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TESTING CGE TRADE MODELS OF THE US – THE INDIRECT INFERENCE APPROACH

by

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Abstract

Evaluating trade policies in addressing the welfare effects require both general equilibrium models that characterise the trade relationships across nations and regions and methods to assess the quantitative credibility. Two rival Computable General Equilibrium (CGE) models of trade against the US facts are set up in this study, one is derived from the classical theories of comparative advantage, the other is formed according to recent gravity theories. These two versions of CGE models are tested by indirect inference, a method that allows the use of small samples of data and can powerfully reject a model that is not correctly specified. The test procedure mainly focuses on a comparison between real data behaviour and simulated data behaviour by using an 'auxiliary model'. The US is a large continental economy, its effect on other countries' GDPs and world prices should be incorporated when the model is being tested. A convenient approach of doing so is to introduce the 'part-of-model' test into the testing procedure, where other countries' GDP and world prices are simulated by a reduced form Vector Autoregression model. The Monte Carlo experiments show that these tests have a high power. Empirical findings show that both versions of model pass the test with close probabilities. The US seems to have close ties to the neighbouring economies modelled in the Gravity version and this will not compromise the model's ability to match its trade facts. Tariff simulation indicates an approximately 10% welfare loss from an increase in tariffs imposed by the US government, this implies that protection harms welfare, to a similar extent in both versions of the trade model we have examined.

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1 Introduction

Trade policy occupied a significant part of the US foreign policy and is essential to reaffirming the US leadership from their perspective. It also acts as a bond between domestic and foreign economic policies, affecting everything from the supply side of the economy to individual families. As commented on by Liu and Woo (2018), three primary concerns prompted the United States to initiate the trade war: i) China's long-term huge trade surplus was inhibiting the US job creation; ii) concerns that China is obtaining American technologies at effective discounts by using illegal and unfair approaches; iii) concerns that China's attempts to weaken the national security of the US and its international status. There is no doubt that both the US and China have been suffered from the trade war. $27 billion worth of US agricultural exports were negatively impacted by China’s tariffs imposed on July 6th, 2018, consequently the US provided their farmers with $12 billion in subsidies. China relaxed its credit growth in 2018 to counteract the adverse impacts of US tariffs, effectively suspending the efforts to reduce its debt-to-GDP ratio, which is at a dangerously high 300%, compared with 170% in 2009.

Evaluating trade policies in addressing the welfare effects require both general equilibrium models that characterise the trade relationships across nations and regions and methods to assess the quantitative credibility. There are many types of economic models, the kind that will be exploited in this study is the computable general equilibrium (CGE) model. It is an “economy-wide” model characterises all economic participants’ motivations and behaviour in an economy and the interconnection among them. The leading multi-country models of this kind is the Global Trade Analysis Project (GTAP) build and run at Purdue University. Its global database covers 113 countries and 57 sectors, it includes the input-output table for each country, tariffs and other data relevant to the trade restrictions, trade and immigration flows, and greenhouse gas emission. The differences among various CGE models consider the extent of “gravity”, a term that can capture the effect of distance and size of GDP, affect the relationships built in the CGE models. The term "gravity" generates from the nonlinear form of the gravity equation that has a similar structure as the Newton's law of universal gravitation: exports are proportional to the GDP (a measure of economic “mass”) of exporting and importing countries, and inversely proportional to the geographic distance (but not the square of the distance, like in physics) between them. That is to say, gravity suggests larger countries to trade more, but countries that are farther apart to trade less, probably because of higher transportation costs between them. The gravity trade theories imply that the substitution between countries’ goods is weak, and possibly weaker when the distance between countries is larger; besides, the theories assume that there are channels from trade to technology, so that trade activities with neighbours significantly contribute to the growth in productivity. The overall outcome of trade policies is greatly influenced by these “gravity effects” in the CGE models. Therefore, the call for methods to test the quantitative credibility of these models is imperative to some extent.

