia	82	Cote d'Ivoire	123	Congo, Rep.*		

Notes: Countries with asterisk (*) do not report trade to the United Nations.

Appendix D

Supplementary Counterfactual Figures

D.1 Imports Boycott

Figures D.1 and D.2 in this section provide the detailed import/export volume changes against the baseline for both China and Japan as discussed in Section 3.3.1.1 on page 155. China and Japan's data are excluded from the plotting, as their variation magnitudes would be more significant than that of rest of the world. China, with a nominal wage increase, would import more and export less in both goods; whilst Japan, undergoing a wage cut, would import less and export more. In both countries, the changes in importing would more significant in terms of absolute magnitude and hence would dominate the directions of trade flow changes.

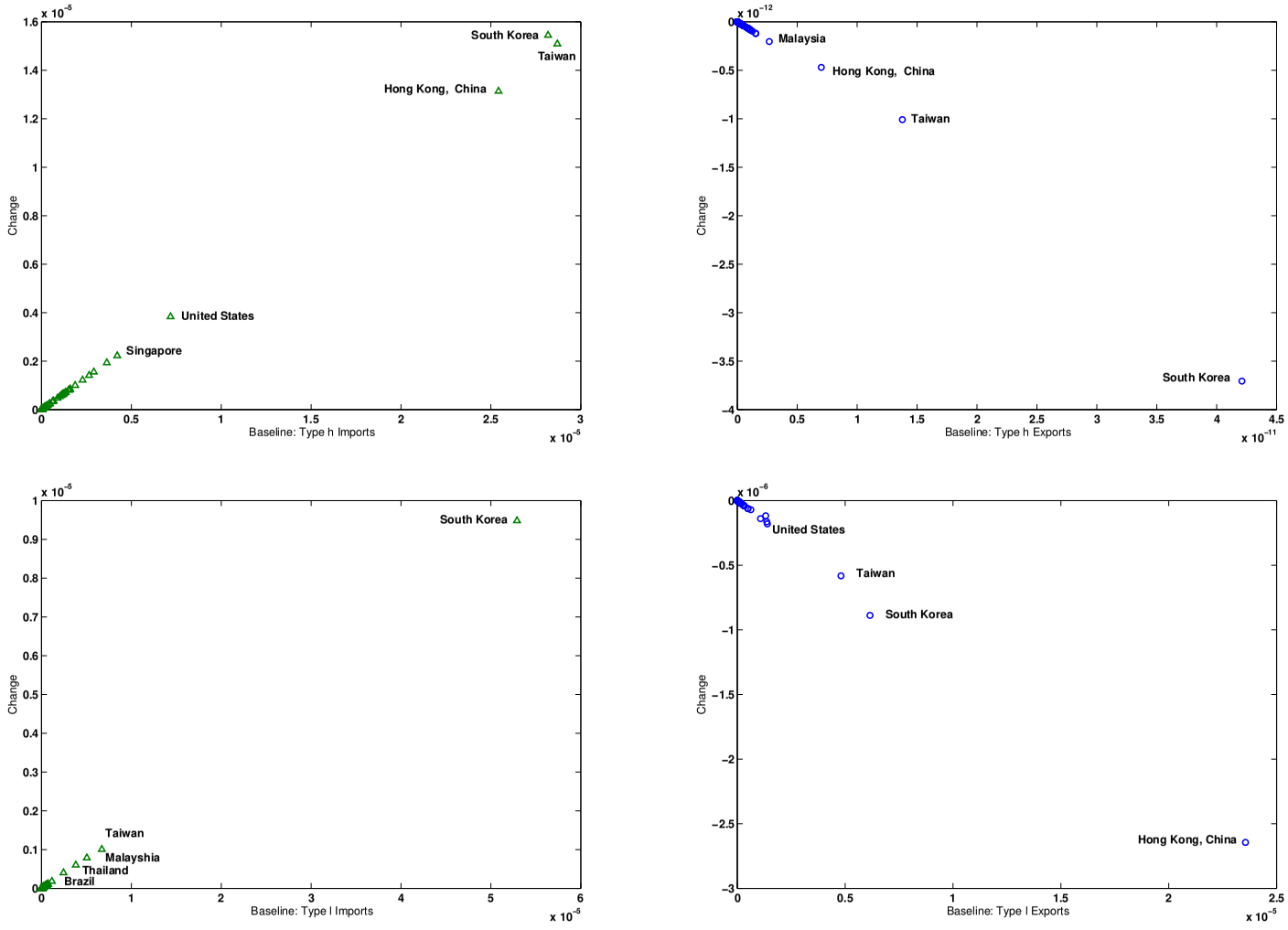


Figure D.1: Imports Boycott: China Import/Export Pattern Change

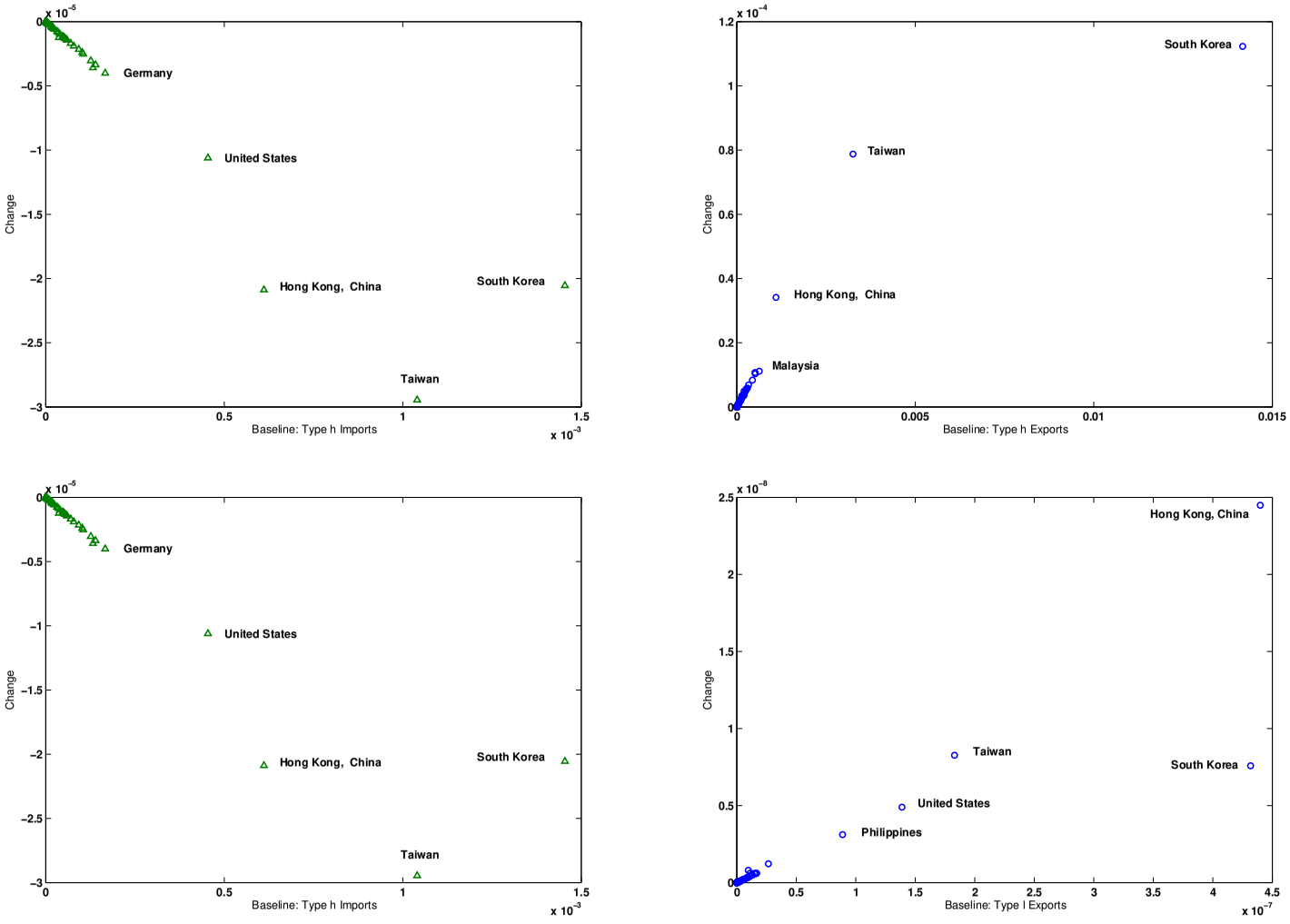


Figure D.2: Imports Boycott: Japan Import/Export Pattern Change

D.2 Exports Embargo

Figures D.3 and D.4 in this section depict the detailed import/export volume changes for both China and Japan in the case of exports embargo as discussed in Section 3.3.1.2 on page 163. Again, China and Japan's data are not plotted in the figures. With the slashed wage, China would have to cut its imports while attempt to expand its export sectors. Japan, in contrast, would import more from the neighbouring countries and reduce its exports.

