A DEBATE ON THE CLASSICAL AND GRAVITY TRADE MODELS:
TESTING EU TRADE FACTS USING INDIRECT INFERENCE

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Abstract

This thesis constructs two Computable General Equilibrium (CGE) world trade models, and examines the empirical evidence on whether the European Union is more governed by a Classical model of comparative advantage or a Gravity model of new trade theory. It applies time series data between 1970 and 2018 and aims to test the models using Indirect Inference Wald (IIW) on EU trade facts. It extends the Minford and Xu's (2018) UK study, treats EU as a large open-economy and simulates world variables by using a reduced form VAR of the unknown true world model, applying a Part of Model test. Empirically, the Classical model passes the tests comfortably; whilst the Gravity modelpasses when test power and gravity effect is low, but cannot survive in the full test power. Based on a Monte Carlo experiment, we find that the auxiliary model creates substantial but not excessive power for the test. The policy implication of our work is that both models suggest that European Union policymakers should liberalize trade policy, because under both model tariff simulations indicate that protection results in general welfare loss.

Key words

Bootstrap, Indirect Inference, Classical Model, Gravity Model, Trade Model, European Union

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CHAPTER ONE

GENERAL OVERVIEW: CLASSICAL AND GRAVITY MODELS

Introduction

In recent decades, the level of debate and attention has increased on the benefits and effectiveness of European Union (EU) trade policy as a customs union that establishes trade barriers around the EU market and countries regulated under Single Market rules.

The EU and other customs unions' welfare effect can be a controversial topic. In accordance with traditional theory of international trade, total welfare is reduced in comparison of free trade;citizens' welfare inside the customs union is worsened on average by the trade barriers, which raises the cost for all citizens within the union. However, Meade (1955) statedthat citizens could benefit from such a customs union if it was a net exporter to others in the same union, as its terms of trade gains could overcome the welfare reduction suffered by other consumers. Today, besides the classical view on trade theory, the gravity model, covered by many authors such as Rodriguez (2014), customizes trade into sectors and production specializations, as well as skilled and unskilled labour forces. These models collect size and distance as well as neighbourhood characteristics, and the greater the distance covered, the greater the trade volumes will be. Here, lowering the costs of trade would have negligible impact on demand in the presence of imperfect competition.

Therefore, it is worth constructing a formal test on the statistical performance of both the classical and gravity models, because they may have different welfare implications. Limited empirical evidence has been derived from comparing the statisticalperformanceofboth models, although some trade economists insist that the gravity model is more favourable as it tends to take trade characteristics more into account. Tinbergen (1962) built a regression of gravity model and concluded that the gravity modelwas better; however, classical trade models could also replicate these resultsbased on different assumptions. Therefore, the main issue in distinguishing between models is that they could both possibly generatesimilarsimulated trade data; if simulated trade data from both models behave similarly, we need to identify which model fits the actual data better.

Classical has been the main model used in analyzing trade trends over a long period. But recently there has been a switch among many trade theorists to the gravity model. For example, the gravity model was used as the predominant model by the remain-side in the Brexit debate. It was also been used widely to argue that ‘nearby’ trade relations dominate in welfare calculation for trade policy. It is highly relevant to modern policy debates in trade. Other models remain interest but have left to future work; the testing method used in this thesis could also be applied for other trade models.

In order to capture trade relationships and evaluate welfare performance, recently a series of generalequilibrium models of global trade have been formulated to evaluate trade policies, such as GTAP model (Corong, 2017) and the CESIfo model (Felbermayr, 2020). These computable general equilibrium (CGE) models suggest that distance affects a country’s trade with another given country, and trade between countries is linked to productivity growth. Gravity modellersassert that trade occurs more frequently and at higher volumes between neighbouring countries than between more distant markets, and that stronger trade links positively impact on technology transfer and productivity growth. However, the process of the general equilibrium model that captures trade facts can take on different forms. A dominant approach in trade models is to relate trade to distance and economy size; apart from economic factors, the speech of Neary in Royal Economic Society and its associated article

(Carrere, 2020) recently outlined that colonial ties should be incorporated as cultural gravity into such models. Others have argued the gravity model similarly from panel data including time and price variables as well as cross-section variation (Costinot and Rodriguez-Clare, 2014). Thus, it would also be of interest to perform a general equilibrium model that is more closed to the truth; we need to conduct an empirical test on the model's performance to ascertain, whether model simulation replicates actual data behaviour. Moreover, if both models behave similarly as suggested above, we should determine which matches the data better.

This thesis aims to test rival models, namely the classical and gravity CGE models, by taking an indirect inference approach. Compared with Bayesian estimation and other popular procedures, indirect inference approach is a relative unfamiliar method but has been merging in recent years to test macroeconomic models (Meenagh et al., 2019). The test procedure is described roughly here and is extended in detail later with mathematical expressions. As a first step, the indirect inference Wald (IIW) test requires an estimation of an auxiliary model based on actual data, the role of which is to describe actual data behaviour and to capture the most mentioned trade descriptors of concern to macroeconomic modellers. This auxiliary model describes the basic relationship between key trade indicators and macroeconomic factors, which takes the form of moments or regression equations used in this thesis. As a second step, we generate structural shocks on the null hypothesis of structural models being true, and bootstrap its shocks to replicate a series of parallel histories under the condition of the same auxiliary model is used. It generates a distribution of auxiliary model coefficients based on simulated data in many parallel histories, and indirect inference is used to compare the distribution of auxiliary model parameters based on simulated data with auxiliary model descriptors based on actual data; if these reach a sufficient likelihood level, normally a probability of 5%, the model is not rejected.

In this thesis, I propose applying an indirect inference method to test the classical trade model and gravity model on EU data, as an empirical study that complements the UK case study of Minford and Xu’s (2018). It is also the first attempt to the author’s knowledge that EU trade models’statistical performance have been empirically compared using a recent computerised approach and it should represent a comprehensive contribution to the investigation of EU trade policies. In the second section of the thesis, I plan to test the policy implications if the models include a potential tariff from a sector-based perspective, and consider whether it would be of another interest to further investigate which sector productivity innovation is superior to promote, and to identify which industry in the EU would be most significantly affected. I predict that both models’simulation behaves similarly and that the policy implications of tariff simulation and productivity innovation do not differ; the classical model is also able to replicate data behaviour described by the gravity model. In the third part of the thesis, I plan to extend the study by using a large open-economy perspective, as the EU has a higher weighted share of total world GDP than the UK; this leads to endogenous world prices and country outputs. To do so, the model is established using simulations of world and other large countries variables from a reduced form of the full unknown true world model. Then, we follow the same first two steps as outlined above, and evaluate the differences between the two cases.

To test the empirical performance of the two rival models in comparison to actual data behaviour, it is necessary to select data features to ensure model fitness. The indirect inference approach tends to give a test unlimited power, as the power of the test can be ultimately raised by adding more equations; it requires that the model be apparently closed to the real world in order to gather all data behaviour. Hence, on the one hand, the structure model should be as closed to the true model as possible; on the other hand, if models with little falsity are strongly rejected, it is also possible that some good models capable of capturing moderately relevant data behaviourcould be overlooked. Therefore, this thesis aims to conduct an Indirect Inference test by applying different testing power to a reasonable level.

Breaking down the organisation of this thesis,chapter one begins with a literature review on the macroeconomic effects of trade tariffs, while related trade theories behind classical and gravity trade models are also mentioned. In the second part of this chapter, the CGE models and indirect inference approach are described in detail, after which research questions are set out. In chapter two, this thesis discusses the full set up of both rival models, and attempts to explain the differences where the gravity model departs from the classical model assumption. Chapter Three describes the data source and lists the auxiliary model, and evaluate empirical results under the assumption of endogenous world variables and from a large open-economy perspective. Two policy implications are evaluated at the end of Chapter Three, and Chapter Four gives a general conclusion.

Part 1.1 Literature Review: Macroeconomic Effect of Trade Tariffs

Global studies: Macroeconomic Effect of Trade Tariffs

The gradual move towards free trade, especially after the global financial crisis in 2007, has attracted much attention towards both theoretical and quantitative studies concentrating on international trade and trade-related macroeconomic effects. According to the IMF (2017), trade liberalization and openness has resulted in higher productivity, increased regional competition, lower living costs, and towards production specialisation. However, recent studies have argued that although free trade has had a positive effect on the global economy as a whole, some particular sectors and industries have suffered as a result of higher competition. According to the Department of Labour of United States (2018), free trade has resulted in lower employment in the auto and raw materials industries in the US domestic market, which has spawned calls for more protectionism and increased anti-globalization sentiment, as well as leading to a decreasing trend in trade frequencies. More recently, the US government has become more aggressive in its trade policy, which is considered to have been largely driven by its negative trade balance with other trade partners.In addition, there have been increasing concerns that the US-China trade conflict will negatively affect global output and trade, albeit some countries may actually benefit from a trade spill-over.

Previous literature has discussed the motivation behind trade wars as well as their economic impact. A view once commonly held was that one country could gain from increasing tariffs until its trading partners retaliate, in accordance with Johnson's contribution (1951) of the optimal tariff, supported by Ossa (2014) who recently undertook an empirical analysis of US-European trade. However, Caliendo and Parro (2015) argued that an optimal tariff may have a negative impact when production issues and intermediate goods are taken into consideration. Earlier, Johnson (1953) analysed the motivations of imposing tariffs, and found that a country could possibly gain from a trade war by imposing an optimal tariff providing that the other country or countries did not retaliate. Ossa (2014) put forward a different argument that there would besubstantial global and individual country losses in the event of a full-scale tariff war with retaliation. Otherwise, Kutlina (2017) reported a similar impact but with less extreme results in his study where the two countries are of extremely different scales.

Apart from the impacts of trade tariffs on output, there have also been some studies to address macroeconomic effects such as employment and trade balance. Van Wijinbergen (1987) built a theoretical model in order to illustrate the impact of trade tariffs on domestic employment and current accounts in a simple small open-economy model under the assumption of a lump sum tariff as well as temporary or permanent tariffs. Van Wijinbergen (2018) extended his own study to a general equilibrium model in 2018; however neither provides a quantitative assessment of the macroeconomic impact of trade tariffs.

Rather than offering an analytical solution and qualitative assessment, Linde and Pescatori (2017) presented a quantitative model focusing on two countries using the

DSGE model with a variety of macroeconomic frictions highlighted, albeit the global market clearing mechanisms were not entirely clear from the model. In addition, they quantified the macroeconomic costs of a trade war, with permanently lower real income and foreign trade volumes. Meanwhile, Erceg (2018) explored different tax equivalences to tariff policies within a small open-economy New-Keynesian model. Therefore, it would now be of considerable interest to analytically evaluate the macroeconomic effects of tariffs by using a general equilibrium framework. In other words, we want to ascertain the macroeconomic impact of US trade tariff and tariffs imposing for the European.

EU tariff facts: Response to US trade tariff

In 2018, the United States administrations began its 'America First'protectionist policies and immediately imposed on China steel and aluminium tariffs on 23 March, which accounted for US $2.8 billion in Chinese products (Lu and Schott, 2018). The EU was spared from these tariffs in the beginning, but by June that year with steel (25%) and aluminium (10%) tariffs were imposed on EU goods by the US, which amounted to over EUR 6.4 billion, according to European Commission in 2018. The EU quickly retaliated to the US tariff policy on 22 June, affecting on US imports to the tune of EUR 2.8 billion.

The United States remains the most significant and largest trade partner for the EU, thus leaving EU policymakers unsure as to whether they should retaliate to the US's protectionist policies, in light of the possible economic and welfare effects for EU. Demertzis and Fredriksson (2018) built up a game theory model for an EU-US trade war, assuming that both would either decide to cooperate or impose sanctions on another. They found that a respectful agreement would be most beneficial and also most likely. However, if the US was to announce its protectionist sanction and did not cooperate with the EU, the latter would pursue a strategy of imposing trade tariffs more frequently and both parties would suffer, especially the US. They concluded that although retaliation would damage EU trade outcomes, it was the only option for the EU policymakers in response to the US tariffs.

Economic theory suggests that engaging in a trade war makes a country worse off for three reasons. First, as Demertzis and Fredriksson (2018) concluded, the imposition of tariffs raises the cost of imported goods and reduces the purchasing power of domestic consumers. Second, Kutlina (2017) suggested that a tariff on intermediate goods would push up the costs of production; if companies take the higher production costs into account and increase product prices accordingly, consumers would essentially bear the tariff costs instead of the firms, which instantly damage the purchasing power of consumers. Third, retaliation from other countries would damage external demand for domestic products, and protectionism also deters other countries from trading or investing even without sanctions (Berthou etc, 2018). Overall, trade tariffs decrease total output and lower the volume of trade, with a price level rise in sector and total level.

Besides the global empirical studies on measuring trade tariff effects using a macroeconomic model, it would also be of potential interest to measure the EU tariff effect and trade facts using an appropriate macroeconomic model. For instance, according to the OECD's study in 2016, a 10% rise in trade costs for all goods in China, the EU, and the US would decrease global GDP by 1.4% and EU GDP by 1.8%. Furthermore, Ossa (2014) estimated that tariffs would rise in a trade war in response to an optimal retaliation based on a multi-nation, multi-sector general equilibrium model. Their study found that all trading partners' welfare was reduced in reaction to the imposition of a trade tariff, while global welfare would be reduced by 2.9% and EU welfare by 2.2%.

Therefore, it is clearly worthwhile to evaluate trade tariff effects and other trade facts using the moreappropriate macroeconomic model. The following section prepares an illustration of the differences between the classical and gravity models in their assumption, and this thesis aims to apply these two rival models in a computable general equilibrium (CGE) framework. The indirect inference approach is a recently developed method to empirically test the accuracy of both models, and here we illustrate the basic idea pertaining to how the indirect inference method helps to distinguish between the two rival models taking into account their fitness to handle data behaviour.

Part 1.2 Literature Review:Classical and Gravity Trade Models

Overview

There are many literature reviews on both classical model and gravity models. The classical model has been widely used in trade trends analysis over the past two decades of the twentieth century; and the gravity model, which introduces the scale economies in production, is recently very popular in many empirical researches. The gravity model has limited theoretical explanation until Anderson (1979) firstly established the Armington model for the gravity relationship. The basic intuition for the gravity theory is that the closer the geographical distance between two traded parties and the larger scale of economies, the more volumes of trade will be between two countries. The classical model formulated its theoretical framework from Ricardo’s comparative theory (1817), however its empirical performance is relatively weak compared to the gravity model.

There are two important problems to solve. First, empirical results could be biased due to omitted variables and miss-specification. If classical model can be correctly constructed, it may also provide con-vincible estimation results. Second, there is still insufficient evidence to distinguish the empirical performance between the classical model and gravity model. Minford and Xu (2018) set up two CGE models of trade and tested the empirical performance for the first time based on UK data; however, it is relatively a small country case and maintains enough interest to evaluate how classical model and gravity model behaves in a large-scale-economy perspective.

There are several other models that also capture the trade relationship. Staffan Linder (1961) offered a term of ‘overlapping demand’ to illustrate the pattern of trade. He assumed trades between nations were typically demanded at the respective per capita income for a range of goods. To produce and trade, representative demand in each country requires having an overlapping zone for a range of goods that are produced and consumed in common. In his view of trade, it is demand and not supply that determines the pattern of trade.

Krugman (1981), as for the scale economies, permits a reduction in cost calculation when trade scale comes to global while dislocating production from those less-cost-efficient countries. As with other scale economies, Helpman (1984) pointed out that small economies were supposed to gain from trade by liberalization that otherwise cannot have access into those external economies. He argued that a small country has more possibility to gain from trade as markets are open and external economies of scale are able to access at an international level.

Brander and Spencer (1985) formulated the term of ‘strategic trade’, which relates the scenario when demand curves are subject to elasticity that is different in the two countries. When countries that are historically ahead of another country in particular goods, it holds the advantage of price lower than other countries at the starting point in other goods relating to that area.

Besides, we have other trade models, such as the heterogeneous-agent model of Melitz (2003), divergent-economic-development model of Darity and Dvis (2005). However, this thesis will set up the two rival models, including classical trade model and gravity model, by using computable general equilibrium model (CGE), and then test them using Indirect Inference Wald test based on EU data. On the one hand, classical model has been widely used in the past few decades, but it is, in some extent, ‘theoretical but not empirical’ model for trade; and gravity model has attracts increasing interest because of its satisfactory empirical performance. Both models has be predominate model for a period of time, so it is of interest to compare with these two models to see which model has better statistical performance. On the other hand, there are some other models, such as heterogeneous-agent model, and they are of interest to evaluate their policy implication. These models could have been left to future work to evaluate their statistical performance, and the Indirect Inference approach could also be applicable for them.

In the following chapter, we focus on a review of classical model and gravity model studies, and a brief introduction of computable general equilibrium model and Indirect Inference approach.

A Review of Gravity Model Studies

Since the introductive pieces of researches were conducted by Tinbergen (1962) and Linnenman (1966), the concept of gravity has been practiced in trade models and the term of gravity has been widely discussed in this regard. Tinbergen (1962) was the first to apply the mathematical equations for the gravity model. The idea of gravity came from the Newtonian physics; in terms of trade, however, Linnemann (1966) illustrated that trade parties are linked by their sizes and proximity. He used the concept of gravity in a trade model, concluding that bilateral trade could be predicted according to economic size (the larger in size, the greater the likelihood of trade) and distance (the closer in geographical distance, the greater the likelihood of trade). However, Baldwin (1994) stated that although the gravity model had described trade flows in empirical works, it often was criticised for an apparent lack of theoretical grounding in economics or for being ‘physics rather than economics’. Bergstrand (1985) in particular raised doubts about the gravity model’s absence of theoretical foundations, and also mentioned that this model continuously demonstrated a high level of statistical strength in explaining trade relations. Furthermore, Filipinni and Molini (2003) also supported this view of ‘facts without theory’ in the gravity experiment; they concluded in their East Asian study that gravity model results were consistent with the facts and 'popular for practical application'.

Anderson (1979) was the first economist to formulate gravity in a trade model applying a theoretical economic foundation based on the assumption of product differentiation by country of origin and Constant Elasticity of Substitution (CES) settings. In this first theoretical foundation of the gravity model, Anderson derived gravity equations from the product differentiation approach and formulated a mathematical study based on Armington's assumption (1969). Bergstrand (1985) extended the gravity model in a microeconomic perspective to include the supply force of the economy in bilateral trade theory. Moreover, Helpman and Krugman (1985) constructed a link between gravity and monopolistic competition. Others, such as Krugman (1979), and Anderson and Mercouiller (1999) have alsofound several theoretical rationales for the concept of gravity to economic theory. Baldwin (1994) summarised the rising interest in the gravity model in practice as being attributable to some economic foundations, and claimed in contrast to common understanding that the gravity model was popular in empirical research and did have some theoretical foundations. Kabir etc. (2017) broke down the gradual development of the application of the gravity model into four types: generalized gravity model; intra-industry trade; homogenous and heterogeneous products; and structural gravity model. Notice that these other models reviewed here mostly include the central Armington gravity assumption, and so if tested would behave quite similarly to the gravity model we test.

The Heckscher-Ohlin framework is one of the most influential theoretical applications in trade economics. This model differentiates country characteristics, and breaks down the endowment and intensity of each relevant factor; countries tend to export the products in which they are well endowed and import those in which they are not. This model links comparative advantage theory with the given country's factors of production and technology. Deardorff (1998) summarised that the gravity model was consistent with theHeckscher-Ohlin (H-O) model and the Ricardian model, and other traditional trade economics model, while Evenett and Keller (2002) claimed that the gravity equation would be successful depending purely on the H-O model and increasing returns to scale.

'The border effect', which was raised by McCallum (1995), has become one of the most popular topics to be discussed in relation to the gravity model. In his first attempt in aCanada-US study between 1988 and 1990, the estimated inter-provincial trade between provinces in Canadawas more than significantlymorethan trade between provinces in Canada and the US. The border effect carries a substantial cost for international trade and tends to dampen the volumes of trade between countries. There have been plenty of researches to have dealt with the so-called home bias in consumption and the effect of distance and national borders, which is known as the 'McCallum Border Puzzle'.

There have been hundreds of papers to have covered the border effects in the gravity model. Anderson and van Wincoop (2003) in their study 'A solution to the Border Puzzle' provided a renewed solution based on the same dataset used by McCallum, and they found that McCallum's estimation suffered from omitted variable bias; when they added multiple resistance factors into the same dataset, the puzzle was solved. Feenstra (2004) further studied the resistance factors that help to solve the puzzle, finding that these resistance factors could be estimated by applying importer- and exporter-fixed effects. Conversely, various studies have concentrated on the estimation method and econometric techniques applied to the gravity model. Olivero and Yotov (2012) used panel data with the dynamic gravity model to evaluate the changing nature of data and estimation methods; Westerlund and Wilhelmsson (2011) stated that applying a linear method to the gravity model was problematic when there is zero trade flow. When there is no trade between two countries, a logarithm of zero is not defined. Therefore, the loss of information increases exposure to sample selection bias arising from the elimination of trade flows. Saleh and Lu (2019) summarised recent methods applied on the gravity model, with each of them having their own advantages and disadvantages. In particular, the Heckman sample selection model is designed to avoid the inconsistent estimation of gravity parameters, and the Poisson pseudo maximum likelihood model ensures the robustness of estimations in the presence of zero trade flows. Meanwhile, the Poisson quasi maximum likelihood model provides better empirical evidence than traditional ordinary least square (OLS).

A Review of Classical Model Studies

Classical international theory is credited to Adam Smith (1776), who was the first researcher of absolute advantage. The successful emergence of absolute advantage theory was based on the division of labour and large-scale industries in Smith's nativeScotland, with low labour costs enabling the country being intentionally competitive. Hume (1776), during the same period, called for an 'automatic adjustment' through a price-specie flow mechanism that demanded monetary adjustment for economies with an absolute advantage in traded products.

Ricardo (1817) sets out the basic theory of free trade in terms of 'comparative advantage'. During Industrial capitalism in Ricardo's native England, large-scale industries and captive markets in British colonies have been grown rapidly; in particular, it could import corn at a significantly lower labour cost, thus Ricardo found it was comparative advantage and not absolute advantage which determined the extent to which trade is mutually beneficial. Essentially, countries should specialise their production and export products in which they have a comparative advantage in terms of labour hours used per output unit.

Heckscher (1919) and Ohlin (1933) assumed traded goods to contain a mixture of factor endowments, such as land, capital and labour. Therefore, trade between nations is mutually beneficial exchange of abundant factors and scarce factors. According to the H-O model, technology is identical across countries, which is different from the technology-driven Ricardian theory, and factor endowments determine trade flows.

Samuelson (1948) summarised the factor price equalisation theorem, according to which a factor-intensive country will produce more products with this factor than relative factor-abundant country, leading the factor price to stay unchanged through trade. Stolper and Samuelson (1941) studied the source of commodity price rises, and they argued that the increasing price of a commodity/factor intensively used will result into the decreasing price of another commodity/factor. Another study of price in trade theory was carried out by Rybczynski (1955), who assumed that when prices of goodsare constant, an increase in factor endowment leads to a rise in factor-intensive production and a downward trend in the production of another factor. Moreover, many studies have been published to evaluate innovated models based on the 2*2 H-O model. Vanek (1968) was the first theorist to apply a multi-factor, multi-country model, and concluded that a country tends to export its factor in which it isintensively endowed. Ethier (1984) deals with multi-product, multi-factor and multi-country situations but did not provide empirical evidence of their relevance.

However, although the H-O-S model has been sufficiently explained in trade theory, the failure of H-O-S theory to address the realities of empirical researches has been raised over the pastdecades. Leontieff(1953) performed the first empirical test based on US data and at an empirical level he observed a tendency for labour-intensive exports rather than imports, which could be explained by the US being a relatively capital-abundant country. Leontieff (1956) posed a paradox in terms of the endowment-based illustration of trade patterns under H-O-S theorem; he made the attempt to explain the paradox ofa unit of labour in the USbeingworthgreater than a unit of labour in other countries.

Minhas (1960) restricted the H-O-S model to CES production functions, i.e. assuming constant elasticity of substitution (CES) between production factors; it ruled out factor intensity and questioned the uniqueness of factor prices. Furthermore, he assumed different endowment ratios across countries and various factor intensities for goods, with constant returns to scale and diminishing returns to factors used in production.

Other economists have attempted to introduce economics of scale in production. Krugman (1981) assumed monopolistic competition and increasing returns to scale, and stated that the increasing returns to scale was a source of mutual benefit from trade attributable to the size of the economies involved. These assumptions are the foundation of theoretical implications underpinning the gravity model, as mentioned above. However, one disadvantage of the classical H-O-S model stems from a lack of empirical evidence. In the modern computerised approach, it is common to apply many equations and simulate more data. The classical trade model's performance has not been yet tested using such a method and doing so may lead to the similartrade trends with the gravity model simulation.

Part 1.3 Overview: Classical and Gravity Model of Trade

Gravity Model of Trade

In recent decades, trade economists such as Breinlich (2016) and Costinot (2014) have favoured the gravity model of international trade. Under the gravity model mechanism, trade is mainly driven by demand forces, for instance the import tendencies of neighbouring countries and a country's specific characteristics such as size and distance from the country with which it is trading. It is assumed that competition is imperfect as prices are set by producers as a mark-up to cover production costs, transport costs and other costs, so prices are not particularly volatile much in response to demand. Perfect competition can also be assumed, under which prices are equal to marginal cost. Once demand is determined by a neighbouring country and production costs are absorbed in the price, under the gravity model, supply of trade could be determined and modified by demand forces (i.e. foreign direct investment flowing into the domestic market and boosting productivity and innovation accordingly). Thus, the gravity model is determined by demand forces, and supply follows afterwards with its demand.

According to the summary provided by Dhingra (2016), there are four common assumptions for gravity modelers: Dixit-Stiglitz preferences (which contain a CES utility function representing consumers' preference for product variety as in Armington, 1969); one production factor; linear cost functions; and perfectcompetition. Moreover, other restrictions at the macroeconomic level are balanced trade; profits being considered as shares of revenue in aggregation; and constant elasticity of substitution (CES) for import demand. Some other trade models have also become popular such as the new trade theory model by Krugman (1980), the Ricardian model of Eaton and Kortum (2002) and the heterogeneous-firm model of Melitz (2003).

From foundations like these one can assemble a gravity-based general equilibrium model- as discussed below.

The EU, as a customs union, is a freely-traded single market between its member states, so a rise in trade tariffs settled by the United States and other countries damages existing market demand in the union. From a gravity model perspective, demand determines production and supply as well as trade, which would fall accordingly. If the EU seeks to lower trade barriers with other countries in the world to compensate for the loss suffered from the increased US tariff, it could effectively substitute the loss of demand by simulating more demand from the rest of world. However, the reduction of trade tariffs with rest of world might not be enough to cover such a loss because the US is the EU's largest trade partner.

Free trade inside the EU should be evaluated carefully as it currently protects its own single market by imposing trade tariffs with the rest of the world. Hence, if reducing trade tariffs with the rest of the world under the gravity model, the EU market would benefit from increasing demand from the rest of world but would suffer a loss in demand from inside the EU market. It would also be worthwhile to evaluate the potential trade-off here by implementing a sensitivity analysis on trade tariffs to try to determine whether reducing trade tariffs with the rest of world would increase market demand within the EU.

These considerations from the gravity point of view encourage the examination of relationships between exports and GDP of trade partners with the gravity effect of market size and distance between countries taken into account. However, this gravity model essentiallyillustrates the trade trends of key endogenous variables, such as trade, output and prices. On the other hand, the classical trade model could also possibly replicate this estimated trade trend relationship.Therefore, the research question pertinent to this issue is as follows:

1. ***Can the classical trade model replicate the similartrade trends thatsimulated by the gravity model?***

Classical Model of Trade

As mentioned above, the classical model, as the rival model to the gravity model of trade, has been developed for longer than two hundred years, as catalysed by famous trade theorist Ricardo (1817). The claim of gravitymodelers that the classical model is outdated has not been empirically proved with relevant evidence. Indeed, although the classical model is less adopted by modern theorists, in the latter part of the last century we saw the Keynesian Revolution, heralding a revival of interest in classical principles.

Unlike the imperfect competition assumption in the gravity model, the classical model makes the assumption of perfect competition among countries, with global prices identical among all countries subject to transportation cost and trade barriers. It assumes no barrier to entry into domestic industries thus prices equal to average costs. There is also an assumption of free capital flow through countries in the world, but in reality of course each country differs in its levels of skilled labour and unskilled labour, as well as size of land and scale of industry. In the classical model, it is supply forces, including supply factors, sector productivity and so on, which determine the contribution of each industry to the economy; this is the main difference compared to the gravity model, for which demand is the dominant force. Thus, in the classical model framework, the supply of domestic products is twofold; some are purchased by domestic consumers, and such demand can be constrained if the income level is low among consumers in the given country; on the other hand, any surplus of supply is then exported. Meanwhile, products for which there is domestic demand but a deficit in supply are imported in each sector.

Both the classical and gravity models can be set up as a computable general equilibrium (CGE) model, enabling us to compare each of them from a quantitative perspective. The next research question to consider for this thesis is how to distinguish between both models and figure out which model accommodates the data better:

2. ***Between the classical and gravity model, which model better accommodate the EU actual trade data?***

Differences and Similarities between the Rival Models

The classical model is significantly apart from the gravity model with its causal structure; in the classical model, supply factors and productivity determine trade activity; it follows comparative advantage theory whereby each country produces goods in which they have an advantage based on its supply of labour or land size as well as its sector productivity. When the domestic supply is determined, demand must then match the supply; any surplus of supply will otherwise be exported. Meanwhile, goods in which a country suffers from a deficit of supply are imported, which determines the overall trade structure. However, in the gravity model, domestic demand for the given product determines supply; neighbouring markets tend to impose less transportation and border costs, which allow prices to remain competitive. Neighbouring markets are therefore usually of greater interest when it comes to importing goods rather than importing from more distant markets. Once the level of demand is determined, the structure of trade and other supply forces are modified in order to meet the demand. In sum, the classical model is dominated by supply forces and the gravity model is dominated by demand forces.

Besides those differences between the classical and gravity models, this thesis also aims to construct a general equilibrium model of EU trade that can capture features of actual data behaviour. One feature that both models should reflect is the massive fall in tariffs prompted by the rise of global supply chain. According to Evans and Mason (2015), consumers nowadays purchase products from final product distributor at the end of highly competitive supply chains, with those suppliers providing final goods to highly competitive distributors who have to keep costs low to maintain their position in the chain, as exemplified by the likes of Tesco. World Bank data also show a massive decrease in the tariffs in recent decades; it calculated that the weighted average of world tariffs decreased from 34% to 2% in the last twenty years. One can also logically assume that tariff reductions would force non-tariff barriers to decrease in a truly competitive supply chain.

Another feature to consider is the brand. In the retail market, customers' purchasing decisions are influenced by brands; these brands differ in various respects including geographical origin or product differentiation. As a survival strategy, brands maximise their profits by buying the cheapest inputs; but inputs must be of demonstrable quality that can satisfy the needs of the product. In this way, free market entry is beneficial for branded products to maintain their lowest input costs. Moreover, as world market is enough large in size, economies of scale also enable brands to lower their production cost.

The third feature under consideration here is factor endowment, which determines a country's market characteristics and cost. Capital is mobile across countries so the origin of capital is a matter of indifference. However, supply factors such as labour and land differ significantly across countries. For instance, education level has a bearing on the level of skilled labour; having highly educated workers remarkably increases the productivity in a given sector. Other factors that are hard to measure also influence output and sector productivity, such as health care, financial services, legal system and level of infrastructure. These institutional endowments affect productivity in each country, and their effects should be included in both models.

As stated above, there are several similar features shared by the rival models but they are different in their assumptions. The next section provides a brief literature review for both models and highlights their recent developments of empirical studies. It is also worthwhile here to generate a general equilibrium model to illustrate each model's behaviour quantitatively; thus, this thesis proposes a long-run model to judge the long-term trade behaviour of trade instead of tracking short-run fluctuations. Before officially building up our structural model, there are some more points to mention regarding the formulation, namely the CGE, a Computable General Equilibrium model and the unfamiliar testing method of the IIW, an Indirect Inference Wald test.