The estimated relationships using gravity equation are of a reduced form essence among solved values of endogenous variables, because the underlying structural CGE model determine GDP and trade prices. The identification problem might arise from here because these relationships can be used to work backwards to build other CGE models that can also generate such relationships. In order to test different CGE structural models, it is necessary to make empirical comparisons based on the ability of different models to match the regression on endogenous variables. Minford and Xu (2018) test two rival CGE models using such testing mechanism. One is the “classical” CGE trade model and the other is the “gravity” version of the CGE trade model. These two models are formed to feature the trade time series behaviour for major trading economies across major good categories. The classical model largely adopts the specification of the goods and factor markets operating in the Hecksher-Ohlin-Samuelson model, the gravity version of the model uses the same structure but with the main gravity assumptions imposed – one is the assumption of imperfect competition, imply the limited substitutability among different country products; the other is the effect of trade intensity on productivity. These two models are tested by the indirect inference method using UK facts, where world prices and behaviour of other countries are exogenous. The contribution here, of this study, is to extend this indirect inference method to the US facts. However, as a large continental country, US economy has a non-negligible effect on world prices and other countries. The application of the part-of-model test addresses this problem by simulating the US model as a part of the world trade model to be tested and simulating world prices and other countries' GDPs from a Vector Autoregression (VAR) model, this VAR model acting as the reduced form of the full unknown true world model. The test results could help with the decision making on whether the models can be safely used for evaluating changes in policies.

The CGE model characterised in this study is a comparative static model, where exogenous shocks instantaneously affect the endogenous variables, hence the observed shocks are accumulated effects of lagged and current real-time shocks, representing the adjustment process over time. Consequently, they are trend-stationary or non-stationary and autocorrelated, their autocorrelation processes are captured in the model as parameters. The resulting linear approximation reduced form of the model can be derived as a VAR. Some major features of the model can be summarised as follows: product differentiation exists both by type and origin. This can be achieved by adopting the Armington (1969) set-up, a CES demand system with two layers: one for product type and the other for product origin. The difference between these two layers is the elasticity of substitution. Under this set-up one can obtain the demand for intermediate goods on different types, then the demand for goods from different origins can also be obtained. The market-clearing condition for product types can be satisfied by moving the product-type price in the world market. The market-clearing condition for product origin specified in general CGE models is that the output (GDP) should equals the aggregate demand for output (AD). This implies the market-clearing condition in each origin can be satisfied by the real exchange rate (RXR) of the origin, as the market-clearing gives GDP = AD + RXR*Export(X) – Import(M). Since GDP = AD, one can have RXR*X = M. Then the RXR can be solved by this current account equilibrium condition.

However, this two-layered demand system for intermediate goods will not be adopted for testing purposes here due to the complexity of testing a large amount of demand equations. The number of the demand equations is determined by the number of commodity types (i) and the number of origins (j). These two numbers give the total number of the demand equations, $i \times j$, this potentially large number of model residuals will raise the problem regarding to the power of the test. In order to provide an equivalent comparison with a specification that close to the reality as much as possible, the model characterises the demand for retail product in such a way that the intermediate products are branded to create the retail products, and these retail products are demanded from different origin countries. Thus the model has two kinds of firms, one is the firm who produce intermediate goods, and then sell these to the other kind, the firm who brand those intermediate goods and sell these differentiated final goods to consumers. This maintains the structure of this intermediate good CGE model the same across its two versions – the ‘classical’ and the ‘gravity’, where the default assumption of perfect competition is also preserved. The retail products are branded according to their country of origin for all country markets except for the Rest of World (ROW) market in the classical version of our CGE model. Products in the ROW are branded in an 'country-free' fashion so that intermediate products unsold in other country markets can be sold there. This meets the assumption of perfect substitutability for the classical model in product origin level. Since in the gravity model, the assumption is that there is an imperfect substitutability among country products, the retail products from the ROW are branded in the same way as branding retail products from other origins. Therefore, the perfect substitutability can be justified for the classical model because we have a "residual market", the ROW, who can absorb the unsold countries product at the 'world prices'; while in gravity model, the ROW is treated exactly the same as other countries.