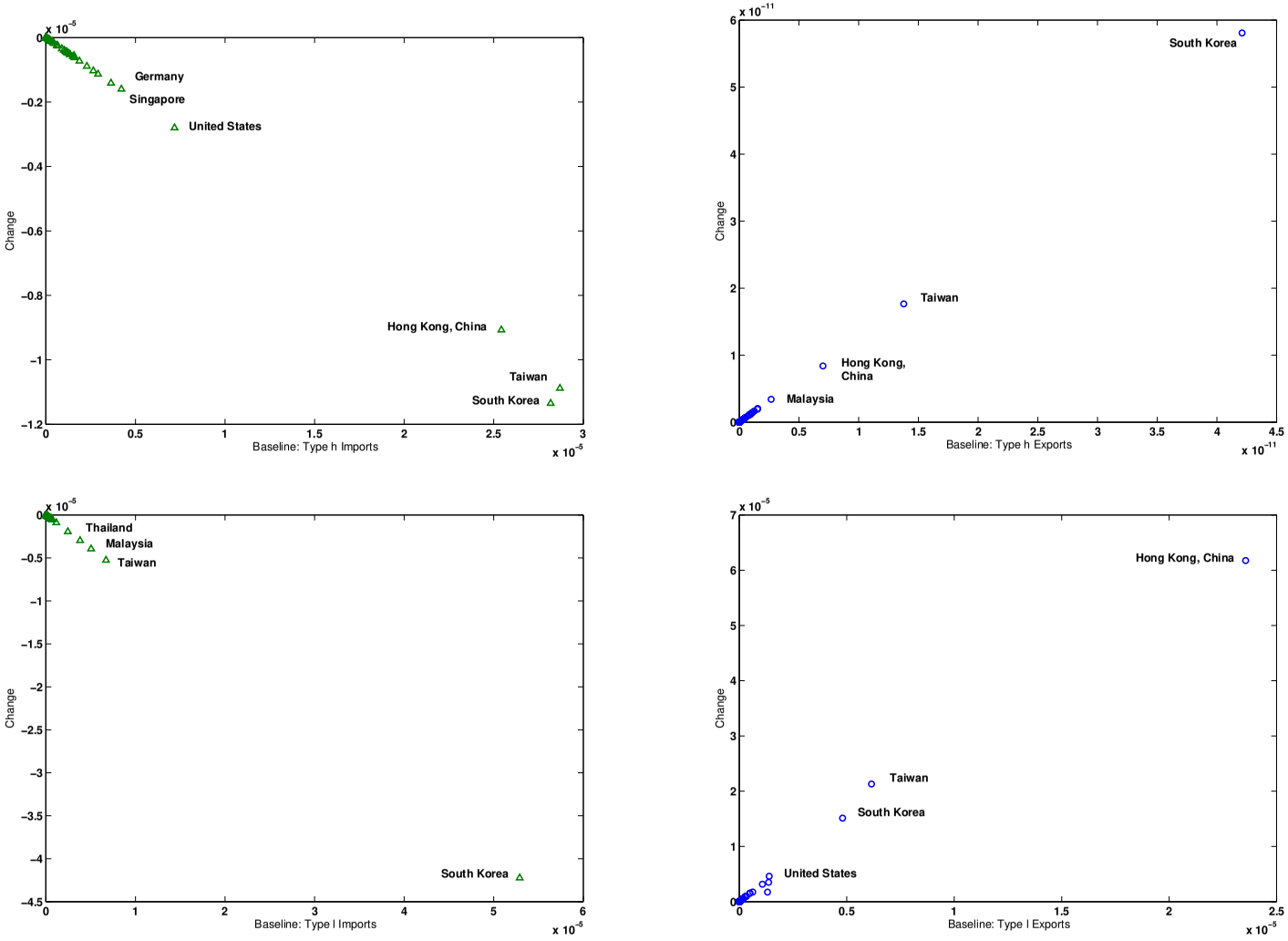


Figure D.3: Exports Embargo: China Import/Export Pattern Change

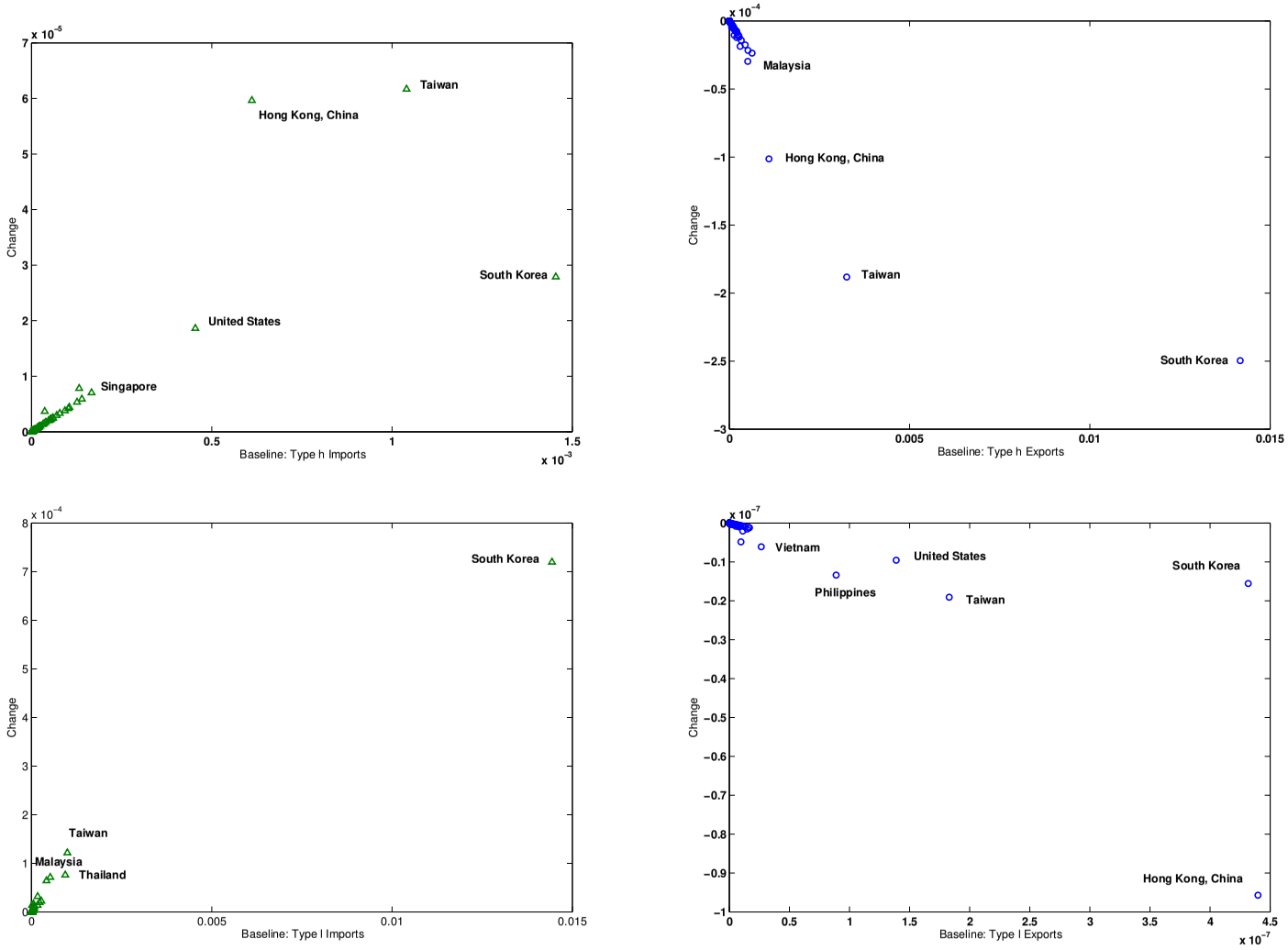


Figure D.4: Exports Embargo: Japan Import/Export Pattern Change

D.3 Trade Suspension

Figures D.5 and D.6 illustrate the patterns of import/export volume changes resulting from the two-way trade blockage, as discussed in Section 3.3.1.3 on page 170. Again, China and Japan's data are excluded from the figures. The patterns resemble those in the previous figures, although the variation magnitudes differ for both countries. The inflow changes would nevertheless, be dominant in determining the change directions.