Part 1.4 Overview: CGE Model and Indirect Inference

Computable General Equilibrium Model

Computerised technology and the power of calculation have been grown massively over the past decades, which allows for computer-intensive estimation and testing. Small samples of data often suffer from data selection bias or estimation error, but the CGE model relies purely on the actual data and is able to simulate histories of simulated data based on actual data distribution, testing them in a quantitative manner. The CGE model also assumes a general equilibrium, which understands that variables change accordingly. We can derive the CGE trade models as equilibrium relationships, and these relationships should be co-integrated. This means that the CGE model will have non-stationary errors, such as productivity, driving those trended behaviours, while there will also be stationary errors; however, these trended variables are co-integrated. For instance, if A is the co-integrating matrix, x is the vector of endogenous variables, z is the vector of non-stationary exogenous variables, such as productivity, and u is the vector of other shocks:

$$Ax_t = Bz_t + u_t$$

z is a non-stationary I(1) process, illustrating the changing equilibrium trend. The other shock vector, u, is stationary under the true model. We treat shock vector,u, as AR(1) process, thus $u_t = Pu_{t-1} + \eta_t$ where P has the auto-regressive coefficients for each error. The shock includes the whole current deviation of x from its equilibrium value, $A^{-1}Bz_t$, including the dynamic effects in response to the shocks due to adjustment costs and expectations. It is the gradual disappearance of these effects that creates the auto-correlation. The reduced form of this model is a VAR-X(1), as we can show using the ABC-D method of Villaverde et al (2005):

$$x_t - A^{-1}Bz_t = A^{-1}u_t$$
$$= A^{-1}Pu_{t-1} + A^{-1}\eta_t$$
$$= A^{-1}P(Ax_{t-1} - Bz_{t-1}) + A^{-1}\eta_t$$
$$= A^{-1}PA(A^{-1}Ax_{t-1} - A^{-1}Bz_{t-1}) + v_t$$
$$= \Lambda(x_{t-1} - A^{-1}Bz_{t-1}) + v_t$$

The coefficient $\Lambda = A^{-1}PA$. Thus x can be written as a VAR-X, with z as its exogenous driving vector of X from its equilibrium value.

The x can be also written as VECM, where the lagged deviation from its equilibrium acts on it, pushing it towards equilibrium. The VECM can be written as:

$$\triangle x_t = \triangle (A^{-1}Bz_{t-1}) + v_t - (I - \Lambda)(x_{t-1} - A^{-1}Bz_{t-1}) + v_t$$

This indicates that x changes with the change its equilibrium value as well as adjusting in response to its lagged deviation from equilibrium. We can also note that the elements of x will be co-integrated in a variety of reduced form relationships with each other and with z, owing to their common trends in z. These relationships we are discussing here are treated as the auxiliary model. In the auxiliary model, where all the variables share common trends, the errors will be stationary; the stationarity of errors in the auxiliary model and CGE trade model will be tested carefully to fit these assumptions.

The CGE model here is a static model so we treat model behaviour as median to long-run, rather than dynamic focusing on the short-run.The point of the model in this thesis is to model trade trends, rather than trade dynamics.The CGE trade model can be regarded as a set of co-integrating relationships, whose reduced form consists also of co-integrated relationships, which we treat as the auxiliary model.In such model, the errors represent non-stationary exogenous variables, such as productivity, and lagged effects of these and other stationary shocks.. In this case, shocks in a CGE model are explained as accumulative effects of today's shocks and shocks in lagged time. That is to say, shocks adjusted over time are also included; we treat shocks and adjusted shocks together in order to simplify the simulation.

Furthermore, the CGE model holds parameters constant over regime change, thus model predictions are relevant for policymakers who change their decisions over time. It satisfies Lucas's critique so that parameters are policy invariant; so the CGE model can be applied to evaluate the effects of change in policy.

Indirect Inference

The indirect inference approach, compared with Bayesian estimation, maximum likelihood and other popular estimation procedures, is recently a new method but is being increasingly adopted because of its advantageous properties when using small samples, according to Le et al. (2016). This study, in which we only use annual data for the EU, is a typical small sample case and we want to apply this method to reject models suffering from mis-specification. Unlike Indirect Inference, the Bayesian estimation is also well-known and widely applied in many physical sciences. Under the Bayesian approach priors are assigned in accordance with the economist's own beliefs. However, in an area of controversy such as we have here over the choice of trade model, the choice of priors will be controversial, biasing the estimated probabilities of the models. Here we wish to test models with different structures for their ability to match the data behaviour; the model that matches it best we regard as closest to the true unknown model generating that behaviour; this is the indirect inference testing procedure.

There are some common features among macroeconomic models, and the same applies for trade models. Many trade models are large and consist of many equations; some of themare driven by maximisation; some of them are non-linear and lack substantial time series data. There are two other approaches deployed to tackle these trade models: maximum likelihood and indirect inference. Le (2016) investigated DSGE models and their small sample properties using a Monte Carlo experiment, and concluded that maximum likelihood had bad small sample properties because of a significant estimation bias and low testing power. In comparison, indirect inference was found to have low estimation bias and greater testing power. This study intends to follow their study and apply an indirect inference method.

In indirect inference, facts with regard to data behaviour are estimated separately from the structural model being tested; this model describing the data behaviour is known as theauxiliary model and it aims to capture key relationships in the data that will allow modelers to select the more appropriate structural model.

With respect to the testing procedure as a first step, I estimate the auxiliary model which records the relationships found in the data for the sample period we are dealing with. In the next step, I simulate the model repeatedly to generate similar histories of the sample periods, and each of these history samples has the same auxiliary model. From these same auxiliary models, each sample can generate a specific auxiliary relationship. The final step entails putting all auxiliary relationships together and generatingthejoint distribution of the estimated auxiliary relationships. From this joint distribution, one could understand the probability of this model generating the actual relationship we found in the real data. If the likelihood is low, then we reject the model which indicates that the real world created from the model is unlikely to accurately replicate real world performance.

Part 1.5 Research Question

In order to investigate the policy implications of EU trade policy, it is of interestto find the more appropriate model to capture EU trade facts. As discussed above, there are typically two types of models we wish to consider: the gravity and classical model we reviewed above. The classical model has been predominant model for trade for past few decades in last century, and the gravity model has attracted increasing attention in recent years. However, we cannot simply judge the gravity model is better than classical model because of its age. The gravity model was fundamentally different with classical model, and they have different assumptions and characteristics. Therefore, it is of interest to evaluate whether the model is appropriate to study the trade policy.

This study is also an extended piece of research based on Minford and Xu's (2018) study in the UK. First of all, it marks another empirical exercise using the relatively unfamiliar testing method of Indirect Inference, which is able to statistically evaluate model accuracy among two rival models. The contribution of the thesis is that there is no one has done this kind of statistical comparison between trade models based on EU data. It is necessary to do such a test before any model is selected to evaluate EU trade policy, because there is an identification problem. That is, although there are many empirical evidences to support the gravity model, the classical model could also produce similar trade trends in line with the gravity model. If both models are able to generate similar simulated trade trends, it is necessary to evaluate which model fits the actual data better and is more appropriate to use for policymakers.

Second, this thesis extends Minford and Xu's study from a small open-economy model to a large open-economy model, which provides model specification and test performance for large scale economies and country groups. The contribution of the thesis is to endogenize the world prices and GDPs by a reduced form VAR, because EU is large enough to influence on the world economy. Therefore, we test the EU model using the part-of-model test.

Finally, this study contributes to providing both models' simulated performance regarding to a tariff policy simulation, and aims to evaluate EU trade policy with regard to free trade or protectionism. It also contributes by simulating both models' performance regarding to a productivity innovation simulation, and aims to identify the sectors in which the EU should prioritize investment.

CHAPTER TWO

MODEL SPECIFICATION

Introduction

The purpose of this thesis is to empirically examine two rival models, namely the classical and gravity models of trade, and figure out which model matches EU trade databetter.As discussed above, the gravity model of trade is dominated by demand forces; import demand from neighbouring countries tends to be greater because of lower transport and border costs. As suppliers set up prices taking into account production cost as a mark-up, the gravity model typically assumes imperfect competition and less substitutability of goods.As geographic distance is taken into account to distinguish the product type, products with different geographic origin have different total cost, in which case product origin matters. Demand drives production supply and trade flows, while foreign direct investment affects productivity in relation to trade. On the other hand, the classical model of trade assumes perfect competition, with identical world prices with transportation and barrier costs considered the same.The assumption of perfect competition in the classical model implies that supply forces dominate the trade; countries will produce what they are comparatively advantaged in factor of supply, and will intensively use these factors of supply to produce goods to export.It assumes no barriers to market entry and thus price equates to average cost. Capital flows freely, but other supply factors are constrained. The classical model is dominated by supply forces; it assumes that a country produces goods with a relative comparative advantage in productivity, and that the supply of goods must meet domestic consumer demand and that any excess supply will be exported. Meanwhile, products for which there is domestic demand but a deficit domestic supply are imported from other trade partners.

With this in mind, this thesis builds up a 4*4*4 CGE model using Minford and Xu’s (2018) model framework as a baseline. Four country groups are used: namely the United Kingdom, the European Union (excluding the UK), the United States and the rest of the world (ROW). In addition, four products are divided into traded and non-traded sectors; traded sectors are identified as primary agriculture, basic manufacture, and services. Non-traded industry encompasses other less tradable products that nevertheless contribute significantly to total GDP, thus we assume half of a country group’s GDP as a proxy. Furthermore, four factors of production are reviewed including capital, unskilled labour, skilled labour and agricultural land.

Looking at production differentiation, they are separated into product type and geographical origin. This model follows Armington’s (1969)’s framework with a constant elasticity of the substitution system where the elasticity can differ across product groups. Demand for intermediate goods can be derived by product type from Armington’s framework, and demand by geographical origin can be derived from the market clearing conditions. The market clearing condition for a country-specific product is achieved by obtaining their relative price at origin, which gives us the real exchange rate for that country group: it implies that GDP = aggregate demand for output + real exchange rate * export – import. As the CGE model supposes that aggregate demand for output equals total output, the equation becomes: import = real exchange rate * export. Therefore, market clearing for products by origin-type entails a shift in real exchange rate which affects the current account balance. On the other hand, market clearing condition for goods by product type is determined using product-type prices among the global economy.

Output by country origin: homogeneity in the classical and heterogeneity in the gravity

In term of product differentiation, the classical model assumes perfect elasticity of substitution regardless of origin, indicating products by geographic origin take into account of trade and should have a gravity component of trade. Meanwhile, the gravity model assumes a finite elasticity of substitution regard of origin and demand effects from the real exchange rate which balances the current account.

To implement the difference in product homogeneity between the two models we introduce a retail distribution sector into them both: the model assumes that bundles of undifferentiated intermediate goods are bundled and sold at retail stores by the retail distributor, who creates distinct products that are differentiated according to the tariff and transportation cost of their geographical origin. In the gravity model, this is done for all product origins and in the markets of all countries. But for the classical model, we assume the rest of the world (ROW) market acts as a residual market and bundles intermediate goods into brands that are not according to geographic origin, so that the intermediate goods inputted into these brands are treated as identical. Essentially, ROW market is origin-free in the classical model and any unsold intermediate goods from other country blocs can be sold to this market at identical world prices. By contrast in the gravity model, retail distributors in the ROW also brand intermediate products by origin, and thus the gravity model assumes imperfect substitutability for all markets. Basically, ROW market in the gravity model is just like the UK and the US in that it acts as a normal market and intermediate goods are branded similarly by origin; each major market now has to adjust the real exchange rate to balance its current account, ensuring that export demand equals import demand for each bloc.

According to the above assumptions, there are two types of firm: intermediate-product firms and final-product firms; and there are two types of product: intermediate products and final products. The first type of firm produces intermediate goods with inputs from a perfect competitive market, selling their intermediate goods to the other type of firm. The other type of firm, here assumed to be a retail distributor, brands these intermediate goods by country of origin to make them into a bundle of branded and differentiated final products. Consumers in each market purchase these final products from retail distributors, branded by origin.

Unlike the classical model, the gravity model includes two gravity components that capture imperfect substitutability, which have been discussed above, and productivity is stimulated by trade accumulation. In the classical model, productivity is an exogenous process, determined by country-specific factors of supply; however, in the gravity model of trade, according to Dhingra (2016) and Cai (2019) trade and economic size positively affect productivity courtesy of foreign direct investment transmission.

Hence, from the following section, a theoretical model will be fully expressed and the models of consumption, supply, production and trade will be outlined in detail. The full classical and gravity models will be detailed afterwards, to be used for further testing.

Part 2.1 The Model of Consumption

Final Demand

The model of consumption objectively maximises a household's utility, taking into account their income budget constraints. Domestic consumers take final products from retail distributors, which are branded with country-specific origin; these final products are fully consumed by the consumer and not in the processes of production. According to Armington's cascade model (1969), demand for each brand is determined in each country *J*. Thus, consumers in each country *J* have an aggregated utility function, C_J, from the consumption of other products branded from all country *i*. We maximise the Armington CES utility function subject to total consumption demand as follows:

$$(1)\ Max\ \ C_J = \left\{\sum v_i C_i^{\frac{\sigma-1}{\sigma}}\right\}^{\frac{\sigma}{\sigma-1}}$$

$$(2)\ subject\ \ to.p_J y_J = \sum p_i C_i$$

Equation (1) is a standard constant elasticity of the substitution utility function. v_i is the share parameter, indicating the share of expenses spent on country *i's* goods by country *J*. The sum of share parameters equals unity. σ denotes elasticity of substitution. Thus, consumption good *C* from different countries *(i)* is perfect substitution for each other when σ is infinite and perfectly complement when CES approaches one. *C(i)* is the amount of consumption goods branded from country *(i)* that is consumed by country *(J)*'s consumer. *P(J)* is the price and *y(J)* is the output in country *(J),* while *p(i)* is the price level for the consumption good in country *(i)*. The utility function represents the consumption good consumed by country *(J)* in a function of that consumption good from all countries*(i)* with share parameter*v* in its expenditure, while the budget constraint represents total income from country *(J)* and should not exceed total expenditure on that good from other country.

We establishLagrangian from Equations (1) and (2):

$$(3)\ L = \left\{\sum v_i C_i^{\frac{\sigma-1}{\sigma}}\right\}^{\frac{\sigma}{\sigma-1}} - \lambda_1\left(\sum p_i C_i - p_J y_J\right)$$

Then conduct first-order derivative with respect to *C(i)*:

$$(4)\frac{\partial L}{\partial C_i} = \frac{\sigma}{\sigma-1}\left\{\sum v_i C_i^{\frac{\sigma-1}{\sigma}}\right\}^{\frac{1}{\sigma-1}} * \frac{\sigma-1}{\sigma} v_i C_i^{\frac{-1}{\sigma}} - \lambda_1 p_i = 0$$

Rearrange Equation (4), multiply by *C(i)* and this yields:

$$(5)\left\{\sum v_i C_i^{\frac{\sigma-1}{\sigma}}\right\}^{\frac{1}{\sigma-1}} * v_i C_i^{\frac{\sigma-1}{\sigma}} = \lambda_1 p_i C_i$$

Subject to budget constraints, take summation of all *(i)* on Equation (5):

$$(6)\lambda^{-1} C_J = p_J y_J$$

Equation (6) substitutes the left-hand side of Equation (5) with total utility so consumers in country *J* can consume at the maximum of their income, thus the inverse of Lagrangian multiplier becomes the price for consumption in country *J*.

Divide Equation (5) by *C(i)* on both sides, then rearrange the equation, raising the power of $(1-\sigma)$ and multiply by *v* to yield:

$$(7) v_i C_i^{\frac{\sigma-1}{\sigma}} = \lambda_1^{1-\sigma} p_i^{1-\sigma} v_i^{\sigma}\left(\sum v_i C_i^{\frac{\sigma-1}{\sigma}}\right)$$

Take the sum of all *(i)* on Equation (7) and the inverse of the result is:

$$(8) p_J = \lambda_1^{-1} = \left(\sum v_i^{\sigma} p_i^{1-\sigma}\right)^{\frac{1}{1-\sigma}}$$

Equation (8) illustrates country *J*'s price index is an index of prices in all countries *(i)* in relation to its share of expenditure to consumption. This is also referred to as the Dixit-Stiglitz price index, which was developed by Dixit and Stiglitz in 1977.

Equation (4) can also be replicated for another similar country, say country *(I)*, following with the same first-order condition:

$$(9)\frac{\partial L}{\partial C_I}=\frac{\sigma}{\sigma-1}\left\{\sum v_I C_I^{\frac{\sigma-1}{\sigma}}\right\}^{\frac{1}{\sigma-1}}*\frac{\sigma-1}{\sigma}v_I C_I^{\frac{-1}{\partial}}-\lambda_2 p_I=0$$

Country *(i)* in Equation (4) and country *(I)* in Equation (9) should be theoretically symmetric, notation for *(i)* and *(I)* is to differentiate between two country groups.

Then divide Equation (9) on Equation (4) to generate the following:

$$(10)\left(\frac{v_i}{v_I}\right)^{\sigma}=\left(\frac{c_i}{c_I}\right)*\left(\frac{p_i}{p_I}\right)^{\sigma}$$

Multiply Equation (10) by *p(I)* on both sides and take the sum of all *I* to yield:

$$(11)\sum p_I C_I * v_i^{\sigma}=C_i * p_i^{\sigma}*\sum v_I^{\sigma} p_I^{1-\sigma}$$

Substitute Equation (11) with respect to budget constraints in Equation (2) and the Dixit-Stiglitz price index in Equation (8) and these yields:

$$(12)p_J y_J * v_i^{\sigma}=C_i * p_i^{\sigma} * p_J^{1-\sigma}$$

Then multiply *p(i)* on both sides and generate the country-specific demand function:

$$(13)E_i=p_i C_i=v_i^{\sigma}\left(\frac{p_i}{p_J}\right)^{1-\sigma}*p_J y_J$$

There are several useful relationships generated from the CES demand function here. First, the larger the share of expenditure in the country *(i)*, the more demand for branded goods in that country *(i)*; second, a higher relative price in country *(i)*compared to country *J* will result in a lower demand in the former; third, a rise in income level in country *J* is positively connected to demand in country *(i)*. Therefore the elasticity of demand is fixed and can be derived from Equation (13), when the demand for each country follows CES preferences. The details of this will be explored in a later section.

Part 2.2 The Model of Trade

Demand for Import

EU import demand for trade blocs, UK, US, ROW:

$$(14)\ ln(M_i) = \theta_{1i} + \theta_{2i}\, ln(E_T) + em_i \quad i = UK, US, ROW$$

The EU imports branded goods from the UK, the US and the ROW. *M* denotes EU import by country of origin, and it is the function of total expenditure on EU-traded goods. Intercept and the slop coefficient of import to traded expenditure are estimated by OLS, and tariffs and other barriers are treated in the trade share error process *em(i)* because of a lack of data.

Demand for Export

Trade blocs, the UK and the US, demand for products exported from the EU. Meanwhile, if there is any excess supply of EU products, these EU products are exported to the ROW:

$$(15)\ ln(X_i) = \theta_{3i} + \theta_{4i} ln(E_i) + ex_i \quad i = UK, US$$

$$(16) X_{ROW} = Y_T - E_T - (X_{UK} + X_{US} - M_{UK} - M_{US} - M_{ROW})$$

The classical model assumes that countries from the EU to export to the UK and the US, and the rest of the world market acts as a residual market to demand for EU products for which there is an excessive supply at constant world prices. There is no need to adjust the real exchange rate here to clear the market, as the current account balance has been cleared because the ROW in the classical model is an origin-free residual market. *X* denotes exports of EU products to country *(i)*, *Y(T)* is total output for EU-traded goods, *E(T)* is the total expenditure of EU spending on traded goods.

ex(i) is the trade share error process for exports and intercept and slop coefficient can be estimated via Ordinary Least Square.

Part 2.3 The Model of Supply

In the standard CGE model, the goal of firms is to minimise their production under current technology endowments. As mentioned above, there are two types of firm in the model of supply: producers make intermediate goods and sell them to retail distributors, and the distributor's brand these bundles of intermediate goods as final goods by country of origin then sell them to the consumers. Thus, we should divide the supply side of the model into two parts: supply of intermediate goods by producers, and supply of final goods by retail distributors.

Producer: Intermediate good supply

The model of supply is set to a standard Cobb-Douglas production function with constant return to scale, and embodies a constant and factor-neutral technology innovation for four factors:

$$(17)\ \ y = A * (N^{\alpha})\left(H^{\beta}\right)(L^{\gamma})\left(K^{1-\alpha-\beta-\gamma}\right)$$

Equation (17) is a typical Cobb-Douglas production function, where A is the productivity multiplier factor which denotes technology; $(\alpha, \beta, \gamma)$are the factor shares, which are constant and vary in each sector, and they represent the elasticity each sector encounters as output changes; (N, H, K, L) are factors of supply: unskilled labour, skilled labour, capital, and agricultural land.

For the suppliers of intermediate goods, producers solve the cost minimisation problem subject to production function:

(18) $Min \ \ C = wN + hH + lL + rK$

$st. y = A * (N^{\alpha})(H^{\beta})(L^{\gamma})(K^{1-\alpha-\beta-\gamma})$

In the cost minimisation equation, we assign factor prices for each sector, namely unskilled wage, skilled wage, rate of return on land and capital return ratio.

We establish the Lagrangian as follows:

(19) $L = wN + hH + lL + rK - \lambda_3\{y - A * (N^{\alpha})(H^{\beta})(L^{\gamma})(K^{1-\alpha-\beta-\gamma})\}$

Then solve factor prices by taking first-order derivative with respect to the factor of supply:

(20) $w = \alpha\lambda_3\{A * (N^{\alpha-1})(H^{\beta})(L^{\gamma})(K^{1-\alpha-\beta-\gamma})\}$

(21) $h = \beta\lambda_3\{A * (N^{\alpha})(H^{\beta-1})(L^{\gamma})(K^{1-\alpha-\beta-\gamma})\}$

(22)$l = \gamma\lambda_3\{A * (N^{\alpha})(H^{\beta})(L^{\gamma-1})(K^{1-\alpha-\beta-\gamma})\}$

(23) $r = (1 - \alpha - \beta - \gamma)\lambda_3\{A * (N^{\alpha})(H^{\beta})(L^{\gamma})(K^{-\alpha-\beta-\gamma})\}$

Sector price equation can be obtained from these equations. First, represent the factor of supply with respect to *N* from Equations (20, 21):

(24) $H = \frac{w}{h} * \frac{\beta}{\alpha} * N$

(25) $L = \frac{w}{l} * \frac{\gamma}{\alpha} * N$

(26) $K = \frac{w}{r} * \frac{1 - \alpha - \beta - \gamma}{\alpha} * N$

Factor supply in term of unskilled labour is determined by exogenous factor prices and factor shares, if we wish to solve the factor of supply, only exogenous variables should exist in the function. So, the next step is to substitute Equations (24, 25, 26) into the production function:

$$(27)\ \ y = A * (N^{\alpha})\left(\left(\frac{w}{h} * \frac{\beta}{\alpha} * N\ \right)^{\beta}\right)\left(\left(\frac{w}{l} * \frac{\gamma}{\alpha} * N\ \right)^{\gamma}\right)\left(\left(\frac{w}{r} * \frac{1-\alpha-\beta-\gamma}{\alpha} * N\ \right)^{1-\alpha-\beta-\gamma}\right)$$

Rearrange equation (27) and solve factor of supply N:

$$(28)\ \ N = \frac{y}{A}\frac{\alpha}{w}\frac{w^{\alpha}h^{\beta}l^{\gamma}r^{1-\alpha-\beta-\gamma}}{\alpha^{\alpha}\beta^{\beta}\gamma^{\gamma}(1-\alpha-\beta-\gamma)^{1-\alpha-\beta-\gamma}}$$

Then substitute the expression of N into Equations (24, 25, 26) to represent other factors of supply:

$$(29)\ \ H = \frac{y}{A}\frac{\beta}{h}\frac{w^{\alpha}h^{\beta}l^{\gamma}r^{1-\alpha-\beta-\gamma}}{\alpha^{\alpha}\beta^{\beta}\gamma^{\gamma}(1-\alpha-\beta-\gamma)^{1-\alpha-\beta-\gamma}}$$

$$(30)\ \ L = \frac{y}{A}\frac{\gamma}{l}\frac{w^{\alpha}h^{\beta}l^{\gamma}r^{1-\alpha-\beta-\gamma}}{\alpha^{\alpha}\beta^{\beta}\gamma^{\gamma}(1-\alpha-\beta-\gamma)^{1-\alpha-\beta-\gamma}}$$

$$(31)\ \ K = \frac{y}{A}\frac{1-\alpha-\beta-\gamma}{r}\frac{w^{\alpha}h^{\beta}l^{\gamma}r^{1-\alpha-\beta-\gamma}}{\alpha^{\alpha}\beta^{\beta}\gamma^{\gamma}(1-\alpha-\beta-\gamma)^{1-\alpha-\beta-\gamma}}$$

Then take the sum of Equations (28, 29, 30, 31) and set the zero-profit conditions as follows:

$$(32)\ \ wN + hH + lL + rK = \frac{y}{A}\{\alpha+\beta+\gamma+(1-\alpha-\beta-\gamma)\}(\zeta)w^{\alpha}h^{\beta}l^{\gamma}r^{1-\alpha-\beta-\gamma}$$

Then, cost function with respect to factor prices is listed as below:

$$(33)\ \ C = \frac{y}{A}(\zeta)w^{\alpha}h^{\beta}l^{\gamma}r^{1-\alpha-\beta-\gamma}$$

The coefficient $\zeta = \{\alpha^{\alpha}\beta^{\beta}\gamma^{\gamma}(1-\alpha-\beta-\gamma)^{1-\alpha-\beta-\gamma}\}^{-1}$means profit is equal to zero and the cost minimisation problem is solved. In a perfect competitive market, price is equal to marginal cost, and the sector price equation follows the structure below:

$$(34)\ p = Marginal\ \ Cost = \ w^{\alpha}h^{\beta}l^{\gamma}r^{1-\alpha-\beta-\gamma} * \quad \pi^{-1}$$

Equation (34) solves the sector price as the marginal cost in a perfect competitive market, the term of π contains two things: first, it includes the above products of coefficients for factor prices; and, second, the technology, or productivity multiplier factor A is also included. Therefore, π can be expressed as an exogenous error process for sector productivity and the sector price equation is summarised as follows:

$$(35)\ p_M = \ w^{\alpha}h^{\beta}l^{\gamma}r^{1-\alpha-\beta-\gamma} * \quad \pi_M^{-1}$$
$$(36) p_S = \ w^{\alpha}h^{\beta}l^{\gamma}r^{1-\alpha-\beta-\gamma} * \quad \pi_S^{-1}$$
$$(37) p_A = \ w^{\alpha}h^{\beta}l^{\gamma}r^{1-\alpha-\beta-\gamma} * \quad \pi_A^{-1}$$
$$(38) p_D = \ w^{\alpha}h^{\beta}l^{\gamma}r^{1-\alpha-\beta-\gamma} * \quad \pi_D^{-1}$$

Therefore, the sector price is determined by the factor price of supply with an exogenous productivity error process assigned to each sector. The parameters of (α, β, γ) are factor shares for each sector; price in each industry has a different weight on the factor prices. For instance, manufacturing sectors are labour-intensive and heavily impacted by unskilled labour wages; service sector are determined largely by the availability of highly-educated workers, thus skilled wage carries more weight.

After the determination of sector prices, in the classical model the rest of the world acts as a residual market; any excess supply of EU goods can be export to the ROW on account of the model's disregard for origin. Essentially, the sector price of the EU is also the world price for each sector, thus the optimal supply of output in each sector can be constructed from world sector prices, factors of supply, and factor prices.

Retail Distributors: Final Good Supply

Refresh the supply chain again; first, the producer makes intermediate goods for the retail store, and these intermediate goods are sold without mark-up price and the distribution of intermediate goods to retail distributors is perfectly competitive. Now, a bundle of products have been stored in the retail store and the distributors wish to sell them; they brand these intermediate goods by country of origin and sell them to customers with those final goods branded by geographic origin. Basically, the elasticity of substitution by the country of origin is finite and final distribution from the retail distributor to consumer is in imperfect competition. Therefore, the retail distributor has to add a mark-up cost to reflect the finite elasticity of substitution.

In this case, the retail distributor is faced with a profit maximisation problem. Retail distributors bundle the intermediate product at marginal cost and sell it to each country by origin to maximise profits; it is subject to a CES demand curve for country *(i)*'s consumption good and the profit is determined by the difference of price and marginal cost as well as country *(i)* demand.

From Equation (12), a constant elasticity of substitution demand curve for country (i) can be derived as:

$$(39) C_i = v_i^{\sigma} * \left(\frac{p_i}{p_I}\right)^{-\sigma} * C_J$$

Maximise the retail distributor's profit function subject to the demand function as follows:

$$(40)\ \ Max\ \ \varpi = \sum (p_i - MC) C_i$$

$$subject\ \ to. \quad C_i = v_i^{\sigma} * \left(\frac{p_i}{p_I}\right)^{-\sigma} * C_J$$

This profit maximisation problem revolves around country of origin: retail distributors brand intermediate goods to final goods at a constant marginal cost based on its production cost, and they sell these bundles of goods to different destinations. In each country, there is a country-specific price and consumption and each destination has to solve the optimisation problem by origin. This satisfies the assumption that the substitution of origin is finite and origin matters: the geographical origin determines the characteristics of product type, and each should maximise profits individually.

Substitute budget constraints into the profit function, then take the first-order condition with respect to *p(i)*to reveal:

$$(41) p_i = \frac{\sigma}{\sigma - 1}\ MC$$

Equation (41) illustrates that the retail distributor sells products from different origins with a mark-up on the marginal cost. Firstly, this solves the identification issue that product differentiation by type is now being differently priced; this difference in price setting, however, is due to country-specific characteristics. Each country differs in origin so each one has a different price, and the retail distributor sells final products from different countries to maximise profits.

What we can see in Equation (41) is that the mark-up is exogenous but it diminishes in relation to the rise of elasticity of substitution. Basically, when country A and B have higher substitutability towards the product than country C, the retail distributor has to mimic the mark-up to sell them; therefore it also proves that when there is infinite elasticity of substitution and products from country A have perfect substitutability with those from country B, the mark-up on the cost should be eliminated.

Part 2.4 The Model of Production

This model of production adopts the assumptions of the Heckscher-Ohlin-Samuelson (H-O-S) framework. The production function follows the standard Cobb-Douglas production function and is identical across different destinations; a different productivity multiplier factor is assigned to each country and factor shares are indifferent, thus each country differs only in their productivity error process and models can be used among them all. There are four sectors: manufacturing, service, agriculture, and non-traded sector. Capital is freely mobile across borders but the other three factors are immobile. These immobile factors, such as labour, are special assets for the particular country and can be treated as country-specific characteristics. The classical model is dominated by supply forces under comparative advantage theory; those immobile factors have a strong effect on the country’s productivity.

Factors of Supply

Capital assumes perfect mobility in the model and should be the same from one country to the next. Each country’s capital has no specific difference in the model, but labour and land do. For instance, labour has low mobility in two ways: on the one hand, there is a legal restriction between borders for immigration, while on the other hand labour is mobile within a country. Land, of course, is immobile and in many cases controlled by government.

In the model of production, we treat agricultural output as exogenous and politically controlled by policymakers via planning restrictions. Minford and Xu (2018) assumed- based on observed UK practice- in their UK study that primary output is exogenously controlled by an interventionist planning system; otherwise they assumed that land is supplied by the planners to sectors according to demand. We assume that a similar system prevails in other countries also.