These two versions of CGE models are tested by indirect inference, a method that allows the use of small samples of data and can powerfully reject a model that is not correctly specified. The test procedure mainly focuses on a comparison between real data behaviour and simulated data behaviour by using an 'auxiliary model'. The form can be the Impulse Response Functions or moments, and it also can take the form of regression equations as is adopted here. It starts with estimating the auxiliary model using the real data, then the second step is to simulate the structural model that is being tested by bootstrapping the shock innovations involved in the model. This process will create a set of simulated data that can be compared with the real data based on the same auxiliary model, in a way that the distribution of the parameters of the auxiliary model obtained by estimating the auxiliary model using the simulated data will be compared with the parameters obtained by estimating in real data. If the comparison indicates a likelihood level above a certain threshold, the model will not be rejected. Since the US is a large continental economy, its effect on other countries' GDPs and world prices should be incorporated when the model is being tested. A convenient approach of doing so is to introduce the 'part-of-model' test into the testing procedure. The US model can be treated as a part of the world trade model, the required other countries' variables, i.e. other countries' GDP and world prices are simulated by a reduced form Vector Autoregression model. The part-of-model test allows the testing of a subset of the equations in the whole model, the procedure being to bootstrap these equations with variables included in the equations' subset, with other equations being simulated by bootstrapping a reduced form, i.e. a VAR of the unknown true model.

This thesis is joint work with my supervisors. The main contribution of this study is the application of the indirect inference test on these CGE models to the US data. Compared with Minford and Xu (2018), who tested the CGE model on UK data, this study endogenises the world prices and GDPs by a VAR due to the significant effect of the US economy on the world economy. It therefore tests the US model using the 'part of model' test. This thesis is organised into the following sections: in section 2, a literature review of the evolution of the trade theory, a brief introduction of the CGE models, and a description of the US economy will be presented; in section 3, a detailed description of the model, including both the classical CGE trade model and the gravity version of it will be illustrated thoroughly; the main testing method, the indirect inference test, with the characterisation of the auxiliary model and the 'part-of-model' test variant will be demonstrated in section 4; and the empirical test results and the policy implications based on the test result will be discussed in section 5; other related materials, for example, the description of the data and the model list will be attached in the Appendix section.

2 Literature Review

2.1 Evolution of the trade theory

One can go back to the publications of Wealth of Nations of Smith (1776) and On the Principles of Political Economy and Taxation of Ricardo (1817) to trace back the evolution of the theory of international trade. These two volumes give birth to the formulation of free trade theory, one can tell this from the unprecedented achievement of England in the industry and trade areas. The division of labour proposed by Smith provided the fundamental for reducing labour costs in the elementary large-scale industries in England, this assures the effective competition across regions and countries. Cost calculations used by Ricardo depend on labour hours, which were regarded as a single homogeneous input factor with constant production costs. The comparative advantage, rather than the absolute advantage, was considered to account for the mutual gain from the international trade, approving complete specialisation of a specific product with a comparative advantage in producing it (in terms of the labour hours needed to produce a unit of output).

As implied by the name, gravity equations are a model that captures bilateral interactions where the size of an economy and distances between economies play a vital role in the modelling approach. They have been adopted recently as a workhorse for studying the determining factors of bilateral trade flows following their introduction by Tinbergen (1962).

2.1.1 Classical trade theory

The pioneering contribution made by Heckscher (1919) to international trade theory, and the following Ohlin (1933), Stolper and Samuelson (1941), Samuelson (1948), and Samuelson (1949) have emphasised the concept of factor intensity in its role to explain the trade patterns and how it affects the distribution of the local income through international trade. The fundamental insight the Heckscher-Ohlin model provides is that traded products are bundles of factors – land, capital, and labour. Therefore the international exchange of products is an arbitrage of indirect factors, transferring the products made by immobile factors from regions where they are abundant to regions where they are scarce. The differences in factor price can be eliminated completely by this indirect arbitrage under certain circumstances. The essential implication of the Heckscher-Ohlin model is that the exchange of products allows the selling of the factor services from domestic to abroad, this converts the local market for factor services into a world market. This leads to a more elastic demand for input factors, and also a more similar demand all over the world. The relatively elastic labour demand function indicates an output with a relatively stable marginal productivity of capital. This is because the capital- accumulation-induced growth in output is largely restricted by the reducing marginal productivity of capital. In a case of a small open economy, the drop in the marginal productivity of capital is entirely neutralised by a reallocation of production towards capital-intensive products. This is rather limited in a closed economy since the shifts in the product mix are generally harder because the selling destination is now only the domestic market. The general conclusion of that is the growth in open economies is more sustained than that in closed economies.