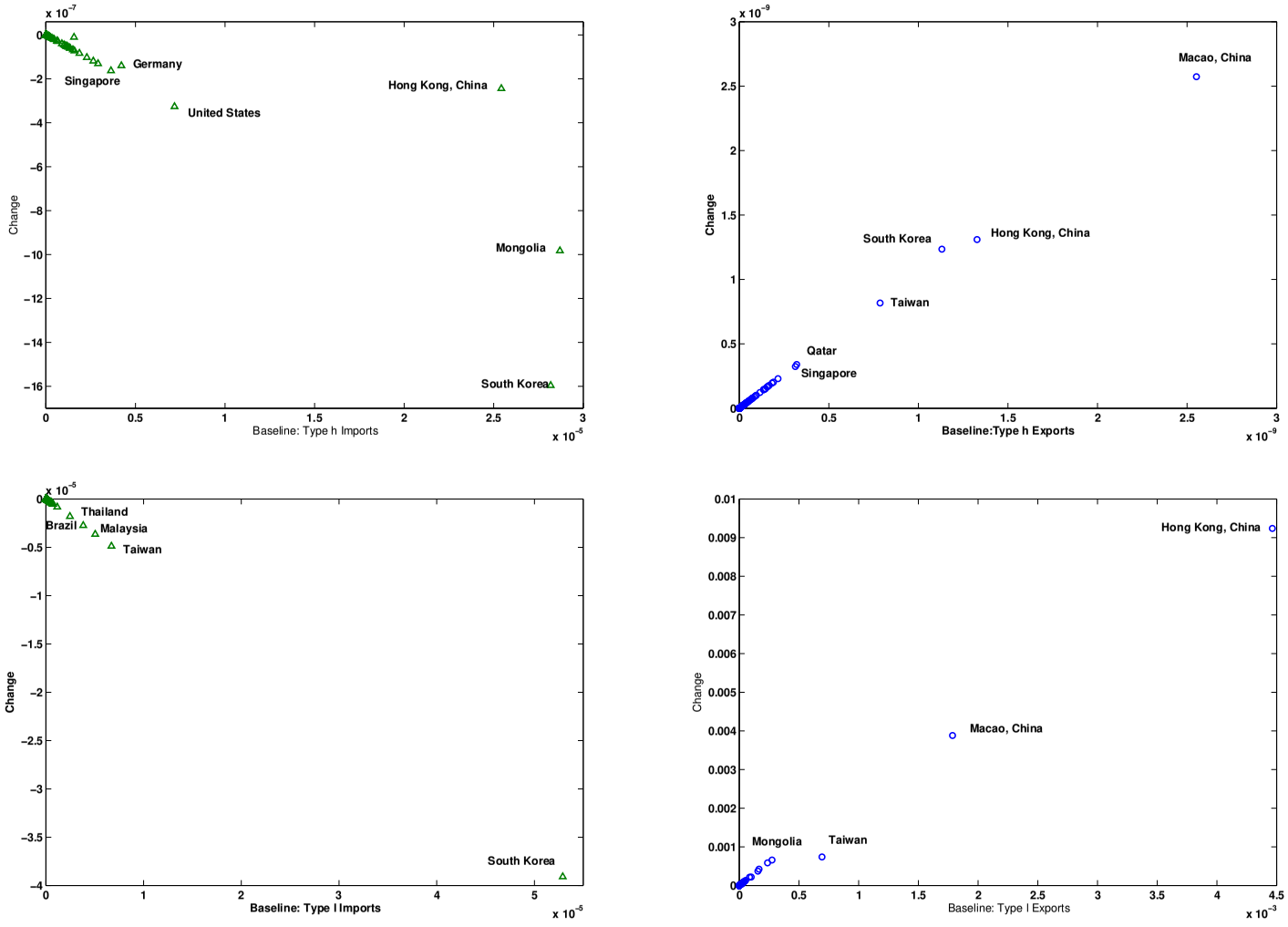


Figure D.5: Trade Suspension: China Import/Export Pattern Change

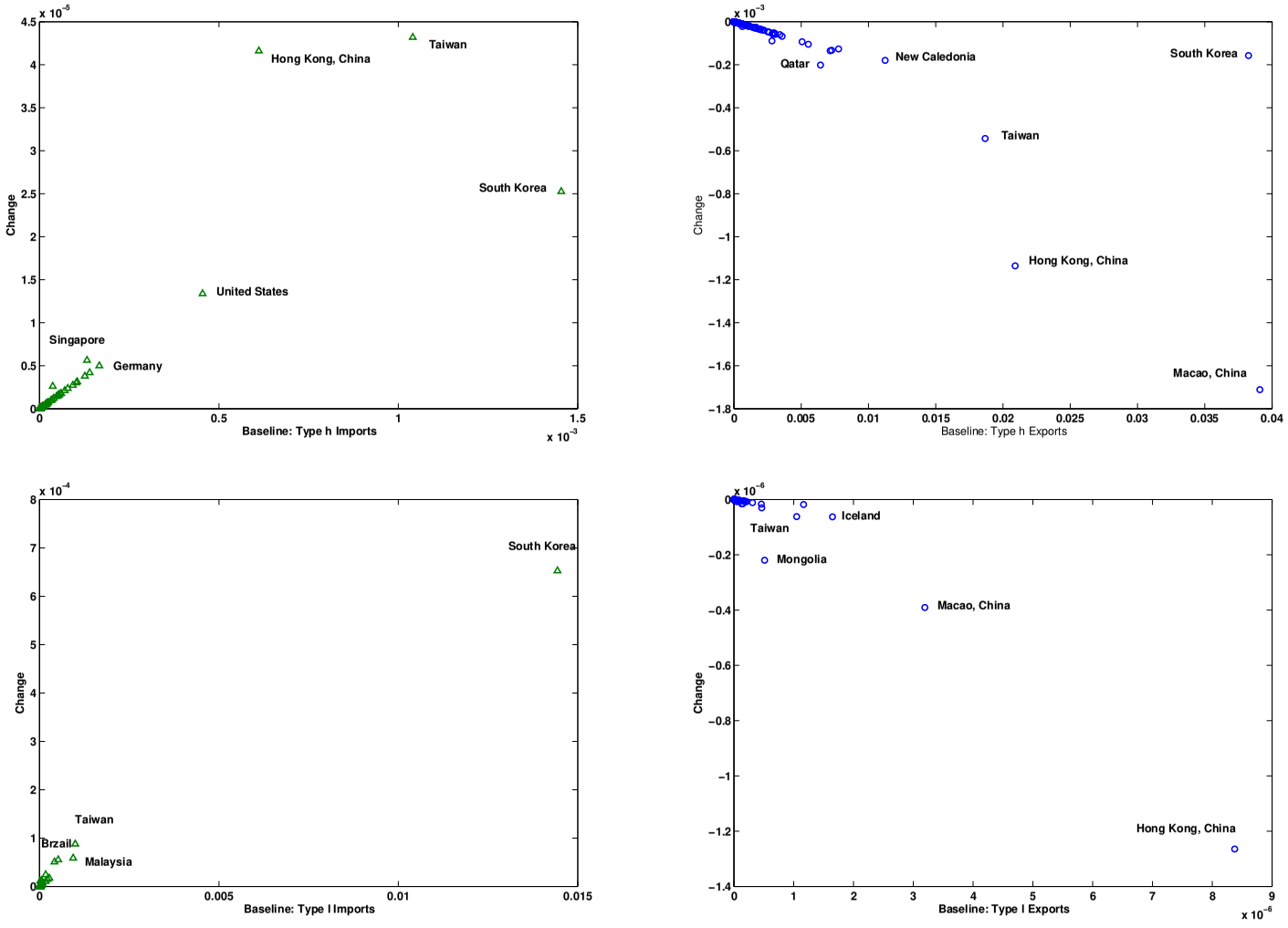


Figure D.6: Trade Suspension: Japan Import/Export Pattern Change

D.4 Impose Tariffs

The supplementary counterfactuals for Section 3.3.2.1 on page 179 are presented in Figures D.9, D.8, D.9, and D.10.