Unskilled labour supply is determined by four factors. Unskilled labour is positively related to total working population and government expenditure, as well as unskilled wages; and it is negatively related to unemployment benefits. The decision of an indifferent person to work or stay unemployed is broken down as follows: if the person decides to work, he earns a wage when he finds a job and earns zero when he cannot; if the worker decides to stay unemployed, he receives unemployment benefit and utility of leisure.

$$(42)\ \ Unemployment = (1 - \varphi) * POP$$

Total unemployment is the proportion of the total working-age population not in work. Therefore, the working population determines the total supply of unskilled labour in the market and government expenditure is positively correlated to employment in the market. If unskilled wages is sufficiently higher than unemployment benefits, people prefer to work more; if unemployment benefits are sufficiently high, people prefer to stay unemployed.

The supply of skilled labour can be treated as another factor of labour supply. With higher investment in education and training through government spending, more people have skills and can handle complicated jobs; they prefer to go into industries requiring more skills to earn higher wage.

Factors of Demand

Recalling the supply chain of the model, producers make intermediate goods for retail distributors in a perfectly competitive market, and the retail distributor brands these bundles of intermediate goods by country of origin and sells these in an imperfect competitive market. Therefore, producers in the perfect competitive market have to produce their goods at marginal cost and earn no profit; distributors in the imperfect competitive market can add a mark-up to their production cost to maximise their profits according to the product's elasticity of substitution. Production for producers in the CGE model also assumes constant returns to scale.

Therefore, here we construct a standard profit maximisation problem, constrained by the producer's Cobb-Douglas production function:

$$(43)\ \pi = py - wN - hH - lL - rK$$
$$st.y = A * (N^{\alpha})(H^{\beta})(L^{\gamma})(K^{1-\alpha-\beta-\gamma})$$

Equation (43) indicates profit as the difference between total income *(py)* and factor supply cost. This equation is identical for each sector and the producer in each sector maximise its profit in relation to the same profit equation form, and then substitute the Cobb-Douglas production function into Equation (43):

$$(44)\pi_i = p_i * A(N_i^{\alpha})\left(H_i^{\beta}\right)\left(L_i^{\gamma}\right)\left(K_i^{1-\alpha-\beta-\gamma}\right) - wN_i - hH_i - lL_i - rK_i$$

Producers in the industry of manufacturing, service, agriculture, and non-traded sectors have an identical profit equation and we want to ascertain the optimal factor demand.

Next, take the first-order derivative of Equation (44) and set it to zero:

$$(45)\frac{\partial \pi}{\partial N_i} = p_i A(\alpha)\left((N_i^{\alpha-1})\left(H_i^{\beta}\right)\left(L_i^{\gamma}\right)\left(K_i^{1-\alpha-\beta-\gamma}\right)\right) - w = 0$$

$$(46)\frac{\partial \pi}{\partial H_i} = p_i A(\beta)\left((N_i^{\alpha})\left(H_i^{\beta-1}\right)\left(L_i^{\gamma}\right)\left(K_i^{1-\alpha-\beta-\gamma}\right)\right) - h = 0$$

$$(47)\frac{\partial \pi}{\partial L_i} = p_i A(\gamma)\left((N_i^{\alpha})\left(H_i^{\beta}\right)\left(L_i^{\gamma-1}\right)\left(K_i^{1-\alpha-\beta-\gamma}\right)\right) - l = 0$$

$$(48)\frac{\partial \pi}{\partial K_i} = p_i A(1-\alpha-\beta-\gamma)\left((N_i^{\alpha})\left(H_i^{\beta}\right)\left(L_i^{\gamma}\right)\left(K_i^{-\alpha-\beta-\gamma}\right)\right) - r = 0$$

Rewrite Equations (45-48) and rearrange the equations as follows:

$$(45')w = (\alpha)p_i N_i^{-1}\left(A(N_i^{\alpha})\left(H_i^{\beta}\right)\left(L_i^{\gamma}\right)\left(K_i^{1-\alpha-\beta-\gamma}\right)\right)$$

$$(46')h = (\beta)p_i H_i^{-1}\left(A(N_i^{\alpha})\left(H_i^{\beta-1}\right)\left(L_i^{\gamma}\right)\left(K_i^{1-\alpha-\beta-\gamma}\right)\right)$$

$$(47')l = (\gamma)p_i L_i^{-1}\left(A(N_i^{\alpha})\left(H_i^{\beta}\right)\left(L_i^{\gamma}\right)\left(K_i^{1-\alpha-\beta-\gamma}\right)\right)$$

$$(48')r = (1-\alpha-\beta-\gamma)p_i K_i^{-1}\left(A(N_i^{\alpha})\left(H_i^{\beta}\right)\left(L_i^{\gamma}\right)\left(K_i^{1-\alpha-\beta-\gamma}\right)\right)$$

Substitute Equations (45'-48') with the production function and solve factor demand as follows:

$$(49)N_i = \frac{\alpha * p_i * y}{w}$$

$$(50)H_i = \frac{\beta * p_i * y}{h}$$

$$(51)L_i = \frac{\gamma * p_i * y}{l}$$

$$(52)K_i = \frac{(1-\alpha-\beta-\gamma) * p_i * y}{r}$$

The aggregation of demand is the summation of demand in each sector, given by:

$$(49')\ \ N = \sum_{i=M,S,A,D} N_i = w^{-1} \sum_{i=M,S,A,D} (\alpha_i * p_i * y_i)$$

$$(50') \quad H = \sum_{i=M,S,A,D} H_i = h^{-1} \sum_{i=M,S,A,D} (\beta_i * p_i * y_i)$$

$$(51') \quad L = \sum_{i=M,S,A,D} L_i = l^{-1} \sum_{i=M,S,A,D} (\gamma_i * p_i * y_i)$$

$$(52') \quad K = \sum_{i=M,S,A,D} K_i = r^{-1} \sum_{i=M,S,A,D} \{(1 - \alpha_i - \beta_i - \gamma_i) * p_i * y_i\}$$

The factor demand and supply equations solve for the output supplies of each sector.

Part 2.5 The Full Model: Classical Model

Equation A.1-A.4 Prices: EU (UK, US, ROW)p_m, p_s, p_a, p_d

Prices of EU, UK, US and ROW are equated to marginal costs comprising*w, h l and pd*:

$$p_m = w^{0.52} * h^{0.14} * l^{0.04} * (p_m r)^{0.30} * \pi_m^{-1}$$

$$p_s = w^{0.21} * h^{0.52} * l^{0.03} * (p_m r)^{0.24} * \pi_s^{-1}$$

$$p_a = w^{0.15} * h^{0.13} * l^{0.08} * (p_m r)^{0.64} * \pi_a^{-1}$$

$$p_d = w^{0.38} * h^{0.17} * l^{0.11} * (p_m r)^{0.33} * \pi_d^{-1}$$

Equations (A.1-A.4) derived from Equations (35-38). *P(m,s,a,d)* is the sector price of manufacturing, service, agriculture, and non-traded goods for the EU, whereas *(w,h,l)* denotes wages of unskilled workers, wages of skilled workers, and rent rate for land.*R* is the real rate of return on capital, and $\pi(m, s, a, d)$ are exogenous productivity error processes. Factor shares follow Minford and Xu (2018), based on UK input-output tables. The reason for using factor shares from UK input-output tables are of high quality; the input-output table used in the study was created by Minford et al. (1997) for measuring the impacts of globalization on the global economy, and the model using these calibrated parameters performed empirically well in analyzing the trade trends between 1970 and 1990. It showed a good fitness to the period's significant features, such as terms of trade, production shares, trade balances in sectors, movement of relative wages, and employment trends. As a result, it is likely to be typical for the broader industries studied. This is confirmed by the fact that the classical model passed the test with these calibrated values, and the gravity model rejection was in spite of using the same calibrated parameters. As we use same set of calibrated parameters in both models, and other parameters values are obtained from OLS estimates on EU data, empirical evidence obtained from these calibrated parameters should be considered valid.

Given the exogenous world price and productivity errors, we solve for*w,h,l*using the above equations. Rearrange Equations (1-3) and formulate the following matrix by taking the logarithm on both sides:

$$\begin{pmatrix} 0.52 & 0.14 & 0.04 \\ 0.21 & 0.52 & 0.03 \\ 0.15 & 0.13 & 0.08 \end{pmatrix} \begin{pmatrix} lnw \\ lnh \\ lnl \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0-0.30 \\ 0 & 1 & 0-0.24 \\ 0 & 0 & 0-0.64 \end{pmatrix} \begin{pmatrix} ln(p_m) \\ ln(p_s) \\ ln(p_a) \\ ln(p_m r) \end{pmatrix} + \begin{matrix} ln\pi_m \\ ln\pi_s \\ ln\pi_a \end{matrix}$$

Rearrange the equations to yield:

$$lnw = \left(\frac{1}{0.52}\right) * (\ln(p_m \pi_m) - 0.14 * lnh - 0.04 * lnl - 0.30 * \ln(p_m r))$$
$$lnh = \left(\frac{1}{0.52}\right) * (\ln(p_s \pi_s) - 0.22 * lnw - 0.03 * lnl - 0.24 * \ln(p_m r))$$
$$lnl = \left(\frac{1}{0.08}\right) * (\ln(p_a \pi_a) - 0.15 * lnw - 0.13 * lnl - 0.64 * \ln(p_m r))$$

<u>Equations A.5-A.8 Factor demand, EU(UK,US,ROW)</u>*N,H,L,K*

Factor demands can be solved as follows:

$$N = w^{-1} * (0.38 * p_d y_d + 0.52 * y_m p_m + 0.21 * p_s y_s + 0.15 * p_a y_a) e_m$$
$$H = h^{-1}(0.17 * p_d y_d + 0.14 * y_m p_m + 0.52 * p_s y_s + 0.13 * p_a y_a) e_s$$

$L = l^{-1}(0.11 * p_d y_d + 0.04 * y_m p_m + 0.03 * p_s y_s + 0.08 * p_a y_a)e_a$

$K = (p_m * r)^{-1} * (0.33 * p_d y_d + 0.30 * p_m y_m + 0.24 * p_s y_s + 0.64 * p_a y_a)e_k$

Equations (A.5-A.8) are derived from Equations (49'-52'), where *e(m,s,a,k)* are factor demand error processes. N is the factor demand of unskilled labourand$H$ is skilled labour; L is agricultural land and K is capital. They are correlated with sector prices and sector prices as well as corresponding factor shares.

Equations A.9-A.11 Factor Supplies*N,H,L*

Factor supplies can be solved as follows:

$$N = e_n\left(\frac{w}{b}\right)^{0.1} * POP^{0.5} * G^{0.5}$$

$$H = e_h\left(\frac{h}{w}\right)^{0.1} * G^{0.5}$$

$$L = l^{-1} * (0.11 * p_d * y_d + 0.04 * p_m * y_m + 0.03 * p_s * y_s + 0.08 * p_a * y_a)e_a$$

Equations (A.9-A.11) are discussed in detail in section 3.4. *N,H,L* are supply factors of unskilled labour, skilled labour and land. Unskilled labour depends on the relative price of unskilled wages *(w)* and unemployment benefits *(b)*, and it is more elastic to total working population *(POP)* and government spending *(G)*. Skilled labour depends on relative price of skilled wages *(h)* and unskilled wages as well as government spending. Land supply is policy-controlled to satisfy demand, so it stays the same in line with the factor demand of land.

The implication of working population and government spending in labour supply can be explained as follow. When unskilled wage rises, unskilled labour has more willingness to work for higher wages; and when unemployment benefit is sufficiently high, unskilled labour has less interest to work and prefer to stay unemployed. According to Eq. 42, when working population increases, total labour force rises and unskilled labour follows. Government spending affects unskilled labour supply through the provision of basic education.

Skilled labour is also related to relative ratio of wage and government spending. When the ratio of skilled wage relative to unskilled wage rises, labour is motivated to switch from unskilled to skilled labour to earn more wages. On the other hand, government spending on higher level education raises the skilled labour supply. We assume these education expenditures vary with total government spending.

It should be noted that in these factor supply functions the exogenous residuals provide the bulk of the input, ensuring thatthese supplies mirror the data.

Equation A.12 Non-traded Outputy_d

$$y_d = \sigma * E$$

Non-traded output is assumed to be a portion of total demand, whilst the percentage σis assumed to be 0.5. It indicates non-traded sector output demand is fixed at half of total demand. By market-clearing supply is forthcoming to meet this demand at non-trade prices determined by marginal costs, in turn set by factor shares and factor prices.

Equation A.13 Total Output$y$

$$y = y_d + y_m + y_s + y_a$$

Total output is the sum of non-traded sector output and all traded sector outputs, including manufacturing, service, and agriculture. It treats all outputs excluding the three main sectors as non-traded, for simplicity of identification.

Equations A.14-A.15 Total Demand and Traded Demand E, E_T^{EU}

$$E = y$$
$$E_T^{EU} = E - y_d$$

It assumes that total demand equals total output, thus total demand for traded goods is the remaining output level subtracted by non-traded output level.

Given POP, G, w, b, h and factor supply errors e_H, e_N, e_L, labour supply N and H and Land supply L can be solved using Equations(9-11). Given world prices p_m, p_s, p_a, p_d, agriculture output y_a, factor supply N, H, L, factor cost w, h, l, and demand error terms e_m, e_s, e_a, one can solve y_m, y_s, y_d by following:

$$y_d = y_m + y_s + y_a$$
$$y_m = \left(\frac{1}{0.52 * p_m}\right)(N * w * e_m - 0.38 * p_d y_d - 0.21 * p_s y_s - 0.15 * p_a y_a)$$
$$y_s = \left(\frac{1}{0.52 * p_s}\right)(H * h * e_s - 0.17 * p_d y_d - 0.14 * p_m y_m - 0.13 * p_a y_a)$$

It defines non-traded output as half of total demand, while demand is equal to total GDP level. Therefore, half of the total output level is contributed toward the non-traded sector output, whilst the remaining half of the output goes toward the traded sector output. That gives the conclusion that the output level of the non-traded sector is identical to that of the traded sector output, including manufacturing, agriculture, and service. Agricultural output is treated as exogenous as it is controlled by policymakers according to planning needs.

The output of manufacturing and service can be derived from Equations (A.5-A.6), given the world price, factor supply, factor cost, and factor demand error.

Then substitute $y_d = y_m + y_s + y_a$ into the equation listed above, and to yield:

$$N * w * e_m = (0.38 * p_d * (y_m + y_s + y_a) + 0.52 * y_m p_m + 0.21 * p_s y_s + 0.15 * p_a y_a)$$

$$H * h * e_s = (0.17 * p_d * (y_m + y_s + y_a) + 0.14 * y_m p_m + 0.52 * p_s y_s + 0.13 * p_a y_a)$$

Rearrange the above equations into the following matrix:

$$\begin{pmatrix} N * w * e_m \\ H * h * e_s \end{pmatrix} = \begin{pmatrix} 0.38p_d + 0.52p_m & 0.38p_d + 0.21p_s & 0.38p_d + 0.15p_a \\ 0.16p_d + 0.14p_m & 0.16p_d + 0.51p_s & 0.17p_d + 0.13p_a \end{pmatrix} \begin{pmatrix} y_m \\ y_s \\ y_a \end{pmatrix}$$

Then represent manufacturing and service output in the following matrix:,

$$\begin{pmatrix} y_m \\ y_s \end{pmatrix} = \begin{pmatrix} 0.38p_d + 0.52p_m & 0.38p_d + 0.21p_s \\ 0.17p_d + 0.14p_m & 0.17p_d + 0.52p_s \end{pmatrix}^{-1} \begin{pmatrix} N * w * e_m - (0.38p_d + 0.15p_a)y_a \\ H * h * e_s - (0.17p_d + 0.13p_a)y_a \end{pmatrix}$$

Therefore, the above matrix reveals that when agricultural output is exogenous and sector prices are given, as well as factor demand and factor prices, sector output can be calculated manually with other necessary information. This is the sector output function that this thesis will use in a later part.

EquationsA.16-A.18 Sector Demand$E_m^{EU}, E_s^{EU}, E_a^{EU}$

Demand for each sector can be described as follows:

$$E_m^{EU} = E_T^{EU} - E_s^{EU} - E_a^{EU}$$

$$E_s^{EU} = 0.9 * E_T^{EU} - 955.03 - 12 * (p_s^{EU} - p_T^{EU})$$

$$E_a^{EU} = 0.5 * E_T^{EU} - 128.20 - 5 * (p_a^{EU} - p_T^{EU})$$

Sector demand is derived from Equation (13) by taking the logarithm on the CES demand curve. According to Equation A.16, demand for traded goods is derived from the difference between total demand amount and non-traded output. Thus, traded goods are divided into three categories: manufacturing, service and agriculture. The equation also indicates a positive correlation between sector demand and traded demand as well as traded price, and shows with a negative correlation between sector demand and sector price. These equations are estimated by EU data.

Equation A.19 Domestic Price *p*

$$p = p_m\left(\frac{E_m^{base}}{E^{base}}\right) + p_s\left(\frac{E_s^{base}}{E^{base}}\right) + p_a\left(\frac{E_a^{base}}{E^{base}}\right) + p_d(\frac{E_T^{base}}{E^{base}})$$

In terms of domestic price level in the EU, it could be calculated using a weighted-average sector price on the demand share. Each sector price would introduce its weight upon the whole price level depending on the weight attached to the industry in the demand base.

EquationsA.20-A.22 Sector Pricesp_m, p_s, p_a

$$p_m = p_m^{world} * (1 + T_m)$$
$$p_s = p_s^{world} * (1 + T_s)$$
$$p_a = p_a^{world} * (1 + T_a)$$

T is simply the total cost of tariff, non-tariff, and transport costs for the EU to trade with other economies. However, this cost is hard to gather in a time-series data set, it takes the value of unity. This assumption indicates that tariff and transport cost could have double the effect on domestic price compared to world sector price. If considering tariff and other non-tariff transportation costs, it assumes everything related to tariffs are absorbed into residuals. For the real exchange rate, it only changes all sector prices in line exactly with the corresponding Euro amount. Therefore, for simplicity, this model uses the US dollar for price level, with the Euro exchange rate converted, relative to world manufacturing prices in dollars. Accordingly, the manufacturing price is treated as unity, and sector prices are relative to the manufacturing price. Therefore, world prices are exogenous processes, and sector prices in this model are effectively in dollars relative to world manufacturing prices in dollar.

Equation A.23 Traded Pricep_T

The price of tradedgoodscan be solved as:

$$p_T = p_m\left(\frac{E_m}{E_T}\right) + p_s\left(\frac{E_s}{E_T}\right) + p_a(\frac{E_a}{E_T})$$

With the logic behind traded price is the same as for sector prices stated above. The traded price is affected by all traded sectors, namely manufacturing, service, and agriculture. The proportion of demand in each sector relative to traded demand reflects how the sector price can change the traded price. Therefore, the traded price is assumed to be a combination of sector prices weighted on proportion of sector demand against traded demand.

EquationsA.24-A.25 Error Process$ln(\pi_i, t)\,, ln(e_i, t)$

$$\ln(\pi_{i,t}) = c_{1i} + \rho_{1i}\ln(\pi_{i,t-1}) + \varphi_{1i}t + \varepsilon_{i,t} \quad i = M, S, A, d$$

$$\ln(e_{i,t}) = c_{2i} + \rho_{2i}\ln(e_{i,t-1}) + \varphi_{2i}t + \varepsilon_{i,.t} \quad i = M, S, A, N, H, K$$

The error processes and logarithms of factors in the model are assumed to follow AR (1) processes with intercept and time trend. In the testing part of this thesis, this assumption will be tested using ADF and KPSS tests for stationarity. We expect and find that productivity errors (including the factor demand errors, reflecting factor productivity) are non-stationary- acting as important exogenous processes- while others are generally stationary.We estimate c_i, ρ_i, φ_i by OLS.

EquationsA.26-A.27Trade share in Classical Model em_i, ex_i

$$ln(M_i) = \theta_{1i} + \theta_{2i}\, ln(E_T) + em_i \quad i = UK, US, ROW$$

$$ln(X_i) = \theta_{3i} + \theta_{4i} ln(E_i) + ex_i \quad i = UK, US$$

In this model, it assumes that the EU imports traded goods from others, including the UK, the US and the rest of world following with the assumption stated in section 3.3.The rest of the world market in the classical model plays the role of a residual market that absorbs any excess supply of EU products. Tariff and transportation costs do affect these demand patterns, and their effect can be seen in the trade error term because of a shortage of transport cost data, as mentioned in the above assumption.We estimate $\theta_{1i}, \theta_{2i}, \theta_{3i}, \theta_{4i}$by OLS.

Equation A.28Market Clearance in the Classical Model

$$X_{ROW} = Y_T - E_T - (X_{UK} + X_{US} - M_{UK} - M_{US} - M_{ROW})$$

In the classical model, market clearance does not rely on any intervention from the real exchange rate; and the residual market in the classical model disregards product origin so any excess supply from the EU can trade to the rest of world market at world prices. In the classical model, we assume that the Rest of World markets, retailers brand their products but not by country origin; thus they buy intermediate products solely on price, disregarding origin, treating them as homogenous. Hence they act as the residual market for any excess supply of a country's intermediate product. Equation (A.28) illustrates $Y_T - E_T$ is the traded output minus demand for traded goods – that is supply of traded good. $X_{UK} + X_{US} - M_{UK} - M_{US} - M_{ROW}$ is the EU's residual supply of traded goods and the remaining supply will be exported to the rest of the world market; at this point, market clearing condition is satisfied.

Part 2.6 The Full Model: Gravity Model

The gravity model is treated as having similar market structure to the classical model, with specified gravity components. The first component arises from our assumption that product origin matters in all retail markets, with branding according to origin universal across the world, and elasticity of substitution in relation to geographical origin is finite. Retail prices have to add a mark-up to the marginal cost depending on the substitutability of the product. The second gravity component is that trade is assumed to boost productivity innovation via foreign direct investment whereas productivity in the classical model is simply exogenous. Other aspects of the gravity model are identical to those of the classical model.

Equation A.29 Trade Share for Import $ln(\frac{M_i}{E_T})$

$$ln\left(\frac{M_i}{E_T}\right) = cm_i + \psi_1 RXR + e_{m,i}, i = UK, US, ROW$$

Similarly, EU import demand from the other three country groups, and the share of each country group's demand relative to the EU domestically traded good is defined as the demand trade share. Thus, EU import demand from the UK, the US, and the rest of world, and trade share is affected by the real exchange rate *(RXR)*. The real exchange rate moves the relative price of EU products nearer to foreign competitors' price in order to balance the current account. $e_{m,i}$ is the exogenous trade share error process for imports and it includes tariffs, and other costs that cannot be calculated.

Equation A.30 Trade Share for Export$ln(\frac{X_i}{E_i})$

And EU exports supply to UK, US, and the rest of the world:

$$ln\left(\frac{X_i}{E_i}\right) = cx_i + \psi_2 RXR + e_{x,i}, i = UK, US, ROW$$

In the classical model, the rest of the world market acts as a residual market for any excess supply from the EU which is indifferent to other countries of origin and set at world prices; however, in the gravity model, ROW market acts as a normal trade partner like the UK and the US. Thus, EU exports to the UK, the US and the ROW market, and the trade share of exports is affected by the real exchange rate. In particular, the real exchange rate alters the relative price of EU goods to balance the current account. $e_{x,i}$is the exogenous trade share error process for exports. This requirement for RXR to balance the current account is the key difference between the two models, stemming from the assumption of heterogeneity across country of origin in intermediate output.

em_i, ex_ican be estimated usingOLS and trade share data with bootstrap Equations (A.29) and (A.30). Elasticity of demand relative to real exchange rate is ψ_1, ψ_2, and the first elasticity is for imports and set to 0.6; while the latter is for exports and set to -0.6.This value of elasticity of demand for both imports and exports is calibrated; on the one hand, elasticity of demand should be close to the lower stability boundary of 0.5, which solves the model’s stability. On the other hand, in accordance with the Marshall-Lerner stability condition, the sum of elasticity of imports and exports must be greater than one. Nevertheless, 0.6 is a moderately good example of demand elasticity calibration; but it can be increased to achieve a more stable condition, as we will do in the gravity experiment.

Equations (A.29-A.30) solve the assumption of imperfect competition in the gravity model, and outlines which goods’ supply are determined by demand forces; it includes the real exchange rate which alters the relative price and balances the current account. The next difference in the gravity model compared with classical model is the determination of productivity in terms of trade.

Equation A.31 Total Trade*T*

Now we can formulate productivity as a function of trade. T, total trade, can be defined as:

$$Totaltrade = M_{UK} + M_{US} + M_{ROW} + X_{UK} + X_{US} + X_{ROW}$$
$$T = \frac{totaltrade}{E_{EU}}$$
$$= \frac{E_T}{E_{EU}}\frac{M_{UK}}{E_T} + \frac{E_T}{E_{EU}}\frac{M_{US}}{E_T} + \frac{E_T}{E_{EU}}\frac{M_{ROW}}{E_T}$$
$$+ \frac{E_{UK}}{E_{EU}}\frac{X_{UK}}{E_{UK}} + \frac{E_{US}}{E_{EU}}\frac{X_{US}}{E_{US}} + \frac{E_{ROW}}{E_{EU}}\frac{X_{ROW}}{E_{ROW}}$$

Then define $\frac{E_T}{E_{EU}} = 0.5, \frac{E_{UK}}{E_{EU}} = r_1, \frac{E_{US}}{E_{EU}} = r_2, \frac{E_{ROW}}{E_{EU}} = r_3$, and *r(1,2,3)* is the percentage of GDP of each country relative to the EU in the sample mean, that gives us the following:

$$T = 0.5\frac{M_{UK}}{E_T} + 0.5\frac{M_{US}}{E_T} + 0.5\frac{M_{ROW}}{E_T} + r_1\frac{X_{UK}}{E_{UK}} + r_2\frac{X_{US}}{E_{US}} + r_3\frac{X_{ROW}}{E_{ROW}}$$

Therefore, the total trade term T is an exogenous variable and a function of the weighted average of the trade share of import to the EU traded goods demand and the trade share of exports to each country demand. This total trade term *T* covers both exports and imports, and affects foreign direct investment and then productivity. Therefore, productivity in each sector is not like classical model productivity; here, productivity is a function of factor supply and factor price. In the gravity model, productivity is no longer an exogenous process but is related directly to total trade, *T*.

Equation A.32 Productivity Error Process

As discussed above, total trade determines the flows of foreign direct investment, with the productivity change affected by the foreign partner's technology level and trade flow. Therefore, the productivity error process is no longer exogenous; it is a function of total trade and can be written as follows:

$$\Delta\, ln(\pi_{i,t}) = c_{1i} + v_i \Delta T + \varepsilon_{i,t}, i = M, S, A, d$$

The transmission of trade share into productivity is the key characteristic of the gravity model; it implies that productivity is partly endogenous. The parameter v is calibrated at 2 for all sectors, though we investigate the results with other values.

According to Equations(A.1-A.4), factor price equations consider productivity in their formulation. Like the classical model, in the gravity model factor prices are determined in line with world prices and productivity. Because of the imperfect competition framework applied in the gravity model, there is a sectoral imperfect competition mark-up on world prices relating to domesticretailprices in each sector.

Equation A.33 Market Clearance Condition

Market clearance is written as follows:

$$X_{ROW} + X_{US} + X_{UK} = RXR * (M_{US} + M_{UK} + M_{ROW})$$

The imperfect competition in the gravity model adjusts prices to include a mark-up on the marginal cost. When the EU imports demand from other country groups, it does not affect the prices; when EU suppliers export to other country groups, it has to add a mark-up on cost, which raise prices compared to the international competitors' price. To satisfy the market clearing condition, RXR has to move to solve the current account equilibrium; that is shifting the real exchange rate to devalue the currency, allowing the market to clear.

Table 2.1 is a description of variables listed in the above model set-up. A full list of variable names and abbreviations is listed in Appendix 4 and 5.

Table 2.1 *Variables Descriptions*	
p	*Price*
y	*Output (GDP %)*
N	*Unskilled labour*
H	*Skilled labour*
L	*Agricultural land*
K	*Physical capital*
w	*Unskilled labour wage rate*
h	*Skilled labour wage rate*
r	*Rate of return on physical capital*
E	*Demand for good*
l	*Rate of return on land*
b	*Unemployment benefit*
POP	*Working population*
G	*Government spending/GDP %*
A,M,S,ROW	*Agriculture, Manufacturing, Services, Rest of the World*

Part 2.7 Testing the Modelsusing Indirect Inference

Auxiliary Model

In order to implement the Indirect Inference approach, the structure of the auxiliary model should also be formulated in a reasonable way. The main data movement of concern here is the output share by sector and trade share by country; these determine the economic structure of output and destination of trade. Thus, the auxiliary model acts as a testing model which captures the most important features of concern to trade modellers: 1) relative world prices and relative productivity of manufacturing and service sectors in the EU; 2) relative factor supply of skilled and unskilled labour; and 3) economic scale and relative wages. Therefore, the auxiliary model assumes that trade is affected by these notable factors, which will be presented in detail in each study in the following section.

These auxiliary models will be used to generate two sets of coefficients, and the disturbance in their distribution will be compared. The indirect inference test process is to be refreshed here. First, we estimate the auxiliary model by using actual data and generating one set of coefficients; essentially, these data descriptors are based on actual data, and they represent real world data behaviour. Next, we compare these descriptors based on actual data and simulated data from the same auxiliary model; these simulated data, however, should be kept in line with the same features of the actual world. One can generate these simulated data by bootstrapping structure shocks affecting the classical and gravity models, with the null hypothesis of the models being the structure model. These structural shocks are estimated from actual data, thus it is akin to simulating bundles of parallel histories taking into consideration local EU shocks and the same histories of the true world. Thereafter, we repeat the process and generate a bundle of stimulated data from structure shocks, and we then estimate them using the same auxiliary model to construct a bundle of auxiliary relationships based on simulated data. Here we have two sets of coefficients: one set is estimated using the auxiliary model with actual data (actual-data-based descriptors); and the other set is of repeated bundles of coefficients estimated using the identical auxiliary model with simulated data from structural shocks (simulated-data-based descriptors). In other words, the Indirect Inference approach aims to evaluate the probability that we can find actual-data-based descriptors in the distribution of simulated-data-based descriptors, by calculating the disturbance between the two and comparing them using the Wald test. If the disturbance of simulated-data-based descriptors is sufficiently close to the actual-data-based descriptors, these structural models are highly likely to be the true model.

Indirect Inference Wald Test

The formulation of the II Wald test is now detailed in the follows. We apply the Wald statistic based on the difference between a_T, data descriptor estimations derived from actual data, and $\overline{a_S(\theta_0)}$, the mean of distribution of data descriptor estimations based on the simulated data. Therefore, the II Wald statistic is given as:

$$WS = \left(a_T - \overline{a_S(\theta_0)}\right)' W(\theta_0)(a_T - \overline{a_S(\theta_0)})$$

The above equation $W(\theta_0)$contains the inverse of the variance-covariance matrix of the distribution of simulated estimates of data descriptora_S and θ_0 is the vector of parameters of the trade model on the null hypothesis that it is the true structural model. It takes three steps to implement the II Wald test by bootstrapping, as shown below.

Step 1: Estimate all error processes of the model conditional on the observed data and $\boldsymbol{\theta_0}$

The first step in the indirect inference approach is to estimate the structural errors of the structural model, given the observed data and the values of vector of parameters if null hypothesis of the auxiliary model is true. There are independent structural errors less or equal to the number of endogenous variables, and these errors are not simply assumed to be normally distributed. These errors, as shown in the above equations, are determined in line with observed regressions and data.

Step 2: Derive the simulated data

The simulated disturbances are derived from structural error processes. The one limit for the bootstrap is that these disturbances should be serially independent. However, in the trade model, some structural errors are assumed in the form of autoregressive processes rather than being serially independent. If they are autoregressive processes, they may be estimated with AR (1), AR (1) with time trend, or AR (1) with first differences. After performing ADF and KPSS tests to check the stationary features of these errors, this thesis endeavours to derive the simulated data by drawing the bootstrapped disturbances by time vector to preserve simultaneity, in order to solve the model. To create a simulated data series, one can use bootstrapping many times and draw from each sample independently.