Ethier (1974) bring together various parts of Heckscher-Ohlin theory in a 2×2 model and use its equilibrium conditions that characterise the competitive markets to derive four core propositions of this theory. A pair of equations depicts the relations between product outputs x_1 and x_2, and labour and capital endowments L, K, through the technology matrix A, and the equilibrium conditions enforce the equality between the endowments of the factors and the demand for factors. The assumption here is that there is a full employment of both input factors owing to sufficient flexibility in technology, this pair of equation is showing as:

$$a_{L1}x_1 + a_{L2}x_2 = L$$

$$a_{K1}x_1 + a_{K2}x_2 = K$$

A second pair of equations reflect the assumption of the competitive equilibrium that all profits are exhausted for goods produced – prices equal unit costs:

$$a_{L1}w + a_{K1}r = p_1$$

$$a_{L2}w + a_{K2}r = p_2$$

The first core proposition derived is the so-called Heckscher-Ohlin theorem, illustrating that countries that are labour-abundant will export labour-intensive goods, here labour-abundant means a higher labour-capital endowment proportion. This conclusion is derived from the supply side of the model, because of differences in tastes among countries, even those countries that share the same technology may offset the divergences in systematic relative production that reflect the asymmetries of factor endowments. If both countries encounter the same free-trade goods prices and share the identical technology, will the country with the higher labour-capital ratio produce relatively larger quantity of labour-intensive goods? Yes, if both goods are produced in each country and their factor intensities are distinct, the second pair of equations shows that factor prices are purely tied to good prices. This bonds to the second core proposition, the Factor Price Equalisation theorem, which is summarised in Samuelson (1948). If the good prices are constant, the production process specified by the first pair of equations is determined by the inverse of the matrix A (characterising the technology), the country that is labour-abundant will produce a larger amount of labour-intensive products x_1 relative to the other country. One problem with the strong form of the theorem is that trade pattern is affected by the tastes. A weak form of the theorem is therefore adopted to get around of this problem, it demonstrates that the country with a lower autarky wage will export the labour-intensive good. The third proposition (the Stolper-Samuelson theorem) states that the real wage will be increased if the relative price of the labour-intensive good increases. The fourth core proposition (the Rybczynski Theorem (Rybczynski 1955)) states that if goods prices remain unchanged (which leads to unchanged factor prices), an increase in labour endowment (while there is no change in capital supply) result in a downward trend of the capital-intensive activity. These two propositions do not stipulate that the technology is same between countries.

Failure of the Heckscher-Ohlin theory to model the realities of international trade was responded to at different levels in the following decades. At an empirical level, Leontief (1953) use 1947 US trade data to perform the first empirical test of the Heckscher-Ohlin theorem. According to the theory, capital-abundant country exports capital-intensive goods. In opposite to what the theory predicts, as a capital-abundant country, the US exports more labour-intensive commodities relative to that of its imports. The number of industries used tends to be more than the number of factors used in subsequent empirical studies, for example, in Leontief (1956), Stern and Maskus (1981) and Trefler (1993), the number of industries they use all largely exceeds the number of factors they apply. Chipman (1987) argued that if the results were not robust for the multi-goods cases, the Heckscher-Ohlin model would lose most of its appeal. However, it should be noted that the theory applies to immobile factors, so that if capital is mobile, it drops out as a factor determining comparative advantage.

2.1.2 Gravity theory

The estimation of the gravity equations using bilateral trade data since Tinbergen (1962) is not the mainstream work conducted in trade research until 1995. One reason of this phenomena is that the concept of the gravity equation is closer to the physics rather than economics. Deardorff (1984) point out the "theoretical heritage" of gravity equations is "dubious". Two years before the Tinbergen's work, Savage and Deutsch (1960) construct a multiplicative model that characterise the bilateral trade, although this model is purely probabilistic, the set-up of a conventional economic model of gravity theory credits on Anderson (1979). His empirical finding shows that trade between two regions is reducing when the trade barriers between these two regions are significant relative to the average trade barriers between these two regions and their other trading partners. In other words, if a region is resistant to trade with other regions, it is forced to trade with a designated bilateral trading partner. However, this model was not widely recognised by other trade economists at that time, Leamer and Levinsohn (1995) critically argue that the work by Anderson (1979) "is formally fruitful but seems too complex to be part of our everyday toolkit." Compared with the situation in 1995, gravity trade theory is now playing an important and integral role in modern international trade theory.