Figure D.7: China Imposing Tariffs On Japanese Imports: Real Wage Change in Percentage (%)

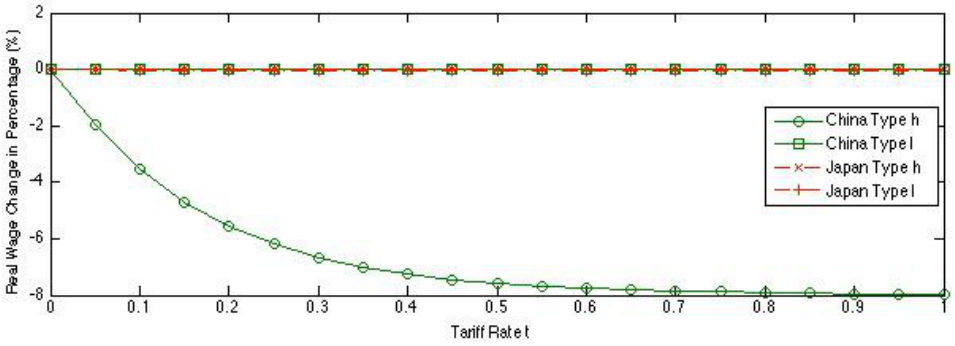


Figure D.8: China Imposing Tariffs On Japanese Imports: Bilateral Imports Volume Change in Percentage (%)

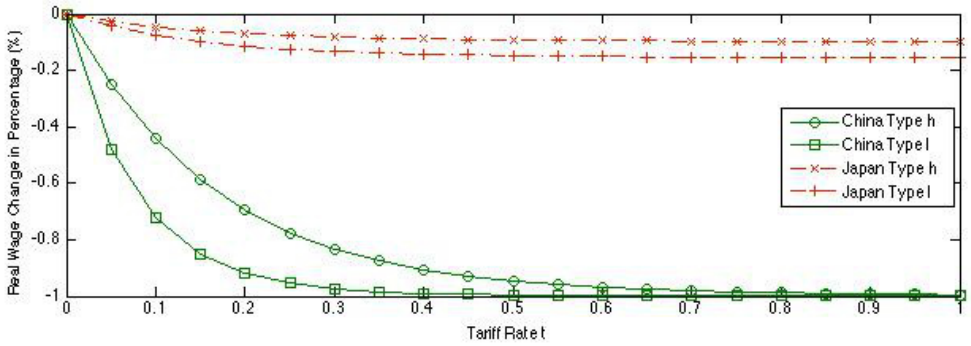


Figure D.9: China Imposing Tariffs On Japanese Imports: China Production and Demand of Type h goods