Step 3: Implement the Wald statistic

On the one hand, estimates a_T are derived by estimating the auxiliary model based on actual data; on the other hand, estimates $a_S(\theta_0)$ are formulated by estimating the same auxiliary model based on repeated samples of simulated data. The distribution of $a_T - \overline{a_S(\theta_0)}$ and its covariance matrix $W(\theta_0)^{-1}$ are estimated using bootstrapping$a_S(\theta_0)$. The bootstrapping runs repeated samples of the structural model, and estimating the auxiliary model on each sample of structural model, this generates a series of values of $a_S(\theta_0)$. Then, the covariance of the simulated variables can directly observe from these repeated bootstraps. The set of a_k vectors denotes the variation implied using the structural model from its mean estimates, while the covariance matrix and confidence bounds could be calculated directly.

Therefore, the estimate of $W(\theta_0)^{-1}$ could be calculated as follows:

$$W(\theta_0) = \frac{1}{N}\sum_{k=1}^{N}(a_K - \overline{a_K})'(a_K - \overline{a_K})$$

The next step is to calculate the Wald statistic for the data sample; doing so aims to estimate the distribution of the Wald statistic from all bootstrapped samples. The II Wald statistics are given by:

$$IIW = \left(a_T - \overline{a_S}(\theta_0)\right)' W\left(a_S(\theta_0)\right)^{-1}(a_T - \overline{a_S}(\theta_0))$$

The Indirect Inference approach shows where the Wald statistic based on the data lies in the Wald statistic's bootstrap distribution. It also indicates the Mahalanobisdistance based on the same joint distribution, which is t-statistic and an equivalent Wald p-value, as an indicator which measures the distance between the model and the data.

The detailed process of Indirect Inference Wald test is given in the next section.

The detailed process of IIW test

Step 1:

1.1 Input actual data into the auxiliary model and generate one set of auxiliary model coefficients, referred as ‘actual-data-based descriptors’.

1.2 Then input actual data into classical model and gravity model respectively, generate structural shocks based on the null hypothesis of these structural models being true. Then bootstrap these structural shocks into the structural model to generate one set of simulated data.

1.3 Input simulated data into the same auxiliary model in the step 1.1, and repeat step 1.2 and 1.3 five thousand times, and generate 5000 sets of auxiliary model coefficients, referred as ‘simulated-data-based descriptors’.

Step 2:

2.1 First, calculate the average of all simulated-data-based descriptors, referred as ‘average simulated based descriptors’, or $\overline{a_S(\theta_0)}$.

2.2 Then, calculate the difference between all simulated-data-based descriptors and average simulated based descriptors, referred as $a_S - \overline{a_S(\theta_0)}$.

2.3 Then, calculate the covariance of the disturbance of simulated-data-based descriptors and average simulated based descriptors, referred as variance-covariance matrix $W\big(a_S(\theta_0)\big)^{-1}$.

2.4 The next step is to calculate the Wald statistics by multiplying $a_S - \overline{a_S(\theta_0)}$ and variance-covariance matrix, referred as simulated based Wald statistics, or IIW_S.

$$IIW\_S = \big(a_S - \overline{a_S}(\theta_0)\big)' W\big(a_S(\theta_0)\big)^{-1} (a_S - \overline{a_S}(\theta_0))$$

Step 3:

3.1 First, calculate the difference between actual-data-based descriptors and average simulated based descriptors, referred as $a_T - \overline{a_S(\theta_0)}$.

.

3.2 The next step is to calculate the Wald statistics by multiplying $a_T - \overline{a_S(\theta_0)}$ and variance-covariance matrix, referred as actual based Wald statistics, or IIW_A.

$$IIW\_A = \left(a_T - \overline{a_S}(\theta_0)\right)' W\left(a_S(\theta_0)\right)^{-1} (a_T - \overline{a_S}(\theta_0))$$

Step 4:

4.1 This thesis transforms the Wald statistics to Mahalanobis distance t-statistic based on the same joint distribution, referred as Mahalanobis t-statistic:

$$T = \left(\frac{\sqrt{2 * IIW\_A}}{\sqrt{2 * IIW\_S^{95th}}}\right) * 1.648$$

4.2 This Mahalanobis distance t-statistic can be transformed to p-value, by calculating the likelihood of IIW_A is less than IIW_S. This gives the readers a more familiar indicator.

The likelihood calculates the probability of IIW_A is less than IIW_S; in other words, compared to the average simulated based descriptors, actual based descriptors have fewer disturbances to $\overline{a_S(\theta_0)}$than the simulated based descriptors. If the p-value is sufficiently high, for instance, the likelihood is greater than 5%, the null hypothesis of structural model being true is not rejected. If both models were not rejected by the data, the p-value also illustrates the probability that the data estimates came from the model; if the p-value of IIW in the classical model is greater than that in the gravity model, it illustrates the data estimates generated from the classical model have higher probability to be true than the gravity model estimates.

Power of Test

The power of the II Wald test is alsoanimportant issue. As shown above in the auxiliary model, this calibrated model takes into account all key indicators that concern economists; it does not have to determine that a model is 100% accurate, and the auxiliary model aims to reflect data behaviour. However, it is still of interest to introduce the power of the test into this thesis, as if such power is too high it may render the model meaningless. If the test power is too strong, models with little falsity will be rejected even if they are appropriate for capturing data behaviour; in order to pass a highly powerful test, the structure model must be exactly true. To keep the power of the test at a reasonable level, we follow Le et al.'s ((2016) Monte Carlo experiment to test the power.

By implementing a Monte Carlo experiment and treating the classical models as true, many samples can be generated from these true models. The next step is to test each model on each of these samples and to devise a rejection rate. When the model is true, it is rejected at 5% among all of these samples. The following step allows the model to depart from its true model; that is when all structural model parameters changes by a certain percentage, the model is accepted even with a certain level of misspecification relative to the true model. What we show in Chapter 3 (Table 3.4) is that the power of the test we use is strong (with a model with parameters on average 7% false being rejected 90% of the time) but not excessively strong so that only modest falseness causes high rejection.

CHAPTER THREE

TEST EU TRADE FACTS

WITH LARGE OPEN-ECONOMY PERSPECTIVE

Overview

This test is based on the procedure applied in the UK-based case study of Minford and Xu (2018), in which they create a classical and gravity model in a Computable General Equilibrium (CGE) framework to capture facts of international trades for several country groups. The classical model is extended from Heckscher-Ohlin-Samuelson assumptions of goods and factor markets under perfect competition, and it typically assumes that trades between countries occur on account of comparative advantages. The gravity CGE model assumes imperfect competition and limited substitutability among products, and it also imposes gravity assumptions whereby factor productivity is determined by trade volumes between the given country groups and the scale of their economies. It replicates the test procedures with updated data from the EU; however, Minford and Xu (2018) treated world prices and other countries' GDP as exogenous in a small open-economy assumption. In this thesis, it raises concerns that whether this small open-economy assumption is still valid for the case of the EU.

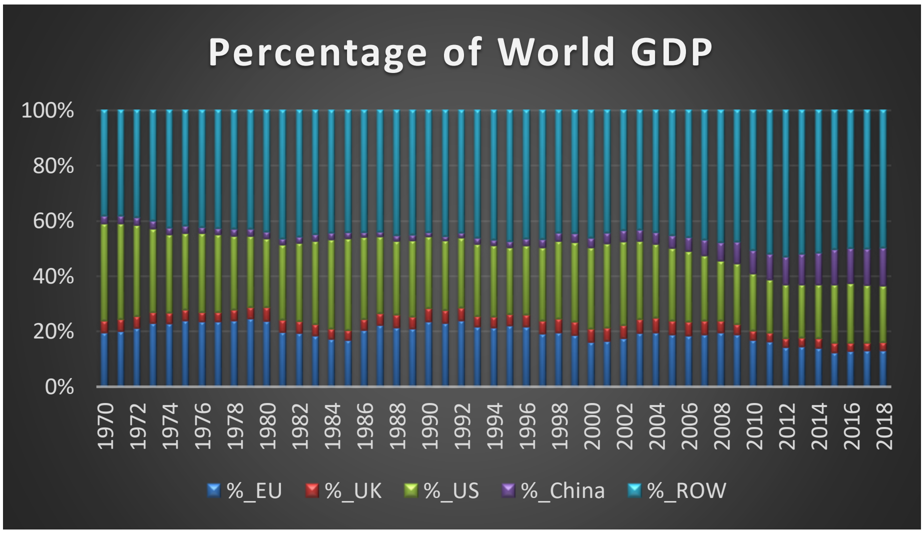

Fig. 1*Percentage of World GDP*

The small open-economy assumption may hold appropriately for the UK economy, as it accounts for about only 4% of world GDP. However, it is not appropriate for the EU case which accounted for more than 20% of world GDP before the financial crisis in 2007, and still holds more than 15% today, according to Figure 1. One can essentially argue that the EU is too large for a small open-economy assumption; this thesis aims to extend the indirect inference test to take into consideration a large open-economy assumption. In the updated test procedure, world prices and other large-economy country variables are simulated from a VAR model, representing a reduced form of an unknown structural world-wide model. It allows for the capturing of facts to show that the EU is a large enough economy to affect world prices, and that the total output levels of other economies are also affected by VAR or an unknown true model.

For this purpose, it follows the same world trade model framework as in the small open-economy case: a model containing four products, four countries, and four production factors. The model follows the CGE framework, which is a static model with endogenous variables affected by exogenous shocks. These shocks are assumed to include current shocks and lagged shocks, with time-effect adjustments taken into consideration. Moreover, these shocks are non-stationary, similar to productivity shocks, and auto-correlated. Therefore, these autocorrelation processes with time lag terms are also considered when determining shocks. Prices and output can be presented as a linear approximation process in vector-autoregressive equations in a reduced form of the model. In this case, endogenous world prices and outputs would not fundamentally change the baseline of the CGE structure of the trade model; in fact, the procedure of this endogenous simulation entails simulating endogenous world prices and other countries' outputs driven by a reduced form VAR, and then compares the features of trade activity trends with simulated results driven by current equilibrium effects of exogenous variables, such as productivity and trade policies.

The test procedure for this endogenous variable simulation is similar to the baseline case. After simulating the endogenous variables using reduced form VAR, the first step is to estimate an auxiliary model, which can determine the key variables' behaviours; we test initially at lower power before proceeding to stronger power by increasing the number of calibrated regressions. The next step is to test the structural model, which is simulated by bootstrapping shocks to replicate a bundle of histories parallel on which the same auxiliary model is estimated. Then it creates a distribution of simulated parameters from auxiliary model and compares these with actual data. If the simulated parameters from the auxiliary model and the estimated parameters from the actual data do not differ to a significant level, the model is not rejected.

To test whether a model's simulation captures the correct features against data behaviours, steps similar to those are taken in the baseline case. In the first step, the testing power remains reasonable and contains some restrictions and equations in the auxiliary model. In that case, models with some level of falsity will be rejected but not all models; on the other hand, models with slight falsity will remain to pass the test, which can help understand data behaviour gradually. In the next step, the test tries to match all features of behaviour by increasing testing power. All equations are included in the auxiliary model, which must have features closely resembling those of the real world.

In this section, the first step is to model the endogeneity of world prices and other countries' behaviours; the full classical and gravity models are listed in the appendix. In the next section, a Monte-Carlo experiment is performed to classify the power of the test for the auxiliary model is appropriate. Then, an II Wald test is conducted on a case study of the EU, and the results of these tests and policy implications are then discussed.

Part 3.1 Data

Endogenous World variables

The baseline case follows Minford and Xu's (2018) study in the UK, treating the EU as a small open-economy case. Similar with Minford and Xu's UK study, the baseline case tests a CGE trade model using indirect inference on EU facts, where the world variables are treated as exogenous. We leave the baseline case in the Appendix 1 as it may not be valid as EU is not a small economy. The UK is relatively a small economy that has little effect on the rest of the world. It is reasonable to assume UK as a price taker with domestic shocks insignificant elsewhere. However, the assumption of exogenous prices and output does not apply to the EU. From Figure 1, we see that the EU accounts for over 15% of world GDP while the UK stands at only 4%. The scale of economy for the EU economy is large enough to have a substantial effect on the ROW market. In order to address the endogeneity, a new version of the II Wald test simulates a country model by bootstrappingits own shocks in addition to the bootstrapped variables generated from a reduced form VAR. This VAR model represents the reduced form of the unknown true world model, taking the effects of shocks from other parts of the full world trade model into account when testing the EU trade model on its own. This is called the part-of-model test, in accordance with Minford et al. (2019), and allows testing EU part of the subset of the equations in the full world trade model.

The idea of the part-of-model test is to bootstrap the shocks from the world prices and other countries' GDPs and produce these simulated world variables regarding to these world variable shocks in the reduced form VAR. The next step is to insert these simulated world variables into the EU model, as well as the EU shocks simulated from actual data, and to generate a system of simulated country variables to simulate the auxiliary model estimation. If the simulation-based auxiliary model's coefficients are close to the actual data-based auxiliary model, then the country model should not be rejected as the simulation is close enough to the actual data behaviour. If the model is rejected using the indirect inference, then the EU model is not appropriately specified as the world prices and other countries' GDPs are stick to the true unknown world model.

Therefore, model specification in the assumption of endogenous world variables is similar to the model structure in the baseline case and list of full models is presented in appendix; it is reasonable to add the following VAR to simulate world variables.

Equation A.34 World variables (Prices and Outputs) p, y

$$p_{it} = \rho_{1it} + \rho_{2it}pA_{t-1} + \rho_{3it}pM_{t-1} + \rho_{4it}pS_{t-1} + \rho_{5it}yUK_{t-1} + \rho_{6it}yUS_{t-1} + \rho_{7it}yROW_{t-1} + \epsilon_{it}$$

$$where \;\; i = A, M, S$$

$$y_{jt} = \rho_{1jt} + \rho_{2jt}pA_{t-1} + \rho_{3jt}pM_{t-1} + \rho_{4jt}pS_{t-1} + \rho_{5jt}yUK_{t-1} + \rho_{6jt}yUS_{t-1} + \rho_{7jt}yROW + \epsilon_{jt}$$

$$where \;\; j = UK, US, ROW$$

The vector of variables in this reduced form of VAR should be co-integrated, thus errors should be expected to be stationary. Table 3.1 shows ADF test results for world variables and residuals, we can find that p-values of world prices and output are greater than 0.05, and p-values of all residuals are less than 0.05.That gives world prices and outputs are non-stationary, however, all residuals are stationary; each equation formulates a co-integration relationship for the variables included in the VAR. Therefore, we can conclude the Equations A.34 are both co-integrated.Table 3.2 reveals the coefficients in the above VAR.

Table 3.1*Co-integration test for the variables in the world VAR*			
ADF test	*Stationary*	*Non-stationary*	*ADF test (P-value)*
p_{UK}		√	*0.5747*
p_{US}		√	*0.9654*
p_{ROW}		√	*0.8867*
y_{UK}		√	*0.9138*
y_{US}		√	*0.9990*
y_{ROW}		√	*0.9982*
Residuals			
ϵ_1	√		*1.0000e-03*
ϵ_2	√		*1.0000e-03*
ϵ_3	√		*1.0000e-03*
ϵ_4	√		*1.0000e-03*
ϵ_5	√		*1.0000e-03*
ϵ_6	√		*1.0000e-03*

Table 3.2 *Coefficients in the world VAR*						
	$p_{A,t-1}$	$p_{M,t-1}$	$p_{S,t-1}$	$y_{UK,t-1}$	$y_{EU,t-1}$	$y_{ROW,t-1}$
$p_{A,t}$	0.9727	-0.1831	-0.0743	-0.0031	0.0046	-8.6E-04
$p_{M,t}$	0.1102	0.8426	-0.0796	-8.9E-04	0.0020	-3.7E-04
$p_{S,t}$	0.2202	0.1159	0.4244	0.0080	0.0043	-0.0012
$y_{UK,t}$	4.8863	0.5802	-7.7446	0.8740	0.1395	-0.0311
$y_{EU,t}$	-7.1044	-2.3802	19.7308	-0.7885	1.0189	0.0172
$y_{ROW,t}$	55.7559	-81.8917	20.5475	-2.1004	1.1443	0.7710

Data

Data in this thesis are collected from World Bank, UNCTAD, IMF, Eurostat and others between 1970 and 2018. Although the EU increased its membership from EU15 to EU28, this paper aims to collect data from the earlier composition of EU15, in order to minimize selection bias and maintain consistency. As it also includes the UK as a main country group in the model, this EU15 data also treats the UK as a single economy and remainder of EU15 is the dataset used for the EU, referred as EU-14. For any missing data unavailable from the above sources, the EABCN also provides up-to-data Euro Area macroeconomic time-series data from the Area Wide Model (AWM) dataset created by Gabriel Fagan, Jerome Henry and Ricardo Mestre. All data series are deflated by the 2015 constant price. The sources of the dataset are listed in full below.

All data are annual data from 1970 and 2018, the sources and the discussions of these actual data are shown in the next section.

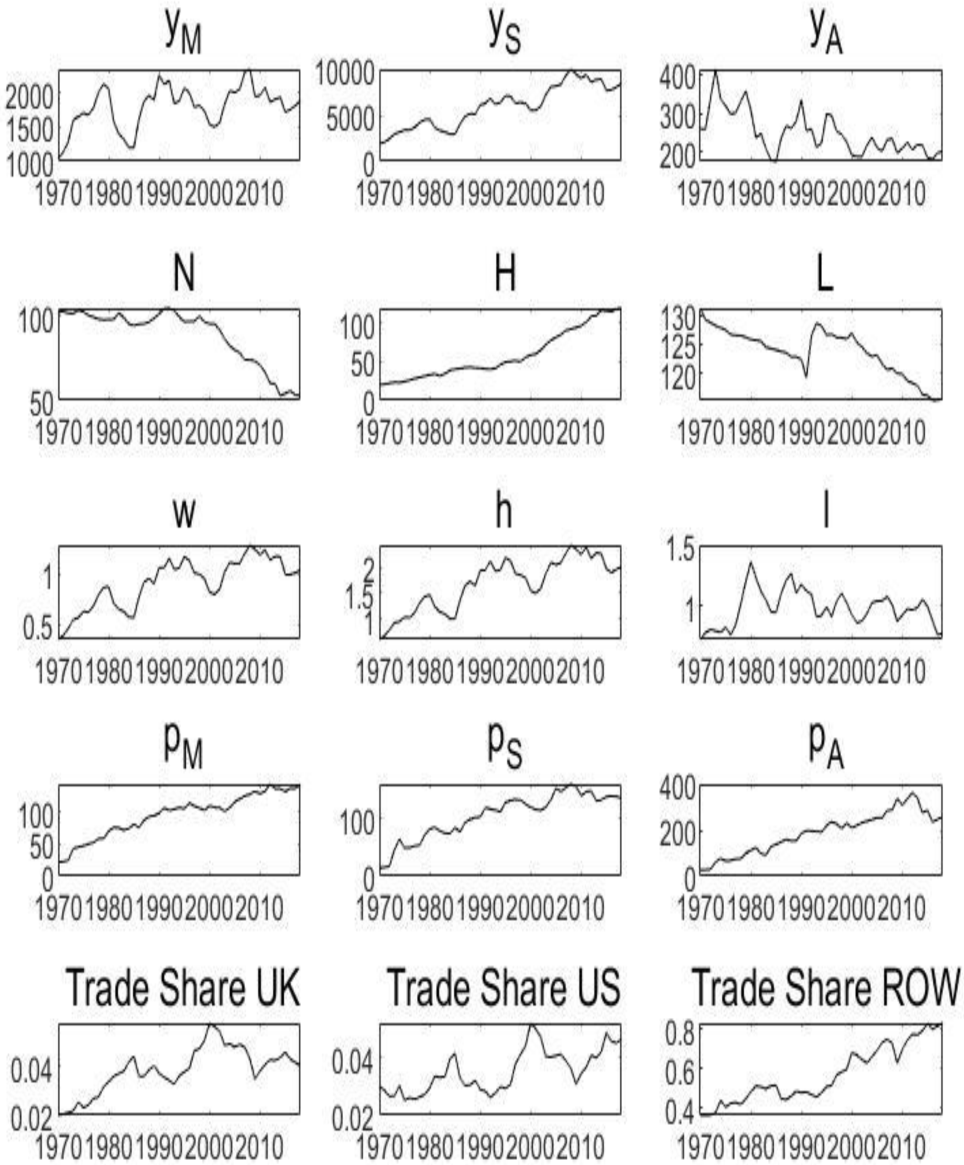

Fig. 2*Plots of actual data*

Source of Data

1) ***Output data*** (y_A, y_M, y_S, y_d)

EU sectoral output is divided in agriculture, manufacturing, service, and non-traded sector. Data are collected from World Bank.

2) ***Trade data*** $(EX_{US}, EX_{UK}, EX_{ROW}, IM_{US}, IM_{UK}, IM_{ROW})$

Trade data by country are collected from the World Bank, in which Ex_US represents the amount of EU exports to the US in US dollars. Ex_ROW and Im_ROW represent the amount of EU exports and imports to and from the rest of the world in US dollars, which is calculated by taking the total figure for EU exports and imports and deducting the UK and US amounts.

3) ***Government spending (G)***

Government expenditure is taken from the AWM database to illustrate government public expenses as an indicator.

4) ***Unskilled labour and skilled labour (N, H, POP)***

Unskilled labour force is calculated by taking the EU population and multiplying it by the percentage of unskilled labour in the EU. The percentage of skilled labour in the total population is available from the World Bank. Skilled labour force in the EU is approximated by taking the population of UK skilled labour and multiplying it by the ratio of the UK tertiary population, and dividing it by the EU tertiary population. UK skilled labour is obtained from the Office of National Statistics (ONS) and tertiary population by country is calculated by multiplying the total population by the tertiary rate. The sum of unskilled and skilled labour is the working population (POP).

5) ***Earnings of skilled workers***

The OECD provides the ratio of skilled earnings to unskilled earnings (Decile 9/Decile 5).

6) ***Sector price*** (p_A, p_M, p_S, p_d)

EU sector prices are collected from several sources. The agricultural price is taken from the food price index in Global Commodity Monitor, and the manufactured goods price is taken from the index of raw minerals. Both indices are collected from UNCTAD. Meanwhile, the service price index is approximated as the UK service producer price taken from the ONS.

7) ***Rent on land (l)***

Rent on land is approximated by land price index in the UK.

8) ***Wage index (w,h), rent on capital (r) and real exchange rate (RXR)***

Unskilled wage index is taken from AWM and skilled wage is an index multiplied by the ratio of skilled earnings. Rent on capital and real exchange rate is collected from the AWM database.

9) ***Agriculture land (L) and Capital formation (K)***

Agricultural land is measured in square meters and calculated by taking EU land area and multiplying it by the percentage of EU agricultural land in total land area; data are obtained from the World Bank and Eurostat. Meanwhile, capital formation is taken from gross fixed capital formation from the AWM database.

Descriptive Analysis

In this section, we aim to present all the data being used in the model. All the data are real data and units of these outputs are in millions of US dollars.

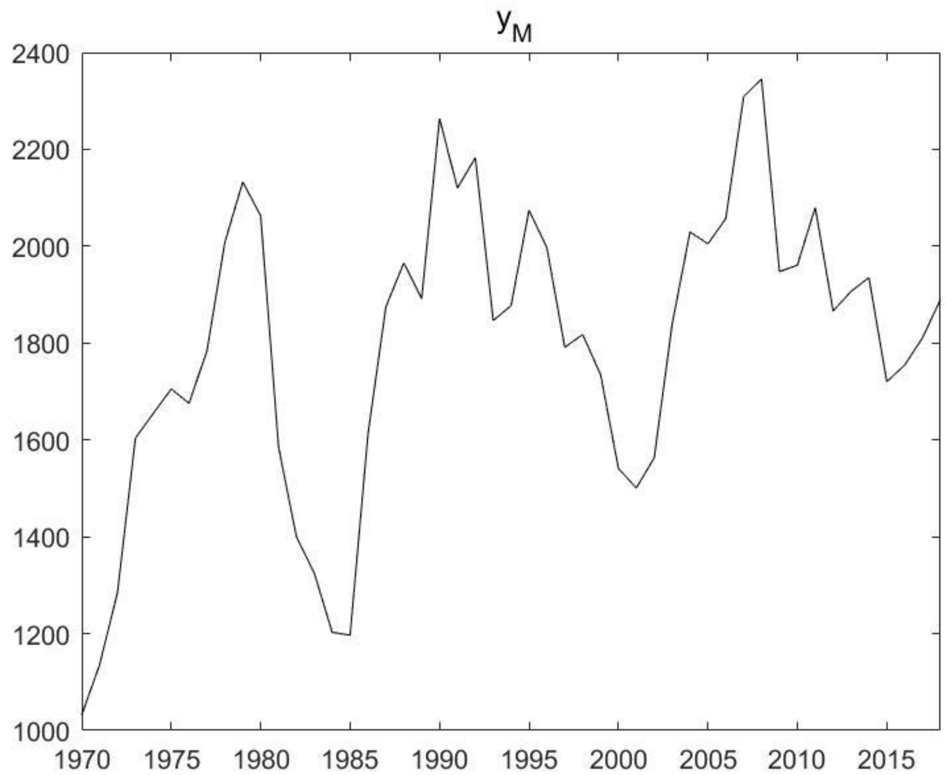

Figure.3 *EU's manufacturing output between 1970 and 2018*

From the figure above, there are three waves for EU's manufacturing output between 1970 and 2018. The first wave was 1980s; it reached the first peak at 1980 and started to decline until 1986. The reason why EU manufacturing output started to fall after 1980 is the steel crisis. There was a recession in the global steel market following the post-World War II economic expansion and 1979 oil crisis. The causes of the steel production decline are the overcapacity resulting from the tripled steel production during the post-war boom and market integration, resulting a significant decline in manufacturing output. The second wave was 1990s, EU manufacturing output recovered from the bottom in the latter part of the 1980s owing to the sharp fall in energy prices and deregulation of financial markets. Bank credit rose rapidly and fiscal policies expanded, thus contributing to the expansion of manufacturing output. However, the boom in EU ended in 1990s, a switch to tighter policies to defend the over-heated economy with higher international interest rates and manufacturing exports weakened further as a result of the collapse of trade with the imploding Soviet Union in 1991.The manufacturing output started the turnaround after 2000 while the economy grew rapidly and new industries entered. The structure of the economy changed fundamentally, high-tech sectors such mobile phones and semiconductor industry dominated the recovery process (Kalela, 2001). Manufacturing output rose to historical peak in 2007, and declined briefly due to worldwide financial market collapse and lower foreign demand. After 2015, industrial production began to recover and rise again.

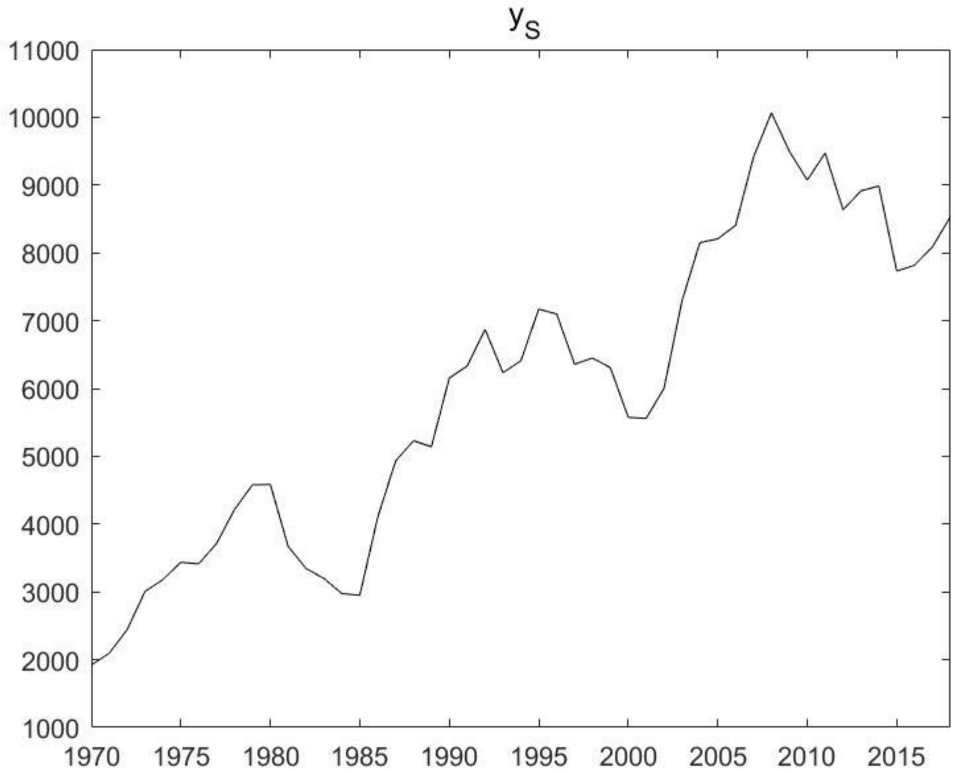

Figure.4 *EU's service output between 1970 and 2018*

From the figure above, we can see the EU's service output gradually increased between 1970 and 2018, and it also had three similar waves like manufacturing output shown above. Compared with manufacturing output, EU's service output refreshed its peak at each wave and reached its historical peak in 2007. According to World Bank, service output stands for over 70% in EU total output, while service output in Luxembourger stands for 87% in its GDP, reaching the highest in EU.

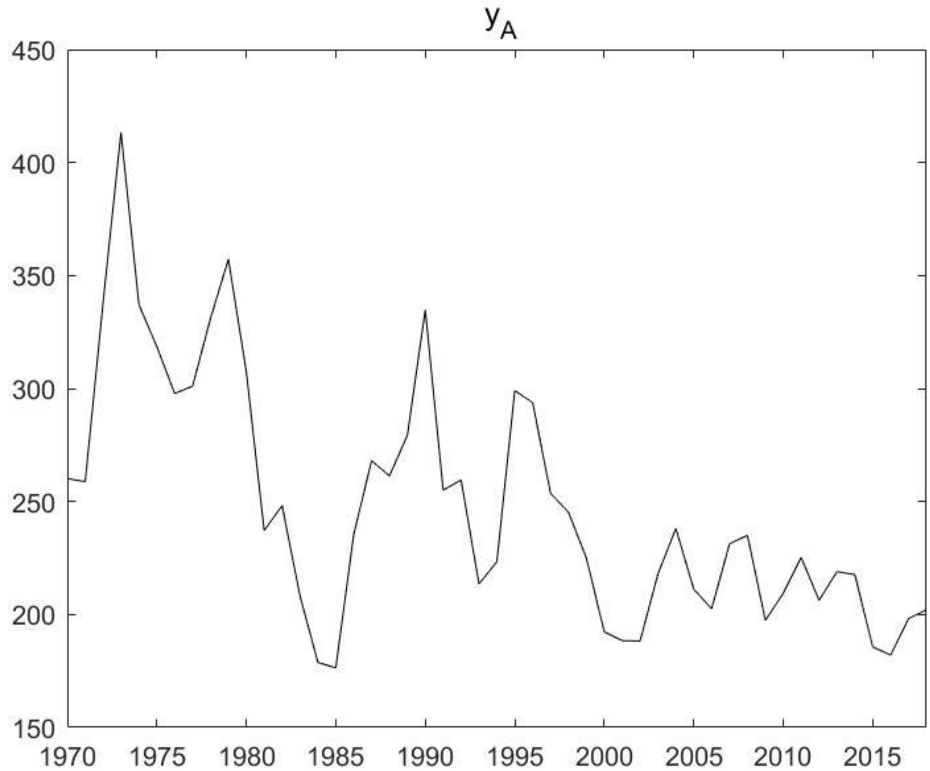

Figure.5 *EU's agricultural output between 1970 and 2018*

From the figure above, EU's agricultural output illustrated an overall decreasing trend between 1970 and 2018, but it showed several main upward trend across the overall decline. The most direct reason of the dramatic upward trend in the early 70s, middle 80s and middle 90s is the newly-entered membership in EU. For instance, EU, Ireland and Denmark entered EU membership in 1973, resulting to a dramatic increase in agricultural output in the early 70s; Spain and Portugal entered EU in 1986, and Austria, Finland and Sweden entered EU in 1995, resulting anther two upward trends in agricultural output in EU. On the other hand, the most important reason of the overall downward trend of EU agricultural output is the urbanization and the reform of economic structural in EU-15. As we do not include EU membership entered after 1995 into the data, those early-entered membership had proceeded to industrial output and service sector; there are only around 2% of total GDP relating to agricultural output in EU, and only Greece is included in our data. There are some other newly-entered EU countries has relatively more weight in agricultural production, such as Romania and Latvia, but these countries entered EU after 2004 and are excluded in our data.