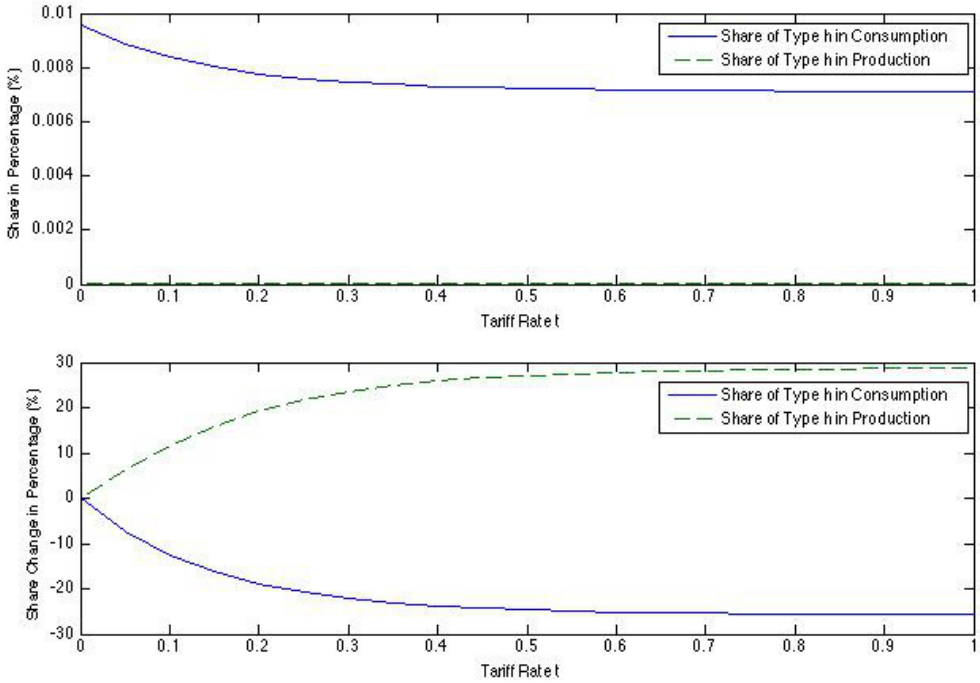
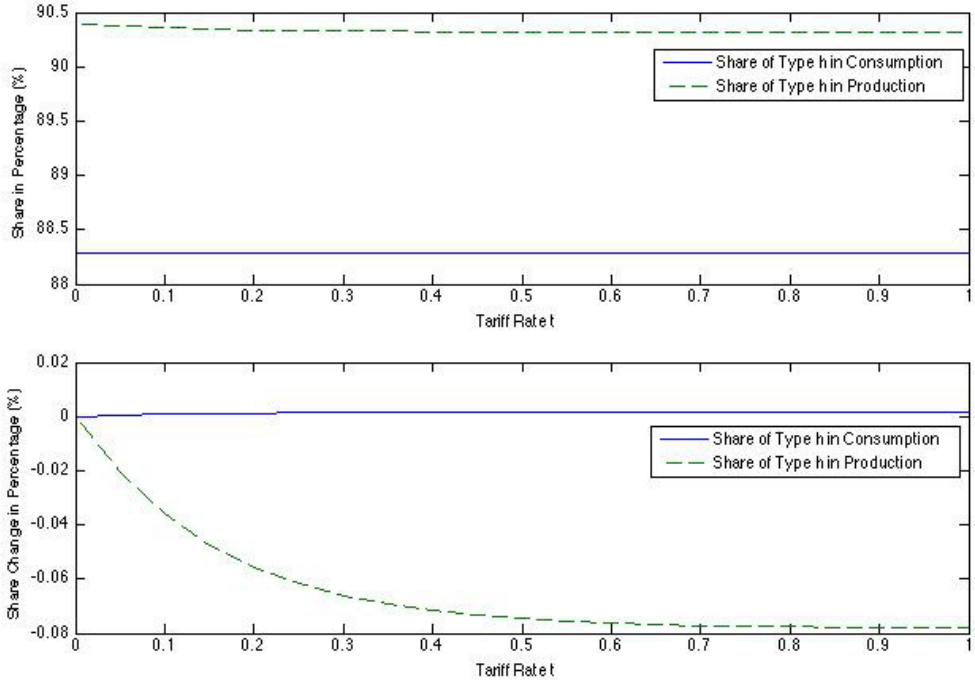


Figure D.10: China Imposing Tariffs On Japanese Imports: Japan Production and Demand of Type h goods



D.5 Levy Taxes

The supplementary counterfactuals for Section 3.3.2.2 on page 181 are presented in Figures D.12, D.12, D.13 and D.14.