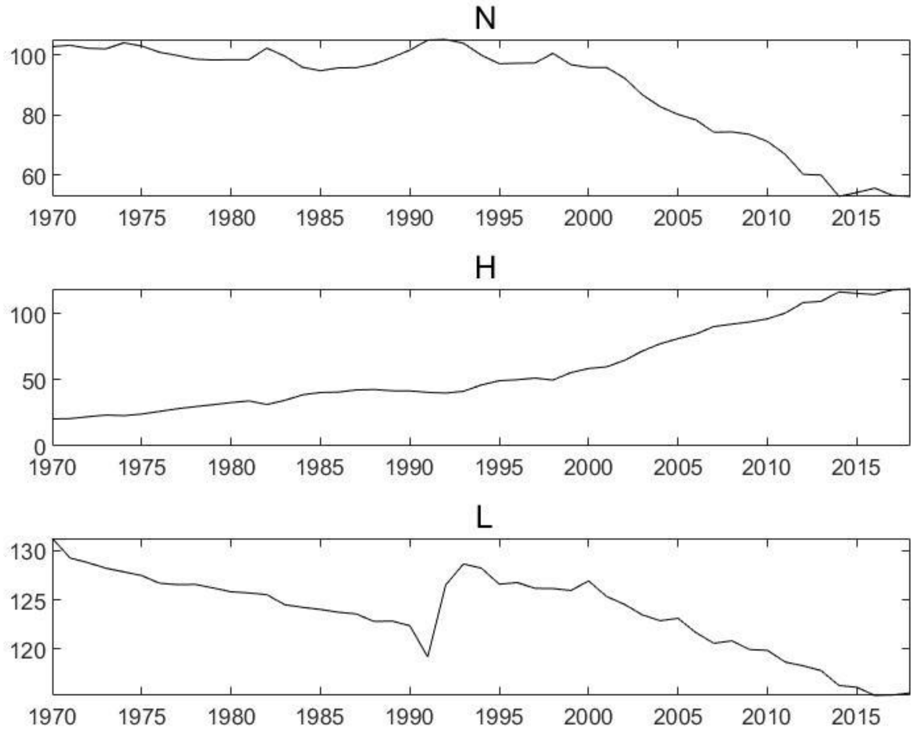

Figure.6 *EU's unskilled & skilled labour and land supply between 1970 and 2018*

From the figure above, N is unskilled labour supply and H is skilled labour supply. We use the tertiary ratio to calculate the skilled labour, in which those who attend the college are defined as skilled labour, and those who do not attend the college are defined as unskilled labour. From the figure we can see that the trends of unskilled and skilled labour were inverse after the 21th century. The main reason of the decreasing unskilled labour supply is the fundamental change of the structure of the economy. Before mid-90s, EU-14 production was heavily weighted on forestry and engineering industries, these are labour-intensive manufacturing sectors and require more unskilled labour. After 2000, the rising development of high-tech industries in EU-14, such as consumer electronics and semiconductor industries, dominated the economic recovery process, leading to a continuous increasing trend in skilled labour demand. On the other hand, there have been more people getting educated after 2000. Due to the expansion of government expenditure on public education, students could have more opportunities to get high education; they also had higher motivation to become more skilled due to the increasing demand for skilled labour in EU-14 high-tech industries.

L is the agricultural land supply, it continuously showed a downward trend and turned upward since 1992. The agricultural land supply turned downward-slopping trend in the mid-90s, and continued to fall until nowadays. As we have explained above, primary sector is seen as politically-controlled and highly intervened by the government planning system. The agricultural land supply is determined by policy-maker's planning system and to meet the demand of agricultural output. The turning point of 1991 was ‘Mac Sharry Reform’. According to Henning (2009), the reform lowered the supporting price of agricultural product and switched to directional subsidy policy. This subsidy was directly paid to the farmers, and the limit of subsidy was directly related to the farmer’s owned agricultural land size and production condition in the last period, instead of current production condition. Furthermore, we can find that the trend of land supply is considerably similar with the trend of agricultural output, this illustrates that the agricultural production depends on the agricultural land supply.

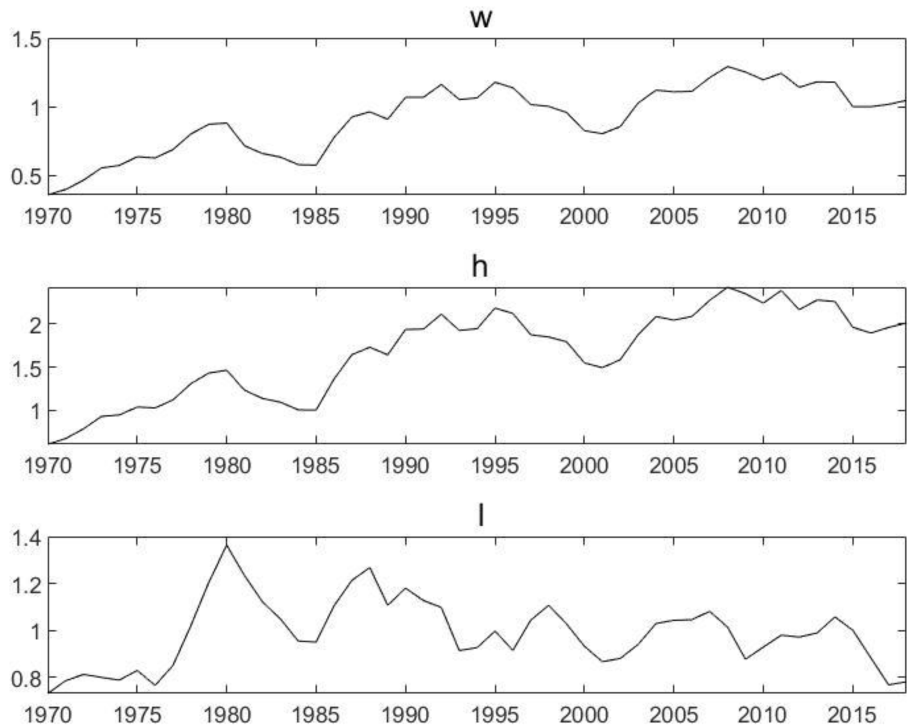

Figure.7 *EU's unskilled & skilled wage and land return between 1970 and 2018*

From the figure above, w stands for unskilled wage and h stands for skilled wage. We use the real wage in the base year 2015. Only unskilled real wage index is available, so we interpret the ratio of skilled earning to unskilled earnings to calculate skilled labour wage. Overall, both unskilled wage and skilled wage increase in general and skilled wage remains higher than unskilled wage all the time.

We use l to illustrate return on land, and we use the rent of land price index in the base year 2015. From the graph, we can see the rent of land reached its peak at 1980, and started to decrease gradually.

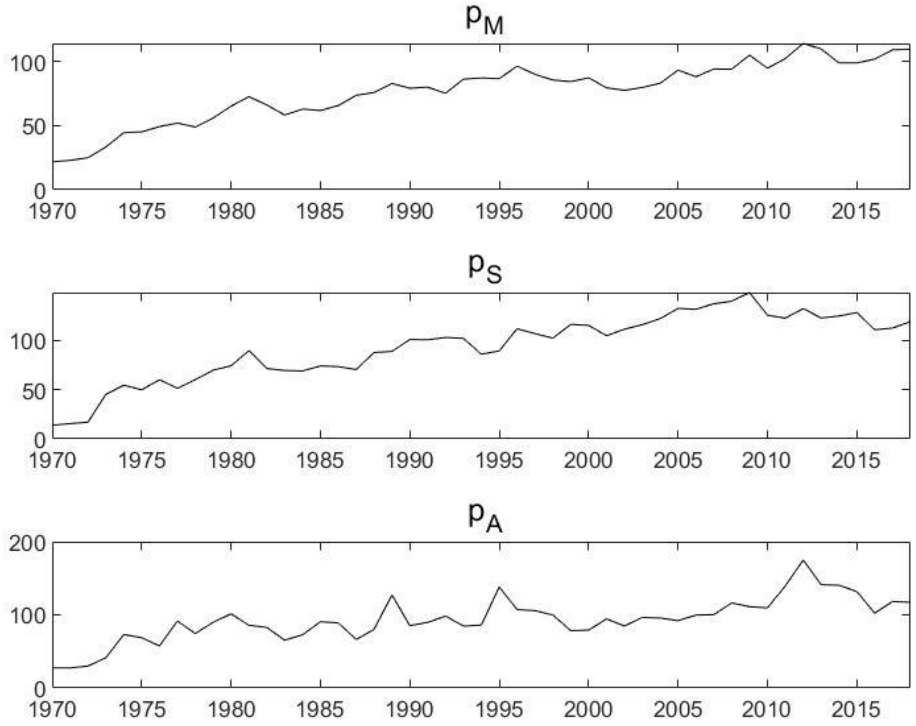

Figure.8 *Price levels in EU between 1970 and 2018*

The figures above illustrate the price indexations for manufacturing, service and agricultural; all price indexations are in constant 100 in the base year 2015. Manufacturing price and service price have gradually increased since 1970, presenting a general upward trend apart from the 2008 financial crisis. Agricultural price index has been relatively stable until 2010, and it started to rise sharply to its peak in 2011 and fell afterwards. There are two main reasons of its sudden price rise in agriculture. Because of weather disasters in the countries such as Russia, major grain exporters reduced their agricultural production, leading to a global grain production reduction and a rise in agricultural price. Second, EU bio-energy developed quickly in respond to continuously increasing price in crude oil, leading to a price rise in agricultural price.

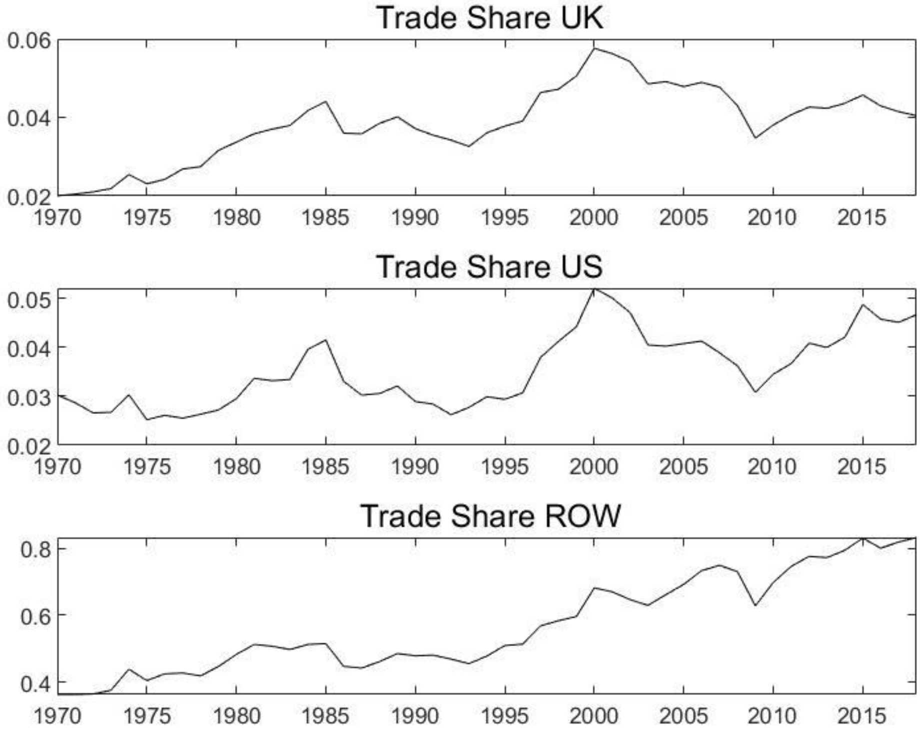

Figure.9 *Trade shares in EU between 1970 and 2018*

The figures above illustrate the trade shares, which are the total trade volumes (including exports and imports) in share of EU total GDP. The trade shares with UK and US reached the peak in 2000, and recovered after 2007 financial crisis. The main reason of the decreasing trend of trade shares with UK and US is the increasing trend in trade with China. This also illustrates trade share of ROW has the inverse trend with other two countries, because EU had more trade volumes with China after it entered WTO in 2001. The 2007 financial crisis heavily impacted on all the trade shares because of the falling demand in the foreign market, and it showed a clear recovery after the EU economy was stabilized.

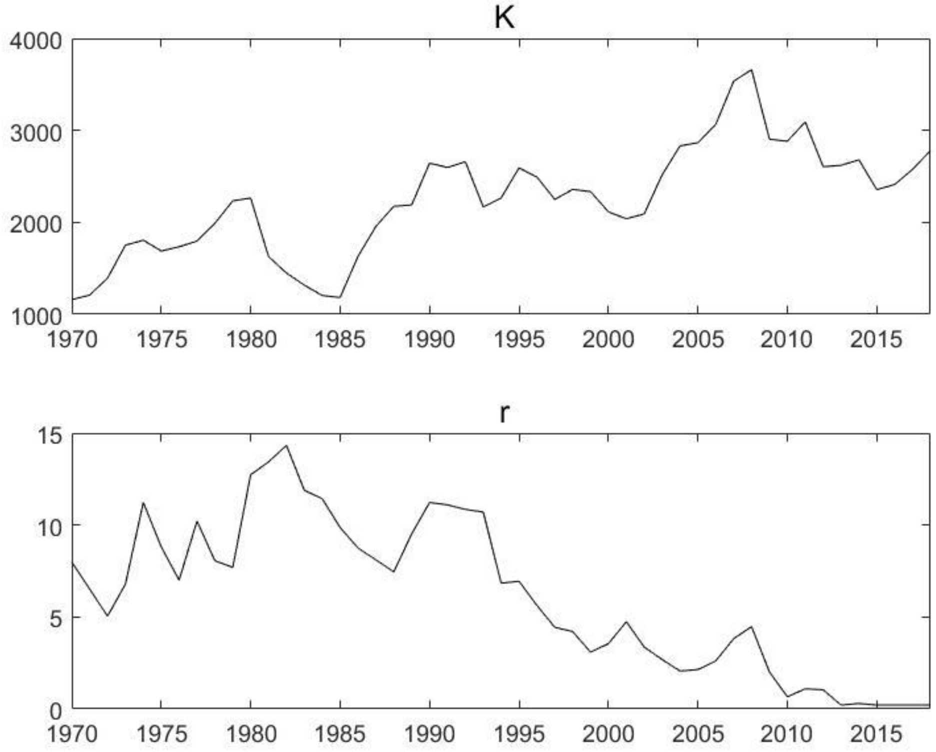

Figure.10 *Capital and return on capital in EU between 1970 and 2018*

From the figure above, K stands for capital and the base year is 2015. We use the capital formation ratio and EU GDP to calculate capital and it shows a similar trend of three waves with manufacturing and service output. It reached the first peak in 1980 and started to fall due to energy crisis in 1979, and it recovered after 1985 and approached the second peak 1990 in result of capital market deregulation. Capital increased sharply after early 2000s and reached the historical high in 2007 and then it turned to fall because of world-wide financial market collapse.

Return on capital, referred as r, represents a general index for capital return and shows a general decline after 1980s. The main reason of declining capital return is that government aims to stimulate economic development by providing more liquidity and creating more consumption. A lower interest rate means lower cost to borrow money, which stimulates consumption and boosts the whole economy.

Table 3.3 Data description					
Variable	Mean	STD	MAX	MIN	Median
y_M	1793.9	307.2	2345.3	1032.2	1846.4
y_S	5978.2	2313.3	10065.4	1920.1	6231.9
y_A	248.2	54.1	413.3	176.3	235.3
N	88.9	16.8	105.3	52.8	97.0
H	58.5	31.6	118.8	20.4	46.1
L	123.7	4.1	131.2	115.3	124.5
w	0.9160	0.2456	1.2918	0.3581	0.9996
h	1.6686	0.5043	2.4229	0.6099	1.8474
l	0.9860	0.1454	1.3634	0.7297	0.9878
p_M	76.930	23.407	111.490	21.762	81.467
p_S	90.039	33.887	138.508	13.844	95.473
p_A	92.088	28.350	148.390	27.447	91.964
TS_{UK}	0.0384	0.0093	0.0576	0.0199	0.0384
TS_{US}	0.0353	0.0074	0.0520	0.0251	0.0334
TS_{ROW}	0.5697	0.1440	0.8320	0.3633	0.5128
K	2239.5	597.7	3659.9	1158.9	2264.0
r	6.0712	4.1448	14.3313	0.2112	6.5168
RXR	82.299	18.943	113.697	54.239	78.469

From the table above, we can see the mean values of sector outputs are closed to the median value. Agriculture output has least gap between the maximum and minimum, while service differs the largest between the maximum and minimum. This indicates agriculture output does not change as significantly as other two sectors, and service sector has grown the fastest over the past few decades. The maximum of skilled labour is almost six times higher than the minimum, whereas the maximum of unskilled labour is only about doubled compared with the minimum, with lower standard deviation in the unskilled labour. Land supply, in other case, does not change significantly during this period. Both unskilled and skilled wages increase significantly, with 4 times increases respectively. The rate of return on land changes the least between the maximum and the minimum, with lowest standard deviation among all the price level. Service price level has the highest standard deviation among all three price levels, indicating the most volatility of trend in service sector.

Part 3.2 The Auxiliary Model

This thesis defines the auxiliary model as follows: on the left-hand side of the model, the trade share equation for each country is $TS_{UK} = \frac{M_{UK}+X_{UK}}{GDP_{EU}}$, $TS_{US} = \frac{M_{US}+X_{US}}{GDP_{EU}}$, $TS_{ROW} = \frac{M_{ROW}+X_{ROW}}{GDP_{EU}}$, and the output share of manufactured goods relative to service is $OS_{EU} = \frac{y_M}{y_S}$. On the right-hand side of the model, the relative productivity residual of manufacturing in relation to service is defined as $\pi_M/\pi_S$and the factor share of unskilled labour relative to skilled labour is $\frac{N}{H}$. Moreover, relative wages of unskilled labour in relation to skilled labour are$\frac{w}{h}$. Therefore, the auxiliary model is potentially a set of trade share equations encompassing relative productivity residual, relative factor share of labour and wage, as well as two main country groups (UK and US).

These selected factors in the auxiliary model aim to capture the most important country trade facts and those factors that might have significant causal effect on them. Therefore, the auxiliary model plays a role of summarising these trade facts; in other words, in accordance to the study of Durlauf and Blume (2016), the auxiliary model is unnecessary to be specified correctly. For instance, if replacing the independent variables of country GDPs with EU GDP, test results should not change too much. It is one of the most significant characteristics of the indirect inference approach; we do not need to specify the most appropriate auxiliary model being perfectly correct. However, we still remain interest of how the auxiliary model we select is close to the true model; this is why we perform a power of test in the next section.

Thus, the auxiliary model equations are potentially:

$$TS_{UK} = \gamma_1 + \alpha_{11}\frac{\pi_M}{\pi_S} + \alpha_{12}\frac{N}{H} + \alpha_{13}\ln(GDP_{UK}) + \alpha_{14}ln(GDP_{US}) + \alpha_{15}\frac{w}{h} + \epsilon_1$$

$$TS_{US} = \gamma_2 + \alpha_{21}\frac{\pi_M}{\pi_S} + \alpha_{22}\frac{N}{H} + \alpha_{23}\ln(GDP_{UK}) + \alpha_{24}ln(GDP_{US}) + \alpha_{25}\frac{w}{h} + \epsilon_2$$

$$OS_{EU} = \gamma_3 + \alpha_{31}\frac{\pi_M}{\pi_S} + \alpha_{32}\frac{N}{H} + \alpha_{33}\ln(GDP_{UK}) + \alpha_{34}ln(GDP_{US}) + \alpha_{35}\frac{w}{h} + \epsilon_3$$

$$TS_{ROW} = \gamma_4 + \alpha_{41}\frac{\pi_M}{\pi_S} + \alpha_{42}\frac{N}{H} + \alpha_{43}\ln(GDP_{UK}) + \alpha_{44}ln(GDP_{US}) + \alpha_{45}\frac{w}{h} + \epsilon_4$$

These equations will be fully or partially used in the following II Wald test and in the Monte Carlo experiment. In the first step, only the first three equations without relative wage rate are introduced to test the model. The reason for this reduced form of testing is to avoid excessive testing power for the test: the more features and equations included in the auxiliary model, the higher the test power will be. Thus, if the testing power is excessive, in which case auxiliary model contains too many coefficients and equations, only those models which are very likely identical to the structural model could pass the test. To maintain acceptable test power and to avoid good models being rejected by excessive test power, the first attempt entails giving considerable test power with limitations on the features and equations included in the auxiliary model. Then all equations with all features are included in order to test with full power, and only models closet to true models may pass the test. If the auxiliary model with all four equations and all features is not rejected, one can state the test power is substantial but not excessive and this auxiliary model is thus very close to the truth.

A Co-integration Test

The following Table3.4 presents a stationarity test for all variables in the auxiliary model, and the results show that these variables, besides output share and skilled-and-unskilled labour ratio, are not stationary, but their error processes derived from the auxiliary model are all stationary.This reveals a co-integration relationship between variables in the auxiliary model. It allows for the model to be tested further to see whether it matches actual data behaviour.

Table 3.4 *Co-integration test for the variables in the auxiliary model*			
ADF test	*Stationary*	*Non-stationary*	*ADF test(P-value)*
TS_{UK}		√	*0.8050*
TS_{US}		√	*0.8001*
TS_{ROW}		√	*0.9857*
OS_{EU}	√		*1.0000e-03*
π_M/π_S		√	*0.4578*
N/H	√		*1.0000e-03*
w/h		√	*0.5696*
$Log(GDP_{UK})$		√	*0.9692*
$Log(GDP_{US})$		√	*0.9990*
Residuals			
ϵ_1	√		*0.0271*
ϵ_2	√		*0.0204*
ϵ_3	√		*0.0020*
ϵ_4	√		*1.0000e-03*

A Monte Carlo Experiment

A Monte Carlo experiment is applied to access the power of the test, in which allowing parameters in the auxiliary model are allowed to contain a certain percentage of falsity. It starts with moderate test power using three trade share equations and no relative wage; if the test power is too great, no model with even a little disparity with the truth can pass the test. However, Table 3.5 illustrates that even when we perform the most powerful test, by adding all four trade share equations and other features in the auxiliary model, the power is still not excessive and produces a good result. In the Monte Carlo experiment, we falsify all parameters on the EU trade model, and create 1000 samples from each experiment. Then, we test the rejection rate of the model with falsified parameters relating to the true model; if a model with certain mis-specifications is not strongly rejected, then these models are still deemed useful.

Table 3.5 illustrates the rejection rate for the EU trade models with certain misspecification. We find that any model with 5% misspecification or more inaccuracy is almost always rejected, and even 1% misspecification in the auxiliary model makes it five times more likely to be rejected than in its original form. It indicates that the auxiliary model we used is highly likely to be the true structural model.

Table 3.5 also displays a difference between the rejection rate here and in the Appendix 1. We find the rejection rate of misspecification is significantly higher here than in the example of world variables treated as exogenous; in this case, when small falsities are permitted for the parameters, the model is more likely to be rejected. This leads to a conclusion that the Monte Carlo experiment serves to discover the auxiliary model on the assumption that endogenous world prices and outputs are significantly more likely to be rejected when falsified; in other words, this attempt of the auxiliary model is more likely to be close to the true world, when the EU is treated as a large open-economy. The power of the test is stronger than in the original attempt, when the EU is treated as small open-economy, but it is still substantial and includes four equations with full test power. This is the one of the reason why we treat the EU as a large open-economy, rather than the original assumption as the UK.

Table 3.5 *Power of II Wald test: classical model as true*

Percentage Mis-specified	Rejection rate at 5%
True	5%
1	26.8%
3	42.6%
5	71.2%
7	90.4%
10	95.7%
15	98.9%
20	99.9%

Note: All four equations and w/h apply.

Part 3.3 Testing Process

Step 1: Estimate the errors conditional on observed data and $\boldsymbol{\theta_0}$

According to the test procedure of the IIW mechanism, errors conditional on actual data are used to bootstrap and replicate the real data series. Therefore, the first step of the test is to estimate error terms for both the classical and gravity models based on the actual data; after error processes are finalised, they are used to simulate the model behaviours. It is important to identify the error structure so the stationary status of each error process can be correctly formulated to estimate the productivity, factor supply and demand indicators in the models.

Table 3.5 illustrates productivity errors, factor demand errors and factor supply errors, in four sectors are non-stationary based on the ADF test. The test result is consistent with the ADF result in Appendix, which reveals that simulated world variables based on the assumption of endogeneity do not significantly affect factor behaviours. Therefore, the first difference of each error process assumes an AR (1) process with drift, which does not change the error structure from the first attempt. Trade share errors are all stationary, following an AR (1) process with drift. The detailed error process structures are listed in the next section.

Step 2: Derive simulated data

Classical Model

The second step of the test procedure is to produce simulated data from bootstrapping implied model residuals and trade share errors. Based on Table 3.6, productivity errors are all non-stationary and we assume the first difference of each error follows an AR

(1) process with drift. The factor share residuals are also non-stationary and they follow the same error structure as productivity errors. Error processes are listed in detail below.

$$\Delta\, ln(\pi_{i,t}) = c_{1i} + \rho_{1i}\Delta\, ln(\pi_{i,t-1}) + \varepsilon_{1i,t}, i = M, S, A, d$$

$$\Delta ln(e_{i,t}) = c_{2i} + \rho_{2i}\Delta\, ln(e_{i,t-1}) + \varepsilon_{2i,t}, i = M, S, A, N, H$$

Therefore, the classical model follows an AR(1) process for the first difference in productivity errors and factor share residuals; first of all, it allocates an appropriate autoregressive process for each error, and then each AR process simulates productivity and factor share residuals from bootstrapping implied model residuals. These error structures, based on the assumption of endogenous world variables, are consistent with the first example of exogenous world prices.

Table 3.6 *ADF and KPSS tests on model residuals*

ADF test		Stationary	Trend stationary	Non-stationary
$\ln(\pi_M)$	Manufacture Productivity error			√
$\ln(\pi_S)$	Service Productivity error			√
$\ln(\pi_A)$	Agriculture Productivity error			√
$\ln(\pi_d)$	Non-traded Productivity error			√
$\ln(e_M)$	Manufacture factor demand error			√
$\ln(e_S)$	Service factor demand error			√
$\ln(e_A)$	Agriculture land demand error			√
$\ln(e_N)$	Manufacture factor supply error			√
$\ln(e_H)$	Service factor supply error			√
Residuals				
em_{UK}	Trade share error	√		
em_{US}	Trade share error	√		
em_{ROW}	Trade share error	√*		
ex_{UK}	Trade share error	√		
ex_{US}	Trade share error	√		
ex_{ROW}	Trade share error	√*		

**Based on KPSS Test.*

However, Table 3.6 indicates that trade share errors are stationary and error structures follow the AR(1) process with drift:

$$em_{i,t} = c_{1i} + \rho_{1i} em_{1,t-1} + \epsilon_{mi,t}, i = UK, US, ROW$$

$$ex_{i,t} = c_{2i} + \rho_{2i} ex_{i,t-1} + \epsilon_{xi,t}, i = UK, US$$

In sum, the ADF test aims to allocate an appropriate error structure for each residual; the results state that the first difference of productivity errors and factor share residuals follow an AR(1) process with drift and trade share errors assume a stationary process with drift. Then, we estimate the AR(1) process above and bootstrap those errors from each allocated error structure; one can bootstrap productivity and factor share data as well as trade share data by solving the classical model presented above.

Gravity Model

The main difference between the classical model and gravity model stems from the gravity effect, where we replace the autoregressive productivity errors with a trade effect T. T is defined as the semi-elasticity of each sector. As mentioned above, semi-elasticity in all sectors is calibrated at 2, indicating that a 1% total trade share in GDP causes a doubling of each sector’s productivity. Thus, both productivity errors and factor share residuals are non-stationary; following the same result as in the ADF test and consist across two examples, the gravity model assumes that factor share errors follow an AR(1) process with drift for its first difference.

$$\Delta\, ln(\pi_{i,t}) = c_{1i} + v_{1i} \Delta T + \varepsilon_{1i,t}, i = M, S, A$$

$$\Delta\, ln(\pi_{i,t}) = c_{1i} + \rho_{1i} \Delta\, ln(\pi_{i,t-1}) + \varepsilon_{1i,t}, i = d$$

$$\Delta\, ln(e_{i,t}) = c_{2i} + \rho_{2i}\, \Delta ln(e_{i,t-1}) + \varepsilon_{2i,t}, i = M, S, A, N, H$$

The ADF test results allocate appropriate error structures for each productivity error and factor share error. It estimates the above equations and bootstraps those residuals accordingly, and then solves the gravity model to bootstrap other endogenous variables.

Trade share errors are stationary and they follow an AR (1) process with drift:

$$em_{i,t} = c_{1i} + \rho_{1i} em_{1,t-1} + \epsilon_{mi,t}, i = UK, US, ROW$$
$$ex_{i,t} = c_{2i} + \rho_{2i} ex_{i,t-1} + \epsilon_{xi,t}, i = UK, US.ROW$$

Therefore, in order to simulate other endogenous variables and trade share data from the gravity model, we estimate AR (1) processes above and bootstrap all residuals accordingly. We then bootstrap other variables by solving the gravity model and take the trade share equations to bootstrap gravity model simulated data and trade share data.

The estimated coefficients of all error processes are shown in Table 3.7 below. It reveals that the estimated coefficients are similar between the classical model and the gravity model, because error structures maintain consistency; the main difference in productivity residuals comes when the semi-elasticity of agriculture, manufacturing and service is calibrated to 2, and the drift in the AR(1) process is lower in the gravity model in compared to the classical model.

Step 3 Compute the Wald statistic

After estimating the errors based on observed data and simulated world prices and country group GDP, we bootstrap the above procedure in both the classical and gravity model frameworks 5000 times to create a simulated history of coefficients of the auxiliary model.

Table 3.7 *Estimated coefficients for the error processes*

	Classical model			Gravity model			
Estimates	ρ	c	ϕ	ρ	C	v	ϕ
$\Delta\ln(\pi_M)$	-0.1211	-0.0077			-0.0138	2	
$\Delta\ln(\pi_S)$	-0.0415	-0.0211			-0.0299	2	
$\Delta\ln(\pi_A)$	-0.2829	-0.0513			-0.0597	2	
$\Delta\ln(\pi_d)$	0.2114	-0.0174		0.1176	-0.0146		
$\Delta\ln(e_M)$	0.1705	-0.0156		0.0714	-0.0187		
$\Delta\ln(e_S)$	0.0864	0.0090		-0.0436	0.0058		
$\Delta\ln(e_A)$	-0.2960	-0.0374		0.0476	-0.0405		
$\Delta\ln(e_N)$	0.2195	-0.0256		0.2662	-0.0238		
$\Delta\ln(e_H)$	0.1733	0.0213		0.1180	0.0229		
em_{UK}	0.8607	0.0330		0.8737	0.0340		
em_{US}	0.8206	0.0248		0.8818	0.0259		
em_{ROW}	0.8465	0.0407		0.8689	0.0427		
ex_{UK}	0.8456	0.0456		0.8676	0.0469		
ex_{US}	0.8444	0.0417		0.9144	0.0442		
ex_{ROW}				0.8776	0.0447		

Note: World prices and other countries' GDP are simulated by VAR.

Model Residual and Innovations

In this section, we present the data chart for the model residuals and innovations. These model residuals are the same for classical and gravity models, and these residuals are constructed from the structural models we set up in the Chapter 2. As we assume endogeneity in the EU case, all the world variables have been simulated from Equation 34, and we input these simulated data into the structural models to construct those model residuals. Figure 11 shows model residuals for the classical and gravity model. From this figure, we can see all these residuals are not stationary. Therefore, we should take first-difference to make these model residuals stationary. We can then re-estimate those residuals by using appropriate VAR, and those residuals of these appropriate VAR are defined as model innovations.

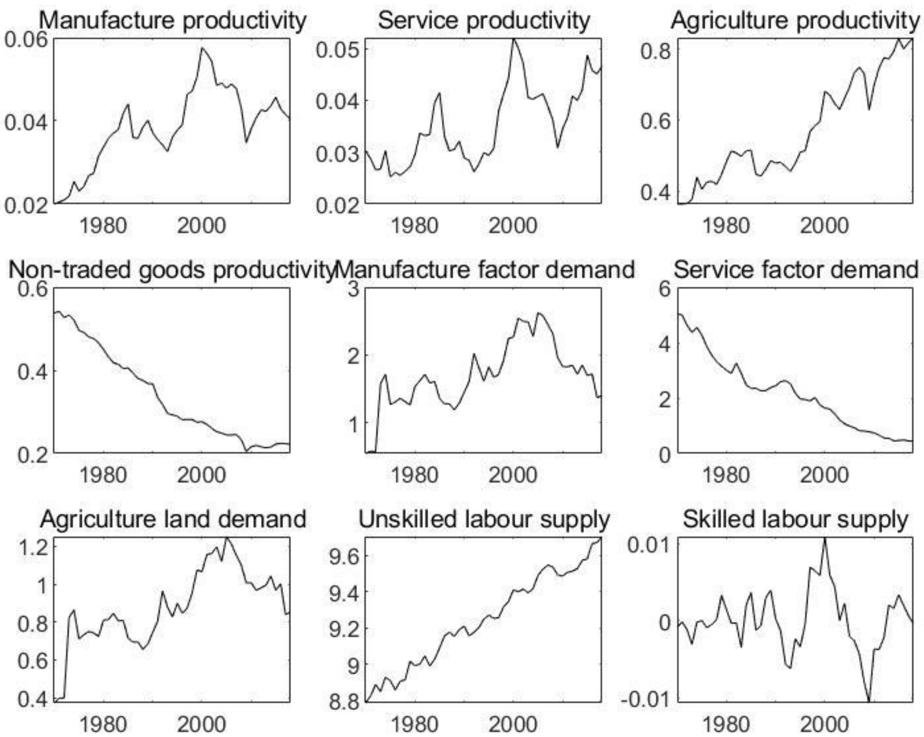

Fig. 11 *Model Residuals*

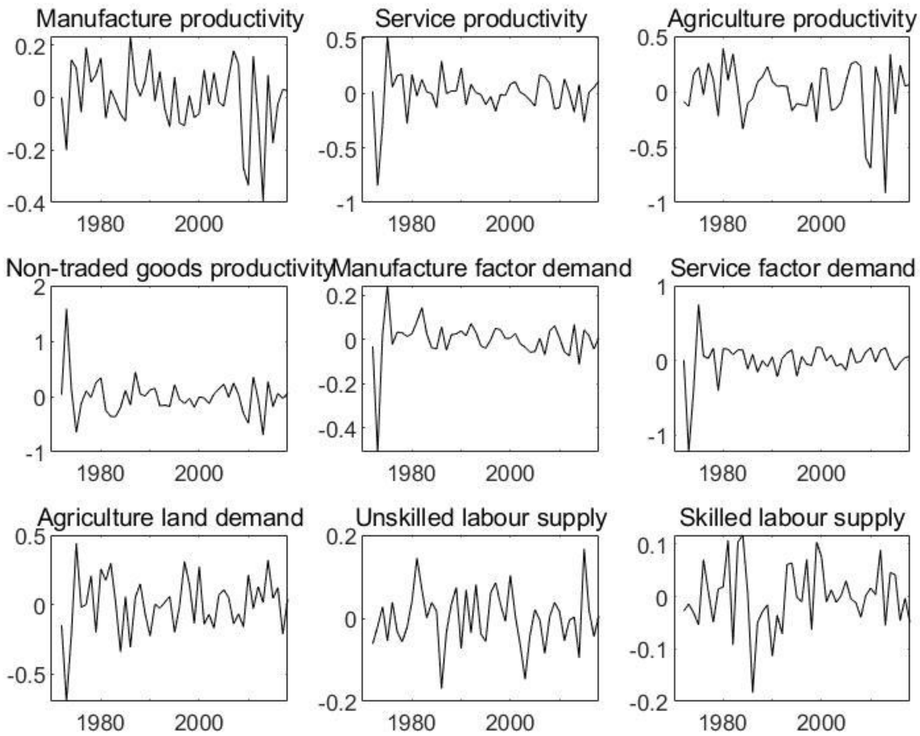

Fig. 12 *Model Innovation: Classical Model*

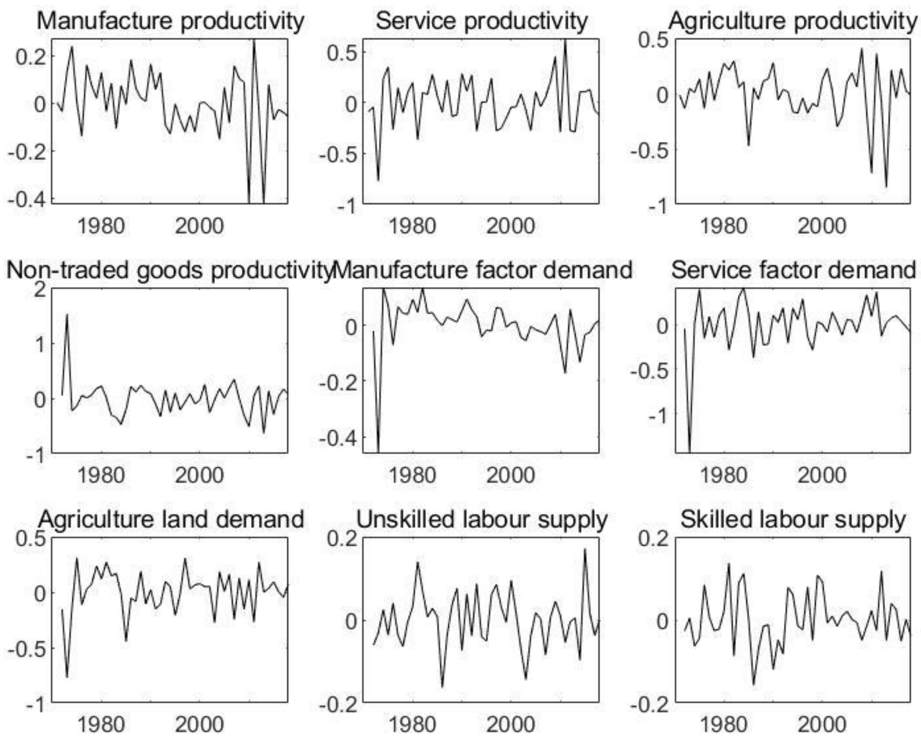

Fig. 13 *Model Innovation: Gravity Model*

Figure 12 and 13 present the model innovations for the classical model and gravity model. We can see that the innovations are different in the two rival models. The difference comes from the VAR set-up: in the gravity model, the productivity is endogenous and determined by trade; on the other hand, it is not in the classical model. In this case, re-estimated error processes are slightly different between the two.

Part 3.4 Empirical Result

Limited Test Power

The II Wald test in Table 3.8 starts with a weak restriction of three equations and no relative wage ratio, and both models pass the test at a 5% significance level but the gravity model is rejected under a 90% confidence level. It is also important to mention that the classical model generates a higher P-value than the gravity one, revealing that the classical model is more likely to pass the test than the gravity. Compared to the IIW result in the case of exogenous world variables and country group GDP, both models pass the test; however, the gravity model is weakly rejected in the endogenous framework rather than moderately passing in the exogenous world variable case (shown in Appendix1). It can thus be concluded that when world prices and country GDP are simulated by VAR and the economic scale effect for a large economy is accounted for, the classical model passes comfortably while the gravity model still passes but with lower probability.

Figure 14 provides a graphical indication of the data behaviour based on actual and simulated series on average for each model. As we can see, both models predict the actual trend more appropriately than the simulation in the same model settings under exogenous world variables; the gravity model still over-predicts the trade shares in three country groups, but it accurately simulates the trend for trade share in the UK and the US. For average simulated data of trade share in the rest of the world, the classical model demonstrates good prediction while the gravity model over-estimates trends. Both models fail to illustrate the trend of output ratio and only moderately pick up the trends of factor demand ratio and wage ratio.

In this section, the II Wald test releases the assumption of endogenous world prices and country group GDP in order to capture the size effect of a large economy. It starts with only three trade share equations and no wage ratio in the auxiliary model; the IIW results here illustrate that both models pass the test comfortably at a 5% significance level. Endogeneity in this example effectively leads to better graphical simulation than the exogenous one, which indicates average simulation under endogenous world prices and country GDP match the data more precisely than the original attempt. On the other hand, the II Wald test depends on joint distribution of simulated co-integrated relationships; the classical model comfortably passes the test while the gravity model passes with less probability.

Table 3.8 *II Wald test results for the EU without w/h*		
	Equation in auxiliary model	P-value
Classical trade model	1,2,3	0.1237
Gravity model (psi=0.6)	1,2,3	0.0923
Note: World prices and other countries' GDP are simulated by VAR.		

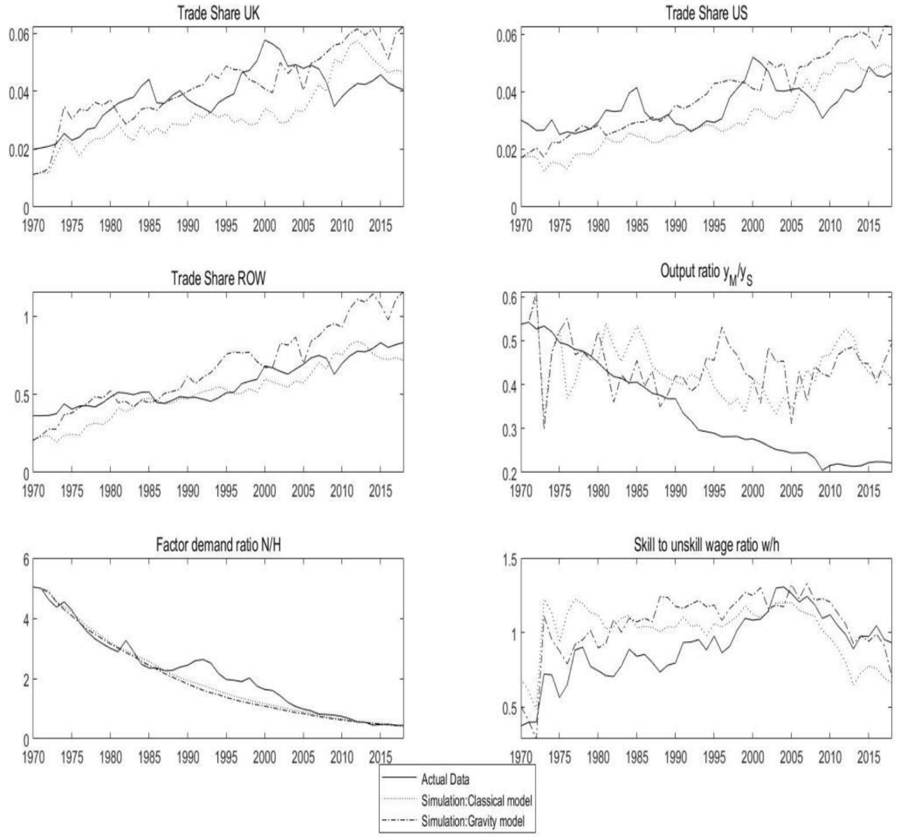

Fig. 14*Actual and Simulated Data: Low Test Power*

Terms of Trade Experiment

The second experiment entails removing gravity effects from the gravity model, showing us the effect of the total trade share on productivity dT, to see how results change compared to the least restricted assumption. The conclusion from Table 3.9 is similar to the one above where the gravity model still passes the test with slightly higher probability. The dT effect allows trade to affect productivity via the channel of foreign direct investment from the gravity model perspective; however, the removal of dT does lead to more fluctuation in trade shares with higher volatility in the gravity model compared to the classical model. According to Figure 15, the trade shares in the gravity model tend to be over-estimated with significant volatility, illustrating the disturbances in the current balance equilibrium. This forces real exchange rate move to balance the current account, so as the trade shares. Having no dT experiment in the gravity model shows a moderately satisfying feature of illustrating a real trade equation, although it tends to over-predict values with more volatility.

We also prepare an inverse experiment for the classical model to include dT effect, as statistically speaking the classical model passes the test with higher probability compared to the least restricted example. However, allowing trade effects on productivity only captures the basic trend of trade shares; Figure15 shows that this experiment eliminates volatility in estimating trade shares in the classical model. Although both models pass the Wald test, average simulations from the graphical prediction show less accuracy.

Table 3.9 *II Wald test results for the EU without w/h*

	Equation in auxiliary model	P-value
Classical model (with dT)	1,2,3	0.1836
Gravity model (psi=0.6) (without dT)	1,2,3	0.1267

Note: World prices and other countries' GDP are simulated by VAR.

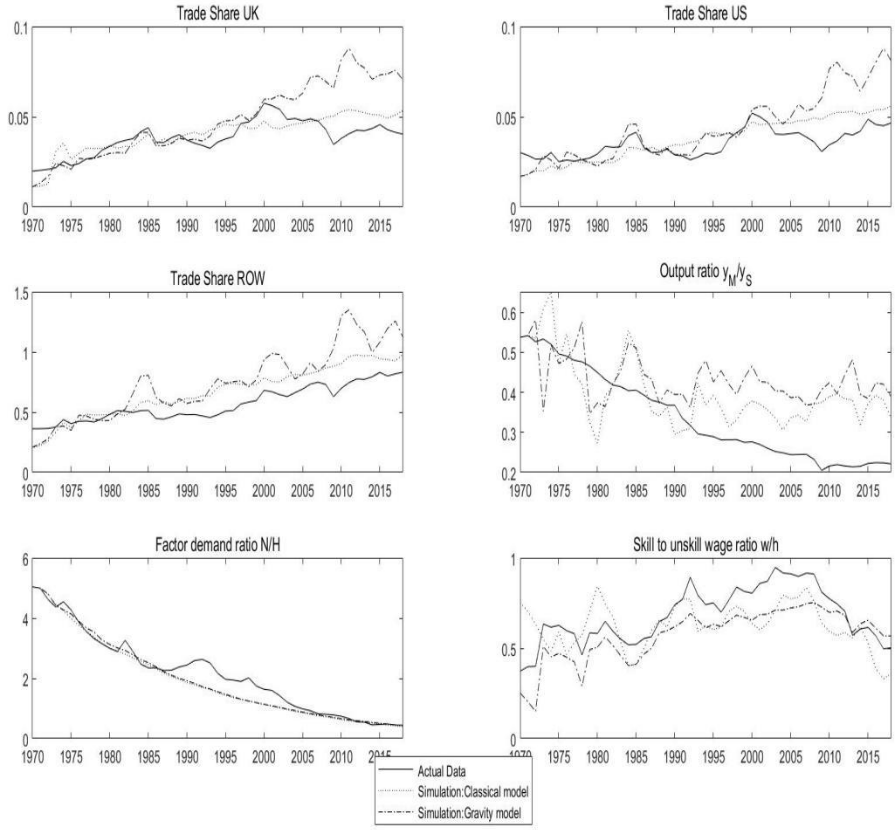

Fig. 15 *Actual and Simulated Data: Terms of Trade Experiment*

Gravity Experiment

Table 3.10 summarises the II Wald test results based on the least restrictive assumption of three trade share equations and no relative wage, and it also includes a third experiment which aggressively strengthens the power of the gravity effect. In the third gravity experiment, we triple the elasticity of trade shares on productivity and halve the real exchange rate's elasticity. Table 3.10summaries the P-value of the gravity model experiment with 0.04, indicating a strong rejection. This gravity experiment reveals that the increasing quantitative power of the gravity effect dampens the possibility of the gravity model passing the test.

The implication of the gravity effect experiment is similar to the first example under the exogenous world variables assumption. The classical model is the most likely model to pass the test comfortably while the gravity model also passes the test but with 25% less probability. Eliminating the link between trade size and productivity does not mean rejection of the gravity model, but does accelerate the volatility in trade shares. On the other hand, the gravity effect experiment on the quantitative size of the gravity power leads to a rejection under the Wald test, which reminds us that the calibration of the elasticity of trade shares and real exchange rate should be kept reasonable rather than excessively powerful. In the conclusion, under the least restrictive assumption with three trade share equations and no relative wage ratio, the classical model passes the test comfortably and its simulation of key indicators follows the trends accurately; however, the gravity model passes the test with lower probability and is rejected when the gravity effect is excessive, while the average simulation of the gravity model tends to over-predict.

Table 3.10 *II Wald test results for the EU without w/h*

	Equation in auxiliary model	P-value
Classical model	1,2,3	0.1237
Gravity model (psi=0.6)	1,2,3	0.0923
Gravity model Experiment	1,2,3	0.0412

Note: World prices and other countries' GDP are simulated by VAR.

Full Test Power

The final experiment is of interest when determining the impact of applying more powerful restrictions to the model specification, in this case raising the testing power byaddingthenumber of equations in the auxiliary model. As mentioned above, by starting with three trade share equations in the auxiliary model the aim is to provide reasonable testing power to avoid the majority of useful models being rejected; both models pass the test at a 95% confidence interval and graphically simulate features well resembling actual trends compared with average simulation. Adding the fourth trade share equation increases testing power and the rejection rate and would entail focusing intensively on trade shares rather than output ratio and other factors. Furthermore, the relative wage ratio of unskilled to skilled is also added into the auxiliary model as an extra parameter. The results are shown in Table 3.11 and Figure 16 below.

Table 3.11 illustrates the probability of both models passing the II Wald test. The classical model still passes the test, but its probability drops by 16% compared to the full power of test result in the first example; however, the gravity model is statistically rejected. These results are also indicated in Figure 8, as when testing power increases, the classical model simulation still accurately captures the trade share and other key ratios in the actual data with good fitness, while the gravity model’s average simulations are significantly over-estimate the trends in trade shares. In other words, the classical model simulation successfully survives and comfortably simulates actual data trends with good fitness; however, when testing power increases, the gravity model cannot pass.

Table 3.11 *II Wald test results for the EU with w/h*		
	Equation in auxiliary model	P-value
Classical model	1,2,3,4	0.1036
Gravity model (psi=0.6)	1,2,3,4	0.0214
Note: World prices and other countries' GDP are simulated by VAR.		

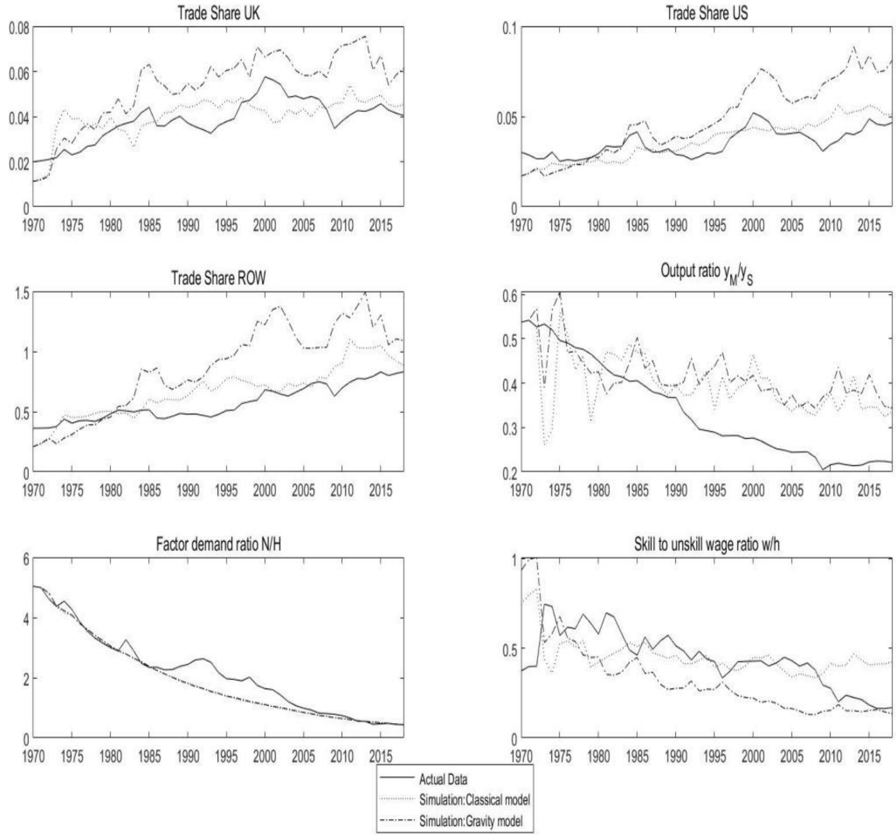

Fig. 16*Actual and Simulated Data: Full Power Test*

Conclusion

Theconclusions from the II Wald test under the endogenous world variables assumption are that, first of all, the classical model passes the test comfortably under weak and strict restrictions of the auxiliary model, and the gravity model passes the test only when testing power is low. For the gravity effect experiment, when the auxiliary model removes the link between trade size and productivity, the gravity model passes the test but with lower probability. On the other hand, when gravity model elements are assumed to be more significant, the gravity model cannot survive. With increasing testing power, the classical model still survives but the gravity model is even more strongly rejected. Therefore, both models are able to capture the trends of actual data under a relatively weak version of the auxiliary model, and the classical model is still fit for EU data under higher testing power but the gravity model only survives depends on the power of test and gravity effect assumption.

It is also worth undertaking a comparison of II Wald test results for exogenous and endogenous world variables. For exogenous world variables, both models pass the test albeit the classical model fits the EU facts better than the gravity model; however, when the economic scale effect is taken under consideration, the gravity model is rejected under a more restrictive version and higher gravity effect. The graphical comparisons between actual and simulated model indicators are also informative: the classical model’s average simulation fits well under both assumptions in all experiments, with moderately higher volatility in the case of endogenous world variables. On the other hand, the gravity model only captures the trends to a limited extent but significantly over-predicts trade shares in the first example. When the size effect of economic scale is included in the model specification, while the gravity model is rejected under a more restrictive version, the average simulation of the gravity model increases its fitness to the actual data trends. This also answers the remaining question regarding the first version of the auxiliary model, where the gravity model can unconvincingly pass the test with four trade share equations, but average simulation fails to explain the data.

The general conclusions to be taken from the exogenous and endogenous world variables are that, first, when we ignore the economic scale effect on world prices and consider the EU as a price taker, the classical model and the gravity model both pass the II Wald test even in the most restrictive test using four equations encompassing trade shares and relative wage ratio; however, the classical model fits the EU trade facts better than the gravity model which tends to over-predict the actual data trends in average. However, the assumption of the exogenous world variables cannot be true: EU’s economic scale is significant enough to influence the world prices. Thus, endogenizingworldprices and outputs from an open large-economy perspective intrusively solves the doubts: the classical model can survive but the gravity model is rejected under excessive testing power. Generally on average, the gravity model simulation provides better explanation at the endogenous attempt. Therefore, both the classical and gravity models can illustrate EU trade facts, with the classical model more likely to pass the test; meanwhile, endogenous world variables do not affect the classical model result, but do lower its probability of passing the II Wald test and provides greater accuracy than the gravity model. In this case, it would be more reasonable to test the EU trade model according to which other world prices and outputs are simulated by a reduced form VAR of an unknown true model, while the gravity model is strongly rejected when the gravity effect is added as well as the more restrictive trade share equations. The classical model comfortably survives in all experiments and fits the actual EU trade data better than the gravity model

Part 3.5Policy Simulation

In this section, we consider two implications in the comparison between classical and gravity models. First, we consider a calibrated policy simulation where we impose a tariff on agricultural and manufactured goods; in the second, we consider a calibrated productivity shock simulation where we impose a shock on all sectors. Tariff policy simulation may illustrate how the EU should increase or eliminate tariffs to increase general welfare; by comparing the two models, we are also able to figure out where welfare change comes from in each model. Alternatively, productivity shock simulation is able to simulate an experiment that allows readers to ascertain how key features may change in accordance with productivity innovation. We focus on two points here: 1) comparison between model reactions; and 2) policy implications in response to policy simulation.

***Table 3.12** Effects of a 10% tariff on food and manufactured goods for the EU*					
Variables	Base Run	10% tariff on food and manufacturing		%Change	
		Gravity	Classical	Gravity	Classical
y	18741	17965	17818	-4.14	-4.93
y_A	202	202	202	0.00	0.00
y_M	1209	2670	2647	120.84	118.94
y_S	8391	6298	6310	-24.94	-24.80
y_D	8939	8691	8659	-2.77	-3.13
E_A	325	294	289	-9.54	-11.08
E_M	1540	1506	1487	-2.21	-3.44
E_S	7247	7002	6981	-3.38	-3.67
w	0.97	1.09	1.07	12.37	10.31
h	1.66	1.31	1.27	-21.08	-23.49
l	1.10	1.25	1.29	13.64	17.27
N	52.81	53.89	53.53	2.05	1.36
H	118.77	116.09	115.72	-2.26	-2.57
L	137.20	103.83	101.50	-24.32	-26.02
K	2107	1982	1948	-5.94	-7.55
p	0.94	1.02	0.99	8.51	5.32
p_A	0.84	0.92	0.92	10.00	10.00
p_M	1.00	1.1	1.1	10.00	10.00
p_S	1.13	1.13	1.13	0.00	0.00
p_D	0.86	0.97	0.92	12.79	6.98
RXR	108.88	117.86	108.88	8.25	0.00
Welfare1				-8.64	-9.29
Welfare2				-5.72	-7.59
CHRES				-0.0026	-0.0028
Welfare3				-5.72	-7.58

Note on welfare1 measure:
Welfare1=100[y^{t}/p^{t}-y/p-(N^{t}+H^{t}+L^{t}+K^{t}-N-H-L-K)]/y +(RXR^{t}-RXR)(IMPORTS/GDP), where y^{t},p^{t},N^{t},H^{t},L^{t},K^{t} are simulated.
*Note on welfare measure: Welfare loss from the tariff is computed as [Welfare2 = % output loss/GDP + consumer surplus lost-Term of Trade gain-TOT gain as % of GDP], where the consumer surplus loss = percent rise in CPI * 0.5 and the TOT gain = RXR percent rise * share of imports in GDP.*
*Note on CHRES: CHRES=base(w*N/GDP)* % change in N + base(h*H/GDP)* % change in L + base(p_m *r*K/GDP)* % change in K*
Note on welfare3 measure: Welfare3 = Welfare2 – CHRES.

The Policy simulation of a Tariff Increase by the EU

A typical policy simulation to increase the tariff on agricultural and manufactured products whereby prices of both agricultural and manufactured goods rise by 10% with calibration. Both model simulations do not differ significantly, as imposing a 10% tariff increase on prices results in a welfare loss of 9.3% and 8.6% in the classical and gravity models respectively. If welfare loss is calculated using a combination of output and consumer surplus loss as well as terms of trade gain, the classical model reduces welfare by 7.6% and the gravity model reduces its welfare by 5.7%. Differences in the calculation approach to measure welfare do not change the conclusion: the classical model generates a greater welfare loss than the gravity model. In particular, the gravity model creates less welfare loss because of the implied gain in terms of trade due to currency appreciation. Greater welfare loss in the classical model and less welfare loss in the gravity model indicates a distinguishable bias towards free trade in the classical model, while the gravity model favours m trade protectionism.

Table 3.12summarizes the trade tariff simulation in more detail. The calibrated price increase in the agriculture sector does not affect agricultural output, because agriculture is policy-controlled; however, it boosts manufacturing output and reduces output in other sectors, as well as the total output level. Although the service price is unchanged, imposing a tariff on agricultural and manufactured goods also raise the total price level across the board including for non-trade goods, this reduces demand for all goods. Furthermore, imposing a tariff on manufactured goods stimulates a rise in unskilled wages and doing the same for agricultural goods causes the land rates to rise. Moreover, as a rise in tariff increases the number of people engaged in unskilled labour and reduces the number in skilled labour, this leads to a capital outflow. The models do not differ much in terms of the value of simulation, as the difference in welfare loss comes only from terms of trade and the real exchange rate: the gravity model generates less welfare loss because of currency appreciation but otherwise the classical model can reproduce similar data behaviour to that of the gravity model.

The application of the tariff policy simulation can be explained as follows. First, when it assumes a 10% tariff on manufacturing and agricultural sector, it directly raises the home prices in manufacture and agricultural sector. Since factor prices are rising in the prices of the traded sector which is intensively used; in this case, when the manufacturing world prices increase, the unskilled wages rise correspondingly. Similarly, the return on land rises as the result of rising agricultural world price. On the other hand, the wage of skilled labour decreases as the factor prices of unskilled wages and land increases; this follows the intuition when one sector is intensively used, the factor price of this sector rises while the factor prices of other sector, which is used less, falls. This illustrates when a 10% tariff on manufacturing and agriculture price increase, unskilled wages and return on land rise in which they are intensively used, whereas skilled wages fall otherwise.

Table 3.12 also shows a 10% factor price rise in manufacture and agriculture leads to a fall in output of service and non-traded sector, while manufacturing output expands. The factor market clearing condition solves for the output of each traded sector; this is to say, the output of a traded sector will increase in response to a factor price rise in the sector which is intensively used. In our assumption, the agricultural supply is exogenous and set politically to meet the daily demand, in this case agricultural output is constant. It implies that, in this model, manufacturing output is determined by unskilled wages and service output is determined by skilled wages. In this case, when 10% tariff increases agricultural and manufacturing price, manufacture output expands and service output falls as it is determined by skilled wages.

Table 3.12 also illustrates a rise in tariff will negatively impact on non-traded output. First, the price of non-traded prices can be determined by the costs based on those factor prices; thus, the production of non-traded goods can be determined by the relative price of non-traded goods to traded goods. If the prices of land rise, this will increase the relative price of non-traded goods which are relatively more used in land than traded goods. The rising relative price of non-traded goods will then lower the non-traded output relative to GDP. In this case, when there is a 10% price increase in manufacture and agriculture, rising land prices will push up the relative prices of non-trade goods to traded goods, which lower the output of non-traded goods.

Table 3.12 also shows the two rival models behave similarly in trends, and the difference in the gravity model comes from a term of trade gain. As the demand of a country must equal to the supply, when the tariffs imposing on the country, imports are diminishing from the rest of world. The real exchange rate must rise to balance to current account, by achieving a real currency appreciation. Under the gravity model, we can see the rise in the RXR, in some extent, offset the welfare loss, giving a term of trade gain by its assumption.

On looking at the policy implications derived from tariff simulation, a tariff on EU food and manufactured product leads to general output loss and welfare loss under both models, which serves as important guidance for EU policymakers when negotiating on tariffs with the US and the UK. Although the classical model is biased towards free trade and the gravity model is biased towards protectionism, both models suggest cooperation and the avoidance of a trade war; the EU should thus try to communicate with the US to eliminate tariffs and impose more liberalized trade policy, based on our results.

In the summary, the tariff policy simulation illustrates general welfare loss in both models, and the classical model generates more welfare loss than the gravity model because of currency appreciation from terms of trade. Hence, the classical model prefers free trade and the gravity model places more emphasis on protectionism. However, both models generate similar effects on the simulation and convey the same conclusion: policymakers in the EU should remove all general tariffs currently imposed on agricultural and manufactured goods, and encourage cooperation rather than retaliation, which could lead to a trade war. The tariff simulation also illustrates that the classical model produces a similar result to the gravity model: both models have a similar effect in accordance with this tariff simulation, putting into doubt the claims of gravity modelersthat the classical models is out of date.