Figure D.11: China Levying Taxes On Japanese Exports: Real Wage Change in Percentage (%)

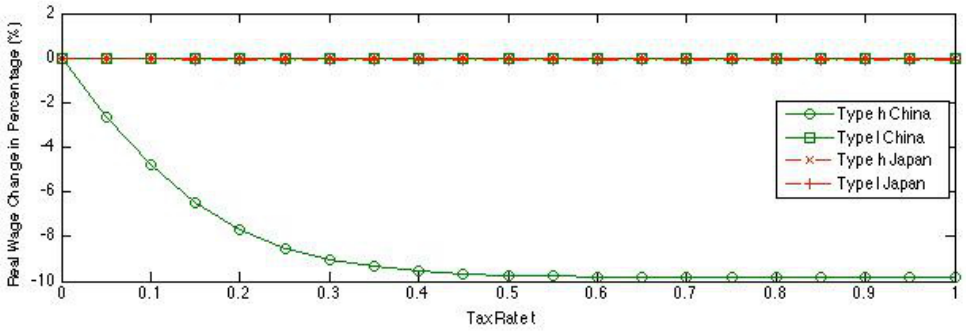


Figure D.12: China Levying Taxes On Japanese Exports: Bilateral Imports Volume Change in Percentage (%)

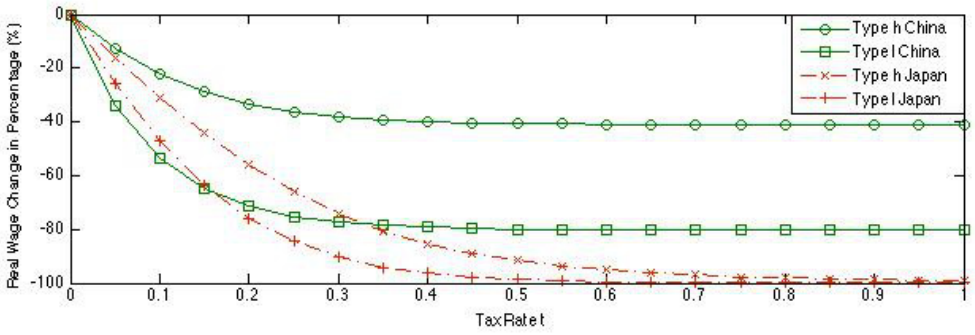


Figure D.13: China Levying Taxes On Japanese Exports: China Production and Demand of Type h goods

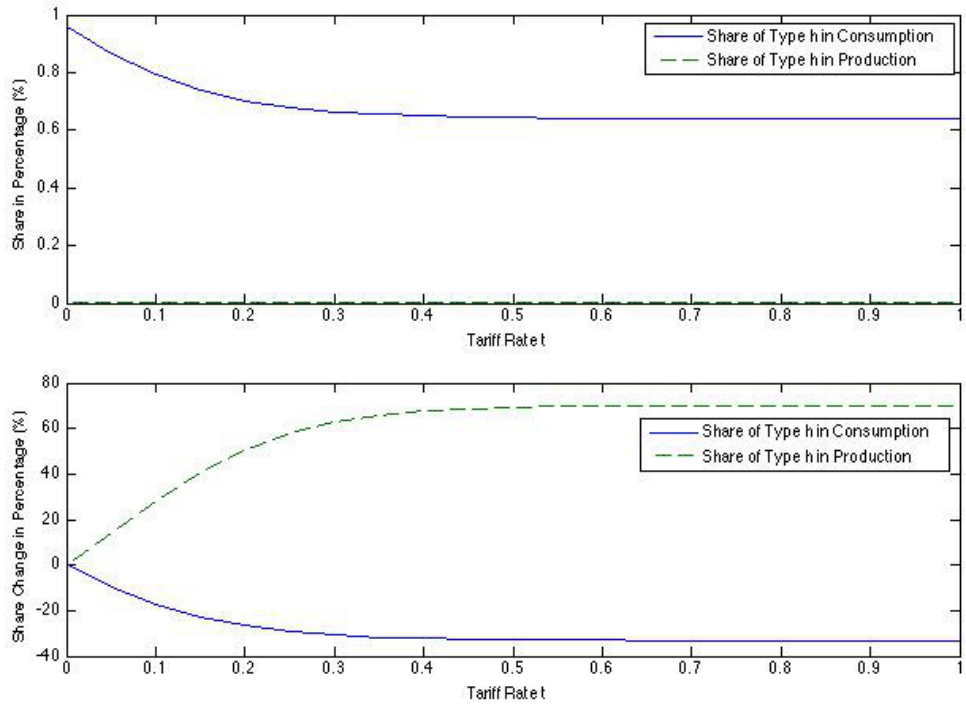


Figure D.14: China Levying Taxes On Japanese Exports: Japan Production and Demand of Type h goods