The IRF of a Productivity Shock by the EU

In this policy simulation, we assume a 1% productivity shock is imposed in each industry. The results of percentage changes of key economic indicators in reaction to sector innovation are summarised in Table 3.13. The results in each sector are listed in the appendix. From this table we can find that all trade share estimates in the gravity model are significantly higher than in the classical model; both models, however, generate a positive reaction to productivity shock in total trades. In each sector, higher productivity leads to a rise in output, and more goods being exported to other countries except agriculture, as it is assumed to be exogenous and policy-controlled. The gravity model balances the current account by modifying the real exchange rate to ensure the price of EU goods stays competitive with foreign counterparts. Therefore, when the Euro continues to depreciate, the prices of EU products becomes more competitive for foreign suppliers, which accelerates exports of EU goods and increases the EU's trade volumes with other country group.

Besides agriculture productivity innovation, a positive productivity shock drives the biggest rise in total output level in manufacturing; 1% productivity rise in the manufacturing sector results in a 1.1% rise for total output in the classical model and 1.9% in the gravity model. In the service and non-traded sectors, total output increases less than in manufacturing but still positively reacts to the shock. In other words, innovation is most preferable in manufacturing for EU policymakers to enhance economic performance by raising domestic output.

A 1% productivity shock in agriculture leads to a total output reduction in both models; it also negatively affects both skilled and unskilled wages, while unskilled employment decreases follow with the shock. As agriculture is assumed to be exogenous, production is set by policymakers to satisfy the daily demand; a productivity boost leads to less land being available to produce the same amount of agriculture goods, and thus the rate of return on land increases. Firms spend more on rent and pay less to unskilled workers, thus both of which hurt the economy.

Wages change in response to a productivity shock differently for each sector. The manufacturing sector is unskilled labour intensive, and a positive productivity shock here results in higher production of manufactured goods, more income for firms and higher wages; service sector is skilled labour intensive but the same logic applies.

In the conclusion, both models react to productivity shock similarly but the gravity model tends to provide higher predictions than the classical model. One possible reason is that the gravity model allows the real exchange rate to be modified to balance the current account, so the terms of trade effect is included in the gravity model. Besides agriculture, other sector productivity shock has a positive effect on total output; in particular, productivity shock in manufacturing stimulates total output the most, so the EU policymakers are advised to invest more in manufacturing innovation.

***Table 3.13** Summary: Impulse response function with 1% productivity shock*

Variable	Base run	1% $\varepsilon_{\pi M}$		1% $\varepsilon_{\pi S}$		1% $\varepsilon_{\pi A}$		1% $\varepsilon_{\pi D}$	
		Gravity	Classic	Gravity	Classic	Gravity	Classic	Gravity	Classic
TS_{UK}	0.0280	18.21	4.64	4.64	1.43	3.93	1.07	14.64	4.29
TS_{US}	0.0286	12.94	2.79	2.79	1.05	2.10	0.35	8.74	1.75
TS_{ROW}	0.4889	11.88	4.81	6.22	2.33	5.87	0.88	7.99	4.66
$ln\pi_M$	-0.5266	1.58	0.97	0.36	0.00	0.24	0.00	0.15	0.00
$ln\pi_S$	0.1875	-0.16	0.00	1.55	0.96	-0.11	0.00	-0.05	0.00
$ln\pi_A$	-0.1302	0.15	0.00	0.08	0.00	1.54	0.99	0.23	0.00
$ln\pi_D$	-0.0905	0.00	0.00	0.00	0.00	0.00	0.00	1.55	1.10
y	18207	1.94	1.07	0.76	0.19	-1.00	-1.13	0.81	0.16
y_A	202	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
y_M	1692	6.56	4.73	2.19	2.48	3.78	2.30	5.97	4.31
y_S	8210	-2.99	-2.41	3.26	2.94	0.05	-0.05	0.16	0.09
y_D	9103	-2.21	-2.33	-0.86	-1.39	-2.42	-2.59	-1.44	-1.82
E_A	324	2.16	4.32	0.93	2.16	5.25	0.62	1.54	0.93
E_M	1540	4.22	3.18	0.78	0.06	-0.91	-0.65	1.04	0.19
E_S	7240	1.81	2.06	4.79	4.13	-0.12	-0.44	1.57	1.20
w	1.07	8.41	4.67	-1.87	-0.93	-1.03	-0.75	2.80	0.93
h	1.98	-4.04	-3.03	2.53	1.52	-1.72	-1.01	4.04	2.02
l	0.84	-3.57	-2.98	-2.02	-1.43	12.14	10.36	-0.95	-2.38
N	52.81	2.22	1.29	-0.79	-1.57	-1.38	-1.48	-0.89	-0.13
H	118.92	-1.55	-1.09	1.04	0.39	0.06	0.09	0.22	0.09
L	139.08	3.28	1.66	1.58	0.41	-12.13	-12.02	-11.10	-11.95
K	1741	9.30	8.67	-1.15	-0.52	-1.61	-2.18	-1.95	-2.13
RXR	108.88	-10.11	0.00	-9.29	0.00	-7.77	0.00	-7.89	0.00

Note: Numbers denote percentage changes regarding to productivity shock.

Conclusion

In this thesis, the EU is treated as a large open-economy that can influence world prices and other countries' variables. The aim of the first part of the thesis is to examine the empirical evidence as to whether EU trade fact is better reflected by the classical model based on comparative advantage theory, or the gravity model based on geographical origin and economic scale. The assumptions in the above test are to treat world prices and other countries' GDP as endogenous and the EU's economic scale can influence the world's variables, and to treat agricultural output as exogenous because of being policy-controlled. The two baseline models differ in two ways; the gravity model assumes imperfect competition in world markets while the real exchange rate is modified to balance the current account, while the classical model assumes perfect competition. The gravity model also assumes that the total trade share has a positive impact on sector productivity, linking trade and economic scale according to the gravity effect. Thereafter, this thesis performs a Monte Carlo experiment with an II Wald test in order to test whether and to what extent the calibrated auxiliary model is a structural model. The results reveal that when parameter errors falsify to exceed 10%, the auxiliary model is highly likely to be rejected. In other words, the auxiliary model is highly likely to be close to the truth and the power of the test is substantial but not excessive.

We find that the classical model passes comfortably in all experiments, although the gravity model passes at a lower probability under lower test power and when weak gravity features areincluded.When the gravity features are pronounced and testing power increased, the gravity model cannot survive and tends to be rejected. Therefore, the classical model more accurately predicts features of average simulated data, and can pass the most powerful test and is closest to the truth. On the other hand, the gravity model demonstrates good features under a low-power test, but when more trade share equations are added into the gravity model, it tends to over-predict the simulated data and can fail to pass the test.This reveals that the more emphasis placed on the gravity effect of trade share equations, the lower the probability of the gravity model passing the test. Overall, with regard to the II Wald test and under the endogenous world variables assumption, both models pass the test but the classical model is preferred to the gravity model.

The tariff simulations results reveal a general conclusion that both the classical model, which is biased towards free trade, and the gravity model, which is biased towards protectionism, suggest welfare reduces in the event of a tariff being imposed. The main implication for EU policymakers here is that current trade tariffs should be eliminated and tries the best effort to communicate and cooperate with trade partners in the world. A trade war between EU and US harms both parties and is not sustainable.

Meanwhile, the productivity shock simulations affect both models similarly, except for a slight difference in the gravity model due to currency depreciation. In agriculture positive innovation hurts the whole economy because, given the control of agricultural output, it raises the price of land, so other sectors' costs, while in the other three sectors positive innovations boost total output as would be expected.

CHAPTER FOUR

GENERAL CONCLUSION

In this thesis I have examined the ability of two rival trade models in widespread use to fit the key trade relationships found in the data. I have used the powerful method of indirect inference. These two models are the Classical, going back to Ricardo and developed by Heckscher, Ohlin and Samuelson; and a more recent rival, the 'Gravity' model, whose key departure from the Classical model is to treat commodities as heterogeneous, with substitution elasticities that typically weaken with distance. In the Classical model by contrast commodities are treated as homogeneous, the reason being that in the long term it is assumed that competition will force all commodity types to give equivalent value. The heterogeneity assumption usually follows the Armington model which works well in macro models to fit the short run business cycle. Gravity models vary in their specific assumptions for elasticities; here we use those found in the data by OLS regressions, to give the model its best chance of fitting the data. However what my tests show on the EU data examined in this thesis is that the gravity model is strongly rejected in its attempt to fit the long run trade relationships whereas the Classical model is accepted with a good p-value.

This key empirical finding has policy implications which I summarise next.

Policy Implications

According to the policy simulation in the Chapter Three, one can argue that although both models imply welfare lossesfrom tariff increases, the gravity model implies suffered more loss than the classical model. The main reason for the difference of welfare cost between the two rival models is that the gravity model implies terms of trade gains from tariffs. These only occur in the gravity model because current account balance equilibrium can only be solved by the real exchange rate movement. Therefore, when we raise the tariffs,the terms of trade improve in response to the rise in the real exchange rate. No such movement occurs in the classical model because the rest of world market acts as a residual market.

The policy implication of the thesis is that, whatever the model is selected to use as a policy guidance, both models suggest a welfare loss if there is a tariff rise. That gives our policy implication that a tariff rise will negatively affect the EU citizen's welfare, based on either classical model or gravity model. However, policymakers will not be so aware of the indirect welfare costs of tariffs and may well focus most on the terms of trade 'beggar my neighbour' effect. This is likely to mean that policymakers are more likely to favor tariffs if they believe the gravity model rather than the Classical.

A full analysis of policy formation in the EU lies well beyond the scope of this thesis. However, it would be an excellent focus for future work. The political economy of levying tariffs must include the role of powerful industrial lobbies, such as French agriculture and German manufacturing industry, in general EU policymaking and inter-country bargaining. Further elements would include the weakness of groups representing the consumer, owing to the wide dispersal of the consumer interest across all households. Also relevant is the non-obserability of the indirect losses caused by tariffs whereas the effect of terms of trade gains is fairly obvious as a 'beggar-thy-neighbour' gain. I cover some of these points in my policy discussion of tariffs above.

However one accounts for it, it is known that the EU has protected agriculture and manufacturing heavily- thus Minford et al (2015) estimate total, tariff and non-tariff, protection of each sector at about 20%, in line with other available estimates. It is my hope that the results of this thesis may by revealing the costs of this protection contribute to reducing it in the future.

Limitation and Future Research

There are several limitations of this study, leading to future researches in related studies. The first limitation of the work done here is the quality of the data.As the European Union increases its membership over time, the country coverage required expands. Here I have tried to maintain the original membership countries (EU-15) as the country group of the EU; this could be extended in future work to check the robustness of my results. A further data limitation arises from the inconsistency of the sources I have had to use. Data are collected from different sources and some data are missing for the EU. Therefore, in this thesis I have had to convert all the data into dollars to maintain its consistency across all the trade data used here; and I have relied on some national sources as well as EU sources, to get complete data. It would also be of interest to repeat the analysis using alternative sources of input-output coefficients from the UK ones used here, as in Minford et al. (1997) and Minford and Xu (2018), though as we have noted those are likely to be good estimates and are vindicated by the success of the Classical model in matching the EU data.

Overall conclusion

The main aim of this thesis is empirical, to test prominent models of EU trade in the existing literature, and if possible to find one that matches EU data behaviour according to powerful indirect inference tests. I am pleased to say that I have found such a model- the Classical model of trade- and that I have rejected the other major model in contention- the ‘gravity’model- as strongly inconsistent with the EU trade data behaviour. My findings have clear policy implications for tariff policies: that they are highly damaging to EU citizens’ welfare- and would be so even under the rejected trade model. The political economy literature suggests reasons why tariffs will happen in the EU nevertheless. It is my parting hope that my work will help to motivate policymakers to oppose such policies.

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Appendix 1

In this Appendix, we treat EU as a small open-economy, just like UK case in the Minford and Xu's (2018) study. This is the original work of this study in this area. One can argue if we treat EU and UK under the same assumption, how results might change for the EU. In this baseline case, EU is treated as a small open-economy and a price taker; there is no need for us to simulate world prices and other countries' GDP because EU now has no effect on other countries. We still treat UK as a single country and not a part of the EU, and the rest of the EU is denoted as EU in this baseline case. Although the baseline case is not valid, I put here for comparison to who are interested.

All data are annual data from 1970 to 2018 from the same source in the Chapter Three. Figure 17 plots all the data series in the below.

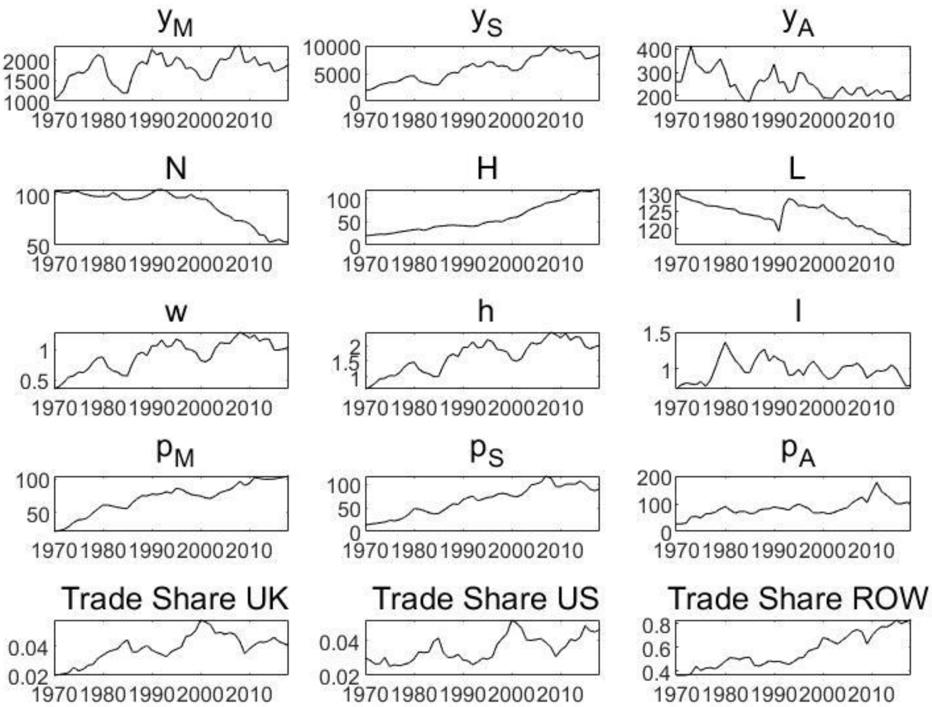

Fig. 17 *Plots of the actual data*

The baseline case defines the auxiliary model as follows: on the left-hand side of the model, the trade share equation for each country is $TS_{UK} = \frac{M_{UK}+X_{UK}}{GDP_{EU}}$,$TS_{US} = \frac{M_{US}+X_{US}}{GDP_{EU}}$,$TS_{ROW} = \frac{M_{ROW}+X_{ROW}}{GDP_{EU}}$, and the output share of manufactured goods relative to service is $OS_{EU} = \frac{y_M}{y_S}$. On the right-hand side of the model, the relative productivity residual of manufacturing in relation to service is defined as $\pi_M/\pi_S$and the factor share of unskilled labour relative to skilled labour is $\frac{N}{H}$. Moreover, relative wages of unskilled labour in relation to skilled labour are $\frac{w}{h}$. Therefore, the auxiliary model is potentially a set of trade share equations encompassing relative productivity residual, relative factor share of labour and wage, as well as two main country groups (UK and US).

The auxiliary model equations are assumed as follows:

$$TS_{UK} = \gamma_1 + \alpha_{11}\frac{\pi_M}{\pi_S} + \alpha_{12}\frac{N}{H} + \alpha_{13}\ln(GDP_{UK}) + \alpha_{14}ln(GDP_{US}) + \alpha_{15}\frac{w}{h} + \epsilon_1$$
$$TS_{US} = \gamma_2 + \alpha_{21}\frac{\pi_M}{\pi_S} + \alpha_{22}\frac{N}{H} + \alpha_{23}\ln(GDP_{UK}) + \alpha_{24}ln(GDP_{US}) + \alpha_{25}\frac{w}{h} + \epsilon_2$$
$$OS_{EU} = \gamma_3 + \alpha_{31}\frac{\pi_M}{\pi_S} + \alpha_{32}\frac{N}{H} + \alpha_{33}\ln(GDP_{UK}) + \alpha_{34}ln(GDP_{US}) + \alpha_{35}\frac{w}{h} + \epsilon_3$$
$$TS_{ROW} = \gamma_4 + \alpha_{41}\frac{\pi_M}{\pi_S} + \alpha_{42}\frac{N}{H} + \alpha_{43}\ln(GDP_{UK}) + \alpha_{44}ln(GDP_{US}) + \alpha_{45}\frac{w}{h} + \epsilon_4$$

These equations will be used as the auxiliary model in our analysis, following with the same step of earlier case.

A Co-integration Test

Table 4.1 below shows variables are not stationary according to the ADF test but these variables either have deterministic or stochastic trends. For the error processes in the reduced form, they are stationary since these regressions are derived from structural relationships in the CGE model. The stationarity of residuals reveals a co-integrated relationship between those variables in the auxiliary regressions, with common exogenous drivers providing the regression coefficients of EU trade facts to match the true facts.

Table 4.1 *Co-integration test for the variables in the auxiliary model*

ADF test	*Stationary*	*Trend stationary*	*Non-stationary*
TS_{UK}			√
TS_{US}			√
TS_{ROW}			√
OS_{EU}		√	
π_M/π_S			√
N/H		√	
w/h			√
$Log(GDP_{UK})$			√
$Log(GDP_{US})$			√
Residuals			
ϵ_1	√		
ϵ_2	√		
ϵ_3	√		
ϵ_4	√		

A Monte Carlo Experiment

Table 4.2 shows the Monte Carlo experiment for the models with all four regressions and the relative wage ratio. According to Table 4.2, when all four trade share regressions and the relative wage ratio are included in the auxiliary model, the power of the test is substantial but not excessive; when parameters allow inaccuracy of 10% or more, the probability of the model being rejected is dramatically increased and models with more than 10% falsity are almost all rejected. However, compared to Table 3.4, rejection rate is significantly lower than the earlier case; this reveals when certain level of miss-specification is allowed, the auxiliary model in this baseline case has lower probability to be the true model than the one in the earlier case.

Table 4.2 *Power of Indirect Inference Wald test: Classical model as true*

Percentage Miss-specified	Indirect Inference test at 5%
True	5%
1	8.7%
3	16.9%
5	31.2%
7	49.7%
10	75.0%
15	91.5%
20	95.6%

Note: All four equations and w/h apply.

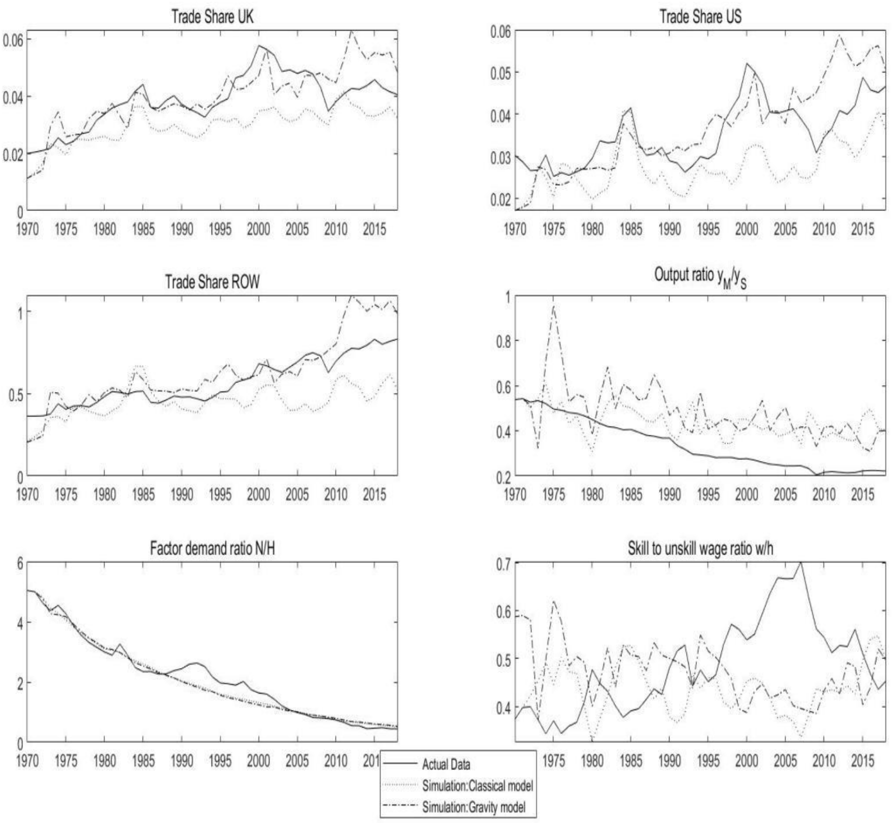

Fig. 18*Plots of Actual data*

Limited Test Power

Table 4.3 shows the Wald test results including three equations in the model framework, with the assumption that the factor share effect of relative wage is eliminated. When test power is limited, both models pass the test while the classical model has higher probability to pass than the gravity model. Figure 10 compares the trends between actual data and simulations of rivals, and the performances of the models differ slightly as the gravity model tends to over-predict the trade share ratio. Thus, the conclusion in the limited test power case is that both models pass the test, with higher probability for the classical model.

Table 4.3 *II Wald test results for the EU without w/h*		
	Equation in auxiliary model	P-value
Classical trade model	1,2,3	0.1870
Gravity model (psi=0.6)	1,2,3	0.1629
Note: World price and other countries GDP are held constant with regard to actual data.		

Terms of Trade Experiment

In the Table 4.4, the experiment, which adds the dT effect into the classical model and eliminatesthedT effect from the gravity model, illustrates that both models pass the test with higher probabilityfoundin the classical model. This conclusion is consistent with the test's original performance, which might explain why the gravity effect emanating from total trade share on productivity is limited. Therefore, one can argue there is no need to construct a specified production function for gravity model that would take into account those gravity effects as the two rival models behave similarly in principle.

Table 4.4 *II Wald test results for EU without w/h*		
	Equation in auxiliary model	P-value
Classical model (with dT)	1,2,3	0.2378
Gravity model (psi=0.6) (without dT)	1,2,3	0.1876
Note: World price and other countries GDP are held constant with regard to actual data.		

Gravity Experiment

Another experiment that can be constructedto study the gravity model entails changing the calibrated gravity effects. In the original settings in the gravity model, the semi-elasticity of three sectors - manufacturing, agriculture, and service - is calibrated to 2, which indicatesthata 1% change in total trade share in GDP will result into a 2% change in the productivity of each sector.This semi-elasticity is experimentallycalibrated to 6, whichrepresents a tripling of its elasticity. Meanwhile, real exchange rate elasticity is calibrated as psi=0.6 in the original settings. Let us decrease the real exchange rate effect by halving its elasticity to psi=0.3. The result of this gravity model experiment is reported in Table 4.5.

The above experiment for the gravity model aims to increase the quantitative size of the gravity effects, by triplingthesemi-elasticity of trade shares in relation to productivity and halving real exchange rate elasticity. Table 4.5 illustrates that the increasing gravity effect does not alter the conclusion; the probability of passing the indirect inference test for the classical model is still higher than for the gravity model using the gravity-enhanced experiment, however the simulation in the gravity model is dramatically over-predicted, as shown in Figure 19. It is shown in Figure 19 that the accelerated gravity effect drives the gravity model out in the prediction; the trade share ratios in three country groups are significantly over-predicted.

Table 4.5 *II Wald test results for EU without w/h*

	Equation in auxiliary model	P-value
Classical model	1,2,3	0.1870
Gravity model (psi=0.6)	1,2,3	0.1629
Gravity model Experiment	1,2,3	0.1474

Note: World price and other countries GDP are held constant with regard to actual data.

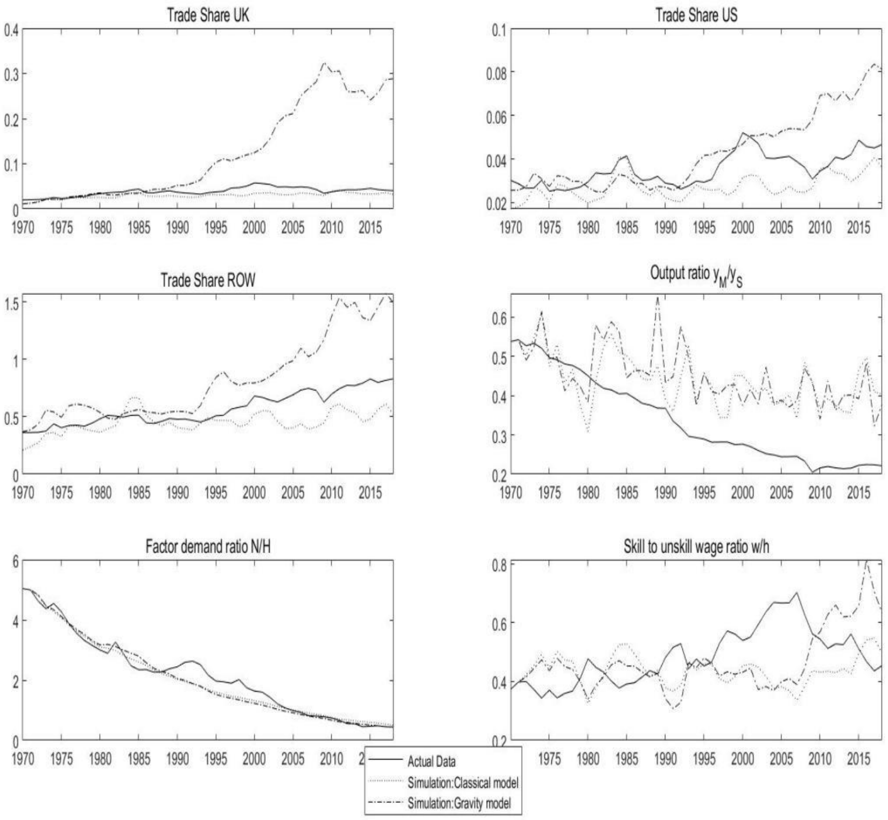

Fig. 19*Actual and simulated data: Gravity experiment*

Full Test Power

From Tables4.3-4.5, both models pass the test well; thus, it would be more logical to raise the testing power to include Equation 4 (trade share equation for the rest of the world) and factor share effect on relative wage w/h. Adding Equation 4 places more emphasis on trade share effect in relation to output, taking into more consideration residual market effects. What we learn from Table 4.6 is that the rejection rate for both increases significantly, which confirms concerns about excessive testing power leading to the dismissal of good models; however, the conclusion is still consistent with the above experiment. The classical model passes the test comfortably, and the gravity model passes the test at 95% confidence level but is weakly rejected at the 10% significance level. In Figure 20, we find that raising the testing power with more equations and factor share effect help to sketch the actual trade share more accurately in the classical model in the diagram, but excessive power dampens the gravity model simulation and over-predicts the actual data; trade share ratios are over-estimated by the gravity model when the experiment is conducted at full testing power..

Table 4.6 *II Wald test results for EU with w/h*		
	Equation in auxiliary model	P-value
Classical trade model	1,2,3,4	0.1120
Gravity model (psi=0.6)	1,2,3,4	0.0840
Note: World price and other countries GDP are held constant with regard to actual data.		

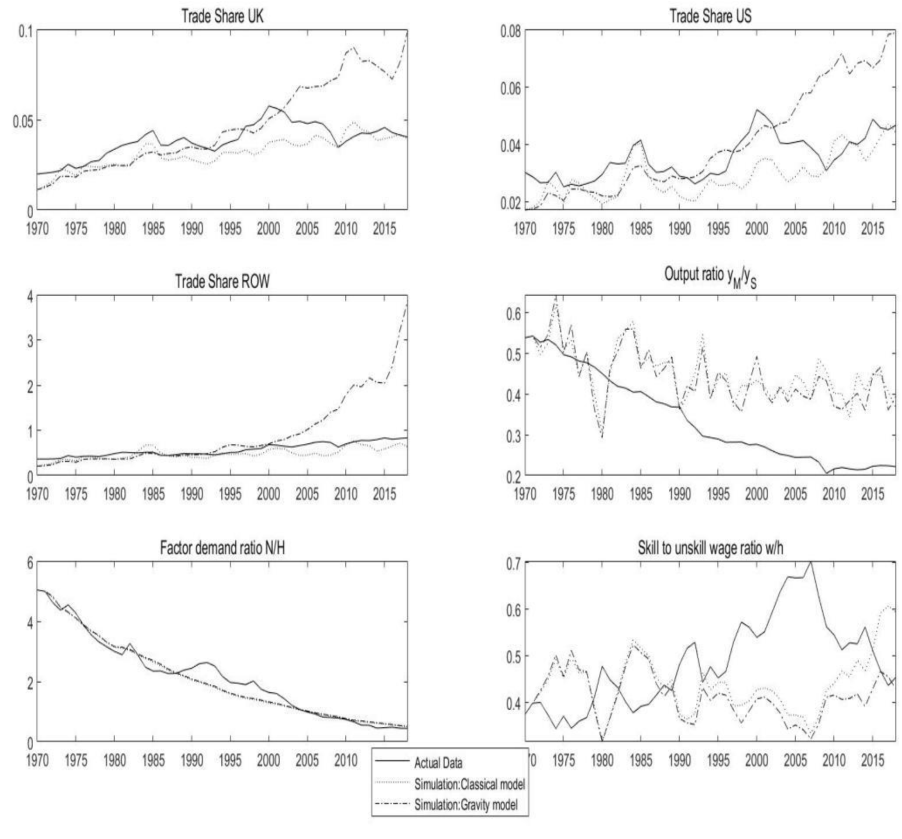

Fig. 20 *Actual and simulated data: Full Test Power*

Impulse Response Function: 10% Tariff on food and manufacturing goods

The first impulse response function is driven by a simulated policy change of a 10% tariff imposed on food and manufacturing goods. There is not much difference but the gravity model generates less welfare loss in response to the tariff.

Table 4.7 *Effects of a 10% tariff on food and manufactured goods for the EU*

Variables	Base Run	10% tariff on food and manufacturing		%Change	
		Gravity	Classical	Gravity	Classical
y	16904	16662	16707	-1.43	-1.17
y_A	202	202	202	0.00	0.00
y_M	1290	2449	2461	89.84	90.78
y_S	8121	5680	5691	-30.06	-29.92
y_D	8452	8331	8353	-1.43	-1.17
E_A	294	287	288	-2.38	-2.04
E_M	1506	1501	1501	-0.33	-0.33
E_S	6652	6543	6563	-1.64	-1.34
w	1.06	1.21	1.22	14.15	15.09
h	2.34	2.06	2.07	-11.97	-11.54
l	1.08	1.15	1.18	6.48	9.26
N	52.81	53.52	53.53	1.34	1.36
H	118.77	115.73	115.72	-2.56	-2.57
L	137.46	104.40	102.53	-24.05	-25.41
K	2394	2421	2234	1.13	-6.68
p	1.02	1.08	1.08	6.00	5.88
p_A	0.99	1.09	1.09	10.00	10.00
p_M	1.00	1.1	1.1	10.00	10.00
p_S	0.87	0.87	0.87	0.00	0.00
p_D	1.15	1.27	1.27	10.52	10.43
RXR	108.88	116.36	108.88	6.87	0.00
Welfare1				-4.40	-5.36
Welfare2				-2.21	-4.11
CHRES				-0.0039	-0.0042
Welfare3				-2.20	-4.10

Note on welfare1 measure: Welfare1=100[y^{t}/p^{t}-y/p-(N^{t}+H^{t}+L^{t}+K^{t}-N-H-L-K)]/y +(RXR^{t}-RXR)(IMPORTS/GDP), where y^{t},p^{t},N^{t},H^{t},L^{t},K^{t} are simulated.
*Note on welfare measure: Welfare loss from the tariff is computed as [Welfare2 = % output loss/GDP + consumer surplus lost-Term of Trade gain-TOT gain as % of GDP], where the consumer surplus loss = percent rise in CPI * 0.5 and the TOT gain = RXR percent rise * share of imports in GDP.*
*Note on CHRES: CHRES=base(w*N/GDP)* % change in N + base(h*H/GDP)* % change in L + base(p_m *r*K/GDP)* % change in K*
Note on welfare3 measure: Welfare3 = Welfare2 – CHRES.

Impulse Response Function: 1% Tariff on food and manufacturing goods

The second Impulse Response Function is driven by the 1% productivity shock. The aim of doing so is to evaluate how the two rival models react to the productivity shock.

***Table 4.8** Summary: IRF with 1% productivity shock*

Variable	Base	1% $\varepsilon_{\pi M}$		1% $\varepsilon_{\pi S}$		1% $\varepsilon_{\pi A}$		1% $\varepsilon_{\pi D}$	
		Gravity	Classic	Gravity	Classic	Gravity	Classic	Gravity	Classic
TS_{UK}	0.0331	7.85	2.42	3.93	1.51	2.72	0.91	4.53	1.81
TS_{US}	0.0423	5.67	2.60	4.49	1.42	2.84	0.96	5.20	2.36
TS_{ROW}	0.4316	5.82	2.13	5.58	1.44	5.33	10.72	5.44	1.06
$ln\pi_M$	-0.3194	1.09	1.00	0.28	0.00	0.22	0.00	0.19	0.00
$ln\pi_S$	0.2145	-0.14	0.00	1.03	0.98	-0.09	0.00	-0.28	0.00
$ln\pi_A$	-0.8822	0.03	0.00	-0.03	0.00	1.17	0.99	0.07	0.00
$ln\pi_D$	-0.5121	0.00	0.00	0.00	0.00	0.00	0.00	1.33	0.99
y	16904	0.42	0.21	0.39	0.24	-0.63	-0.66	0.11	0.01
y_A	202	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
y_M	1290	2.48	1.78	0.23	0.54	0.54	0.23	0.31	0.08
y_S	8121	-1.03	-0.95	0.84	0.91	-0.46	-0.37	0.14	0.07
y_D	8452	0.12	0.21	0.18	0.06	-0.63	-0.66	0.41	0.18
E_A	294	0.14	0.34	0.17	0.34	1.70	1.02	0.68	0.00
E_M	1506	0.04	0.07	0.07	0.07	-0.13	-0.19	0.20	0.07
E_S	6652	0.14	0.42	0.18	0.27	-0.72	-0.75	0.12	0.08
w	1.06	0.65	0.73	-0.18	-0.09	-0.72	-0.09	0.24	0.09
h	2.34	-0.31	-0.24	0.41	0.50	-0.52	-0.55	0.55	0.15
l	0.80	-1.73	-0.97	-1.46	-0.65	14.61	14.29	-1.26	-0.62
N	52.81	0.05	0.08	-0.03	-0.02	-0.09	-0.08	-0.03	-0.01
H	118.77	-0.10	-0.10	0.06	0.06	0.03	0.02	-0.03	0.01
L	137.46	1.91	1.33	1.46	0.85	-12.47	-12.28	-1.10	0.41
K	2394	0.29	0.46	-0.08	0.13	0.08	-0.04	-067	0.29
RXR	108.88	-4.58	0.00	-3.76	0.00	-2.08	0.00	-5.61	0.00

Note: Numbers denote percentage changes in relation to productivity shock.

Summary: Empirical Test Results

Table 4.9 *II Wald test results for EU: Full Power*		
	P-value	
	Classical Model	Gravity Model
Endogenous	0.1036	0.0214***
Exogenous	0.1120	0.0840*
*P-value with * indicates model is rejected at 10% significance level.* *P-value with *** indicates model is rejected at 5% significance level.*		

Table 4.9 illustrates that the large open economy assumption does not change the conclusion: the classical model passes the test in all experiments, and the gravity model cannot survive when test power increases. There are also some differences between the two experiments. First of all, the gravity model is strictly rejected at 5% significance level in the large open economy assumption and it is weakly rejected at 10% significance level under exogenous assumption. The second difference is the average simulation performance; Figure 12 shows that the gravity model poorly simulates the trade share data under exogenous case on average, while Figure 8 reveals a better performance in the average simulation for the gravity model.

Table 4.10*Welfare Loss for the EU: 10% tariff on food and manufacturing*		
	P-value	
	Classical Model	Gravity Model
Endogenous	-4.1%	-2.2%
Exogenous	-7.6%	-5.7%

Table 4.10 illustrates that the classical model and the gravity model would generate a welfare loss in response to a rise in the tariffs, and the classical model would even generate more loss in welfare than the gravity model in the both case. This reveals endogeneity of world variables do not change the policy implication that the EU should continue its policy of free trade rather than the retaliation.

Appendix 2: List of Models

Equation A.1-A.4 Prices: EU (UK, US, Rest of world) p_m, p_s, p_a, p_d

$$p_m = w^{0.52} * h^{0.14} * l^{0.04} * (p_m r)^{0.30} * \pi_m^{-1}$$

$$p_s = w^{0.21} * h^{0.52} * l^{0.03} * (p_m r)^{0.24} * \pi_s^{-1}$$

$$p_a = w^{0.15} * h^{0.13} * l^{0.08} * (p_m r)^{0.64} * \pi_a^{-1}$$

$$p_d = w^{0.38} * h^{0.17} * l^{0.11} * (p_m r)^{0.33} * \pi_d^{-1}$$

$$\begin{pmatrix} 0.52 & 0.14 & 0.04 \\ 0.21 & 0.52 & 0.03 \\ 0.15 & 0.13 & 0.08 \end{pmatrix} \begin{pmatrix} lnw \\ lnh \\ lnl \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 - 0.30 \\ 0 & 1 & 0 - 0.24 \\ 0 & 0 & 0 - 0.64 \end{pmatrix} \begin{pmatrix} ln(p_m) \\ ln(p_s) \\ ln(p_a) \\ ln(p_m r) \end{pmatrix} + \begin{matrix} ln\pi_m \\ ln\pi_s \\ ln\pi_a \end{matrix}$$

$$lnw = \left(\frac{1}{0.52}\right) * (\ln(p_m \pi_m) - 0.14 * lnh - 0.04 * lnl - 0.30 * \ln(p_m r))$$

$$lnh = \left(\frac{1}{0.52}\right) * (\ln(p_s \pi_s) - 0.22 * lnw - 0.03 * lnl - 0.24 * \ln(p_m r))$$

$$lnl = \left(\frac{1}{0.08}\right) * (\ln(p_a \pi_a) - 0.15 * lnw - 0.13 * lnl - 0.64 * \ln(p_m r))$$

Equation A.5-A.8 Factor demand, EU(UK,US,Rest of World) *N,H,L,K*

$$N = w^{-1} * (0.38 * p_d y_d + 0.52 * y_m p_m + 0.21 * p_s y_s + 0.15 * p_a y_a) e_m$$
$$H = h^{-1}(0.17 * p_d y_d + 0.14 * y_m p_m + 0.52 * p_s y_s + 0.13 * p_a y_a) e_s$$
$$L = l^{-1}(0.11 * p_d y_d + 0.04 * y_m p_m + 0.03 * p_s y_s + 0.08 * p_a y_a) e_a$$
$$K = (p_m * r)^{-1} * (0.33 * p_d y_d + 0.30 * p_m y_m + 0.24 * p_s y_s + 0.64 * p_a y_a) e_k$$

$$y_m = \left(\frac{1}{0.52 * p_m}\right) (N * w * e_m - 0.38 * p_d y_d - 0.21 * p_s y_s - 0.15 * p_a y_a)$$

$$y_s = \left(\frac{1}{0.52 * p_s}\right) (H * h * e_s - 0.17 * p_d y_d - 0.14 * p_m y_m - 0.13 * p_a y_a)$$

Equation A.9-A.11 Factor Supplies *N,H,L*

$$N = e_n \left(\frac{w}{b}\right)^{0.1} * POP^{0.5} * G^{0.5}$$

$$H = e_h \left(\frac{h}{w}\right)^{0.1} * G^{0.5}$$

$$L = l^{-1} * (0.11 * p_d * y_d + 0.04 * p_m * y_m + 0.03 * p_s * y_s + 0.08 * p_a * y_a) e_a$$

Equation A.12Non-traded output y_d

$$y_d = \sigma * E$$

Equation A.13 Total output y

$$y = y_d + y_m + y_s + y_a$$
$$y_d = y_m + y_s + y_a$$

$$\begin{pmatrix} y_m \\ y_s \end{pmatrix} = \begin{pmatrix} 0.38p_d + 0.52p_m & 0.38p_d + 0.21p_s \\ 0.17p_d + 0.14p_m & 0.17p_d + 0.52p_s \end{pmatrix}^{-1} \begin{pmatrix} N * w * e_m - (0.38p_d + 0.15p_a)y_a \\ H * h * e_s - (0.17p_d + 0.13p_a)y_a \end{pmatrix}$$

Equation A.14-A.15 Total Demand and traded demand E, E_T^{EU}

$$E = y$$
$$E_T^{EU} = E - y_d$$

Equation A.16-A.18 Sector Demand $E_m^{EU}, E_s^{EU}, E_a^{EU}$

$$E_m^{EU} = E_T^{EU} - E_s^{EU} - E_a^{EU}$$
$$E_s^{EU} = 0.9 * E_T^{EU} - 955.03 - 12 * (p_s^{EU} - p_T^{EU})$$
$$E_a^{EU} = 0.5 * E_T^{EU} - 128.20 - 5 * (p_a^{EU} - p_T^{EU})$$

Equation A.19 Domestic price p

$$p = p_m\left(\frac{E_m^{base}}{E^{base}}\right) + p_s\left(\frac{E_s^{base}}{E^{base}}\right) + p_a\left(\frac{E_a^{base}}{E^{base}}\right) + p_d(\frac{E_T^{base}}{E^{base}})$$

Equation A.20-A.22 Sector Prices p_m, p_s, p_a

$$p_m = p_m^{world} * (1 + T_m)$$
$$p_s = p_s^{world} * (1 + T_s)$$
$$p_a = p_a^{world} * (1 + T_a)$$

Equation A.23 Traded Price p_T

$$p_T = p_m\left(\frac{E_m}{E_T}\right) + p_s\left(\frac{E_s}{E_T}\right) + p_a(\frac{E_a}{E_T})$$

Equation A.24-A.25 Error process $ln(\pi_i, t), ln(e_i, t)$

$$\ln(\pi_{i,t}) = c_{1i} + \rho_{1i}\ln(\pi_{i,t-1}) + \varphi_{1i}t + \varepsilon_{i,t} \quad i = M, S, A, d$$

$$\ln(e_{i,t}) = c_{2i} + \rho_{2i}\ln(e_{i,t-1}) + \varphi_{2i}t + \varepsilon_{i,.t} \quad i = M, S, A, N, H, K$$

Equation A.26-A.27Trade share in Classicalem_i, ex_i

$$ln(M_i) = \theta_{1i} + \theta_{2i}\, ln(E_T) + em_i \quad i = UK, US, ROW$$
$$ln(X_i) = \theta_{3i} + \theta_{4i} ln(E_i) + ex_i \quad i = UK, US$$

Equation A.28Market Clearance in Classical

$$X_{ROW} = Y_T - E_T - (X_{UK} + X_{US} - M_{UK} - M_{US} - M_{ROW})$$

Equation A.29-30 Trade share in Gravity$ln(\frac{M_i}{E_T}) ln(\frac{X_i}{E_i})$

$$ln\left(\frac{M_i}{E_T}\right) = cm_i + \psi_1 RXR + e_{m,i}, i = UK, US, ROW$$

$$ln\left(\frac{X_i}{E_i}\right) = cx_i + \psi_2 RXR + e_{x,i}, i = UK, US, ROW$$

Equation A.31 Total Trade$T$

$$T = 0.5\frac{M_{UK}}{E_T} + 0.5\frac{M_{US}}{E_T} + 0.5\frac{M_{ROW}}{E_T} + r_1\frac{X_{UK}}{E_{UK}} + r_2\frac{X_{US}}{E_{US}} + r_3\frac{X_{ROW}}{E_{ROW}}$$

Equation A.32 Productivity error process

$$\Delta\, ln(\pi_{i,t}) = c_{1i} + v_i \Delta T + \varepsilon_{i,t}, i = M, S, A, d$$

Equation A.33 Market Clearance in Gravity

$$X_{ROW} + X_{US} + X_{UK} = M_{US} + M_{UK} + M_{ROW}$$

Appendix 3: List of results

Table 3.14 *Effects of 1% Productivity shock in manufacture for the EU*

Variables	Base Run	1% productivity shock in manufacture		%changes	
		Gravity	Classical	Gravity	Classical
TS_{UK}	0.0331	0.0357	0.0339	7.85	2.42
TS_{US}	0.0423	0.0447	0.0434	5.67	2.60
TS_{ROW}	0.4316	0.4567	0.4408	5.82	2.13
$ln\pi_M$	-0.3194	-0.3229	-0.3226	1.09	1.00
$ln\pi_S$	0.2145	0.2142	0.2145	-0.14	0.00
$ln\pi_A$	-0.8822	-0.8825	-0.8822	0.03	0.00
$ln\pi_D$	-0.5121	-0.5121	0-0.5121	0.00	0.00
y	16904	16975	16939	0.42	0.21
y_A	202	202	202	0.00	0.00
y_M	1290	1322	1313	2.48	1.78
y_S	8121	8037	8044	-1.03	-0.95
y_D	8452	8462	8470	0.12	0.21
E_A	294	294	295	0.14	0.34
E_M	1506	1507	1507	0.04	0.07
E_S	6652	6661	6680	0.14	0.42
w	1.06	1.07	1.07	0.65	0.73
h	2.34	2.33	2.33	-0.31	-0.24
l	0.80	0.79	0.79	-1.73	-0.97
N	52.81	52.84	52.85	0.05	0.08
H	118.77	118.65	118.65	-0.10	-0.10
L	137.46	140.09	139.29	1.91	1.33
K	2394	2401	2405	0.29	0.46
RXR	108.88	103.89	108.88	-4.58	0.00

Table 3.15 *Effects of 1% Productivity shock in service for the EU*					
Variables	Base Run	1% productivity shock in service		%changes	
		Gravity	Classical	Gravity	Classical
TS_{UK}	0.0331	0.0344	0.0336	3.93	1.51
TS_{US}	0.0423	0.0442	0.0429	4.49	1.42
TS_{ROW}	0.4316	0.4557	0.4378	5.58	1.44
$ln\pi_M$	-0.3194	-0.3203	-0.3194	0.28	0.00
$ln\pi_S$	0.2145	0.2167	0.2166	1.03	0.98
$ln\pi_A$	-0.8822	-0.8819	-0.8822	-0.03	0.00
$ln\pi_D$	-0.5121	-0.5121	-0.5121	0.00	0.00
y	16904	16970	16945	0.39	0.24
y_A	202	202	202	0.00	0.00
y_M	1290	1293	1297	0.23	0.54
y_S	8121	8189	8195	0.84	0.91
y_D	8452	8467	8457	0.18	0.06
E_A	294	295	295	0.17	0.34
E_M	1506	1507	1507	0.07	0.07
E_S	6652	6664	6670	0.18	0.27
w	1.06	1.06	1.06	-0.18	-0.09
h	2.34	2.35	2.35	0.41	0.50
l	0.80	0.79	0.80	-1.46	-0.65
N	52.81	52.80	52.80	-0.03	-0.02
H	118.77	118.84	118.84	0.06	0.06
L	137.46	139.47	138.62	1.46	0.85
K	2394	2392	2397	-0.08	0.13
RXR	108.88	104.79	108.88	-3.76	0.00

Table 3.16 *Effects of 1% Productivity shock in agriculture for the EU*					
Variables	Base Run	1% productivity shock in agriculture		%changes	
		Gravity	Classical	Gravity	Classical
TS_{UK}	0.0331	0.0340	0.0334	2.72	0.91
TS_{US}	0.0423	0.0435	0.0427	2.84	0.96
TS_{ROW}	0.4316	0.4546	0.4347	5.33	10.72
$ln\pi_M$	-0.3194	-0.3201	-0.3194	0.22	0.00
$ln\pi_S$	0.2145	0.2143	0.2145	-0.09	0.00
$ln\pi_A$	-0.8822	-0.8925	-0.8910	1.17	0.99
$ln\pi_D$	-0.5121	-0.5121	-0.5121	0.00	0.00
y	16904	16798	16793	-0.63	-0.66
y_A	202	202	202	0.00	0.00
y_M	1290	1297	1293	0.54	0.23
y_S	8121	8084	8091	-0.46	-0.37
y_D	8452	8399	8396	-0.63	-0.66
E_A	294	299	297	1.70	1.02
E_M	1506	1504	1503	-0.13	-0.19
E_S	6652	6604	6602	-0.72	-0.75
w	1.06	1.05	1.06	-0.72	-0.09
h	2.34	2.33	2.33	-0.52	-0.55
l	0.80	0.92	0.92	14.61	14.29
N	52.81	52.76	52.77	-0.09	-0.08
H	118.77	118.80	119.79	0.03	0.02
L	137.46	120.32	120.58	-12.47	-12.28
K	2394	2396	2393	0.08	-0.04
RXR	108.88	106.62	108.88	-2.08	0.00

Table 3.17 *Effects of 1% Productivity shock in non-traded for the EU*					
Variables	Base Run	1% productivity shock in non-traded		%changes	
		Gravity	Classical	Gravity	Classical
TS_{UK}	0.0331	0.0346	0.0337	4.53	1.81
TS_{US}	0.0423	0.0445	0.0433	5.20	2.36
TS_{ROW}	0.4316	0.4551	0.4362	5.44	1.06
$ln\pi_M$	-0.3194	-0.3200	-0.3194	0.19	0.00
$ln\pi_S$	0.2145	0.2139	0.2145	-0.28	0.00
$ln\pi_A$	-0.8822	-0.8828	-0.8822	0.07	0.00
$ln\pi_D$	-0.5121	-0.5189	-0.5172	1.33	0.99
y	16904	16922	16906	0.11	0.01
y_A	202	202	202	0.00	0.00
y_M	1290	1294	1291	0.31	0.08
y_S	8121	8132	8127	0.14	0.07
y_D	8452	8487	8467	0.41	0.18
E_A	294	296	294	0.68	0.00
E_M	1506	1509	1507	0.20	0.07
E_S	6652	6660	6657	0.12	0.08
w	1.06	1.06	1.06	0.24	0.09
h	2.34	2.35	2.34	0.55	0.15
l	0.80	0.79	0.80	-1.26	-0.62
N	52.81	52.80	52.81	-0.03	-0.01
H	118.77	118.81	118.78	-0.03	0.01
L	137.46	135.96	138.03	-1.10	0.41
K	2394	2378	2401	-067	0.29
RXR	108.88	102.77	108.88	-5.61	0.00

Table 4.11 *Effects of 1% Productivity shock in manufacture for the EU*

Variables	Base Run	1% productivity shock in manufacture		%changes	
		Gravity	Classical	Gravity	Classical
TS_{UK}	0.0280	0.0331	0.0293	18.21	4.64
TS_{US}	0.0286	0.0323	0.0294	12.94	2.79
TS_{ROW}	0.4889	0.5470	0.5124	11.88	4.81
$ln\pi_M$	-0.5266	-0.5349	-0.5317	1.58	0.97
$ln\pi_S$	0.1875	0.1872	0.1875	-0.16	0.00
$ln\pi_A$	-0.1302	-0.1304	-0.1302	0.15	0.00
$ln\pi_D$	-0.0905	-0.0905	-0.0905	0.00	0.00
y	18207	18561	18402	1.94	1.07
y_A	202	202	202	0.00	0.00
y_M	1692	1803	1772	6.56	4.73
y_S	8210	7964	8012	-2.99	-2.41
y_D	9103	8902	8891	-2.21	-2.33
E_A	324	331	338	2.16	4.32
E_M	1540	1605	1589	4.22	3.18
E_S	7240	7371	7389	1.81	2.06
w	1.07	1.16	1.12	8.41	4.67
h	1.98	1.90	1.92	-4.04	-3.03
l	0.84	0.81	0.82	-3.57	-2.98
N	52.81	53.98	53.49	2.22	1.29
H	118.92	117.08	117.62	-1.55	-1.09
L	139.08	140.64	141.39	3.28	1.66
K	1741	1903	1892	9.30	8.67
RXR	108.88	97.87	108.88	-10.11	0.00

Table 4.12*Effects of 1% Productivity shock in service for the EU*					
Variables	Base Run	1% productivity shock in service		%changes	
		Gravity	Classical	Gravity	Classical
TS_{UK}	0.0280	0.0293	0.0284	4.64	1.43
TS_{US}	0.0286	0.0294	0.0289	2.79	1.05
TS_{ROW}	0.4889	0.5193	0.5003	6.22	2.33
$ln\pi_M$	-0.5266	-0.5285	-0.5266	0.36	0.00
$ln\pi_S$	0.1875	0.1904	0.1893	1.55	0.96
$ln\pi_A$	-0.1302	-0.1303	-0.1302	0.08	0.00
$ln\pi_D$	-0.0905	-0.0905	-0.0905	0.00	0.00
y	18207	18346	18241	0.76	0.19
y_A	202	202	202	0.00	0.00
y_M	1692	1729	1734	2.19	2.48
y_S	8210	8478	8451	3.26	2.94
y_D	9103	9025	8976	-0.86	-1.39
E_A	324	327	331	0.93	2.16
E_M	1540	1552	1541	0.78	0.06
E_S	7240	7587	7539	4.79	4.13
w	1.07	1.05	1.06	-1.87	-0.93
h	1.98	2.03	2.01	2.53	1.52
l	0.84	0.82	0.83	-2.02	-1.43
N	52.81	52.39	51.98	-0.79	-1.57
H	118.92	120.16	119.38	1.04	0.39
L	139.08	141.28	139.65	1.58	0.41
K	1741	1721	1732	-1.15	-0.52
RXR	108.88	98.76	108.88	-9.29	0.00

Table 4.13*Effects of 1% Productivity shock in agriculture for the EU*					
Variables	Base Run	1% productivity shock in agriculture		%changes	
		Gravity	Classical	Gravity	Classical
TS_{UK}	0.0280	0.0291	0.0283	3.93	1.07
TS_{US}	0.0286	0.0292	0.0287	2.10	0.35
TS_{ROW}	0.4889	0.5176	0.4932	5.87	0.88
$ln\pi_M$	-0.5266	-0.5279	-0.5266	0.24	0.00
$ln\pi_S$	0.1875	0.1873	0.1875	-0.11	0.00
$ln\pi_A$	-0.1302	-0.1322	-0.1315	1.54	0.99
$ln\pi_D$	-0.0905	-0.0905	-0.0905	0.00	0.00
y	18207	18025	18002	-1.00	-1.13
y_A	202	202	202	0.00	0.00
y_M	1692	1756	1731	3.78	2.30
y_S	8210	8214	8206	0.05	-0.05
y_D	9103	8883	8867	-2.42	-2.59
E_A	324	341	326	5.25	0.62
E_M	1540	1526	1530	-0.91	-0.65
E_S	7240	7231	7208	-0.12	-0.44
w	1.07	1.06	1.06	-1.03	-0.75
h	1.98	1.95	1.96	-1.72	-1.01
l	0.84	0.942	0.93	12.14	10.36
N	52.81	52.08	52.03	-1.38	-1.48
H	118.92	118.99	119.03	0.06	0.09
L	139.08	122.21	122.36	-12.13	-12.02
K	1741	1713	1703	-1.61	-2.18
RXR	108.88	100.42	108.88	-7.77	0.00

Table 4.14 *Effects of 1% Productivity shock in non-traded for the EU*					
Variables	Base Run	1% productivity shock in non-traded		%changes	
		Gravity	Classical	Gravity	Classical
TS_{UK}	0.0280	0.0321	0.0292	14.64	4.29
TS_{US}	0.0286	0.0311	0.0291	8.74	1.75
TS_{ROW}	0.4889	0.528	0.5117	7.99	4.66
$ln\pi_M$	-0.5266	-0.5274	-0.5266	0.15	0.00
$ln\pi_S$	0.1875	0.1874	0.1875	-0.05	0.00
$ln\pi_A$	-0.1302	-0.1305	-0.1302	0.23	0.00
$ln\pi_D$	-0.0905	-0.0919	-0.0915	1.55	1.10
y	18207	18354	18237	0.81	0.16
y_A	202	202	202	0.00	0.00
y_M	1692	1793	1765	5.97	4.31
y_S	8210	8223	8217	0.16	0.09
y_D	9103	8972	8937	-1.44	-1.82
E_A	324	329	327	1.54	0.93
E_M	1540	1556	1543	1.04	0.19
E_S	7240	7354	7327	1.57	1.20
w	1.07	1.10	1.08	2.80	0.93
h	1.98	2.06	2.02	4.04	2.02
l	0.84	0.83	0.82	-0.95	-2.38
N	52.81	52.34	52.74	-0.89	-0.13
H	118.92	119.18	119.03	0.22	0.09
L	139.08	123.64	122.46	-11.10	-11.95
K	1741	1707	1704	-1.95	-2.13
RXR	108.88	100.29	108.88	-7.89	0.00

Appendix 4: List of variables

y_A	EU agriculture output, real ,billion dollars, constant 2015
y_M	EU manufacturing output, real ,billion dollars, constant 2015
y_S	EU service output, real ,billion dollars, constant 2015
y_D	EU non-traded output, real ,billion dollars, constant 2015
y_{EU}	EU GDP, real ,billion dollars, constant 2015
BOP	EU balance of payment, real ,billion dollars, constant 2015
p_A	agriculture price index, 2015=100
p_M	manufacturing price index, 2015=100
p_S	service price index, 2015=100
p	EU CPI, 2015=100
p_D	non-traded price index, 2015=100
w	Wages of unskilled labour, hourly earning, constant 2015
h	Wages of skilled labour, hourly earning, constant 2015
l	Rent on land ($ per hectare), constant 2015
r	Real rate of return on capital, 2015=100
REX	Real effective exchange rate, 2015=100
N	Unskilled labour, million persons
H	Skilled labour, million persons
L	Land, million hectares
K	Capital, real,billion dollars, constant 2015
POP	Working populations, million persons
b	Unemployment benefit, real, billion dollars, constant 2015
X_{UK}	EU export to UK, real, billion dollars, constant 2015
X_{US}	EU export to US, real, billion dollars, constant 2015
X_{ROW}	EU export to ROW, real, billion dollars, constant 2015
M_{UK}	EU Import from UK, real, billion dollars, constant 2015
M_{US}	EU Import from US, real, billion dollars, constant 2015
M_{ROW}	EU Import from ROW, real, billion dollars, constant 2015
E	Expenditure on EU goods
E_A	Expenditure on EU agriculture goods
E_M	Expenditure on EU manufacturing goods
E_S	Expenditure on EU service goods
E_T	Expenditure on EU Traded goods

Appendix 5: List of abbreviation

AR	Auto-regressive
CES	Constant Elasticity of Substitution
CGE	Computable General Equilibrium
EABCN	Euro Area Business Cycle Network
EU	European Union
EUR	Euro (currency)
HOS	Heckscher-Ohlin-Samuelson model
IIW	Indirect Inference Wald test
IMF	International Monetary Fund
ML	Maximum Likelihood
MX	Minford and Xu's research (2018)
OECD	Organization for Economic Co-operation and Development
OLS	Ordinary Least Square
ROW	Rest of World
UK	United Kingdom
UNCTAD	United Nations Conference on Trade and Development
US	United States
VAR	Vector Auto-regressive

Appendix 6: Data descriptions

y_A	EU agricultural output	World Bank	real ,billion dollars, constant 2015
y_M	EU manufacturing output	World Bank	real ,billion dollars, constant 2015
y_S	EU service output	World Bank	real ,billion dollars, constant 2015
y_D	EU non-traded output	Calculated	$y_D = 0.5 * y_{EU}$, real, billion dollars, constant 2015
$y_{EU/UK/US/World}$	EU/UK/US/World GDP	World Bank	real ,billion dollars, constant 2015
y_{ROW}	Rest of World GDP	World Bank/Calculated	$y_{ROW} = y_{world} - y_{EU} - y_{UK} - y_{US}$, real, billion dollars, constant 2015
G	EU Government spending	AWM Database	$Government\ Spending\ Ratio = AWM\ goverment\ Spending/AWM\ GDP$ $G = y_{EU} * Government\ Spending\ Ratio$, real, billion dollars, constant 2015
p_A	agriculture price index	UNCTAD	Global Commodity Monitor price Index (All Food), base year 2015/US price
p_M	manufacturing price index	UNCTAD	GCM price Index (Minerals, Ores and Metals), base year 2015/US price
p_S	service price index	ONS	Proxy by UK service producer price index, base year 2015/US price
p_D	non-traded price index	Calculated by Equation A.19	$p_d * \frac{y_d}{E_T + y_d} = p - p_T * \frac{E_T}{E_T + y_d}$,base year 2015/US price
p	EU CPI	AWM Database	AWM (PCD)
p_{US}	US CPI	OECD	Base year 2015/US price
$decile95$	Inter-decile ratio	World inequality	Decile P90/P50, proxy EU by France and Germany
XE	EU exchange rate	AWM Database	AWM (EXR)
w	Unskilled wage index	AWM Database	AWM (WRN), converted to XE, dollar index, constant 2015
h	Skilled wage index	Calculated	$h = decile95 * w$, dollar index, constant 2015
l	Rent on land	NBS	Proxy by UK rent of land price index, dollar index, constant 2015
r	Return on capital	AWM Database	AWM (STN)

REX	Real effective exchange rate	AWM Database	AWM (EEN), $REX = 1/EEN$
POP	EU working population	AWM Database	AWM (LFN), million persons
$Tertiary$	School enrolment tertiary%	World Bank	Tertiary EU population = EU total population * EU tertiary gross ratio % Tertiary UK population = UK total population * UK tertiary gross ratio %
N	Unskilled labour	Calculated	$N = (1 - \frac{H}{Tertiary\ EU\ Population}) * POP$, million persons
H	Skilled labour	World Bank/Calculated	$EU\ Skilled\ labour = \frac{UK\ Skilled\ labour}{Tertiary\ UK\ population} * Tertiary\ EU\ population$
L	Agricultural land	World Bank	Million hectares
K	Capital	World Bank	$K = Capital\ Formation\ ratio * GDP$, real,billion dollars, constant 2015
X_{UK}	EU export to UK	IMF	real, billion dollars, constant 2015
X_{US}	EU export to US	IMF	real, billion dollars, constant 2015
X_{ROW}	EU export to ROW	IMF	real, billion dollars, constant 2015
M_{UK}	EU Import from UK	IMF	real, billion dollars, constant 2015
M_{US}	EU Import from US	IMF	real, billion dollars, constant 2015
M_{ROW}	EU Import from ROW	IMF	real, billion dollars, constant 2015
BOP	EU balance of payment	Calculated	$BOP = X_{UK} + X_{US} + X_{ROW} - (M_{UK} + M_{US} + M_{ROW})$
$IM_A \& EX_A$	EU agriculture import/export	World Bank	real, billion dollars, constant 2015
$IM_S \& EX_S$	EU service import/export	World Bank	real, billion dollars, constant 2015
$IM_M \&\ EX_M$	manufacture import/export	World Bank	*Goods import (export) minus agricultural import (export)*
BOP_A	BOP by agriculture	Calculated	$BOP_A = EX_A - IM_A$
BOP_M	BOP by manufacture	Calculated	$BOP_M = EX_M - IM_M$
BOP_S	BOP by service	Calculated	$BOP_S = EX_S - IM_S$
$BOP2$	EU balance of payment	Calculated	$BOP_2 = BOP_A + BOP_M + BOP_S$