A remarkable event needs to be written in the evolution history of the gravity theory is the introduction of the "missing trade" by Trefler (1995). A main empirical issue raised from the Heckscher-Ohlin-Vanek (HOV) model is that it over-predicts the trade volume of factor services compared with those observed in the data. Trefler used the term "home bias" instead of distance to address the issue of the missing trade but his work leads to the desire to understand the impediments to trade. Gravity theories have long been criticised that it is lack of the backup of the theoretical fundamentals, just as reminded by Leamer and Levinsohn (1995), "empirical results will remain unpersuasive if not accompanied by a graph." McCallum (1995) states the essential status of national borders in multilateral trade, using the data on interprovincial trade that was not exploited previously in gravity equations. This does not only testify that gravity equation is useful in estimating the effects of policies relevant to trade integration, but also triggered a large amount of survey on understanding "border effects". The first and the foremost paper explain the gravity methodology by Anderson and Van Wincoop (2003) was framed in order to resolve the puzzle McCallum had disclosed.

Conventional judgement of the lack of micro-foundations of gravity equations was dismissed with the paper written by Eaton and Kortum (2002) and Anderson and Van Wincoop (2003). These models shed a light on the estimation methods considering the model structures. It became clear in 2004, when Feenstra (2004) and Redding and Venables (2004) point out that the multilateral resistance terms that are found in various theoretical models can be captured by the importer and exporter fixed effects. The empirical work is then rapidly adopted due to its growing consistency with the theory and its simplicity to implement.

2008 has seen for the rapid growth of the research on heterogeneous firms with the determine factor of bilateral trade flows, the publications of Chaney (2008), Helpman et al. (2008), and (Melitz and Ottaviano 2008) make a large contribution to this work, these three papers tell the compatibility of their heterogeneous firms' models with gravity. Bernard et al. (2007), Mayer and Ottaviano (2008), and Chaney (2008) show that the gravity now is useful in gauging the discrepancy between intensive margin and extensive margin of responsive adjustment to trade shocks.

2.2 Computable General Equilibrium Model

The Computable General Equilibrium (CGE) model is chiefly about shedding light on policy issues in real world. It is an "economy-wide" model that characterises all economic participants' motivations and behaviour in an economy and the interconnection among them. It describes how firms respond to demand – purchasing input factors, employing workers, and operating capital equipment. The revenue achieved from sales of firms' products ultimately flows to households to finance their purchase of goods and services, spending on taxes, and the rest as savings. Revenue generated by taxation is spent on government spending and savings give rise to investor spending. The joint demand by households, government, and investors is satisfied by firms, which purchase inputs and hire workers and capital used in the production process to complete the circular flow of income and expenditure. The CGE model is based on equations derived from economic theory and these equations might depict supply from producers and demand from consumers, or some general macroeconomic identities. All the equations are solved simultaneously to reach a broad economy equilibrium, which is expressed as at some set of prices, quantity of supply equals to quantity of demand in every market.

2.2.1 The first CGE model

In his book, Johansen (1960) develops a 22-sector model of Norway which is widely credited as the first CGE model. The most significant specification that differs from other economy-wide models at that time is the clarification of separate agents' behaviour. In his model, households maximise their utility given their budget constraint, firms satisfy the demand and minimise their production costs by choosing the inputs, and capitalists assign the capital stock in the economy among industries according to their rate of return. Prices determined by the supply and demand system coordinate the behaviour of these participants of the economic activities. Opposed to this multiple-agent specification, the economy-wide models before and at that time treat the whole economy as an individual agent. This school of model is led by Leontief (1936), Leontief (1941), Sandee et al. (1959) and Manne (1963), they work the model using linear programming systems with the input and output analysis. In these models, the necessary output produced by the economy satisfy the exogenous final demand or optimise the welfare function of the whole economy.

2.2.2 The MONASH project

Same as Norway, Australian government also highly rely on CGE models to derive policy implications. The MONASH models applied and extended Johansen's approach and brought these techniques to the world. The very first MONASH model, ORANI, introduced by Dixon et al. (1977) and Dixon et al. (1982), present a set of improvements to Johansen's model: Firstly, they add a computational procedure that get rid of errors raised in Johansen's linearisation system while still maintain the simplicity of the model; secondly, they endogenise the trade flows by introducing the Armington setup to the model, namely the imperfect substitution between domestic and imported products; thirdly, the larger scope of the model allows the analysis of policy relevant aspects; fourth, flexible closures, and fifth, the complexity of the functional form allows the production technologies to be specified more precisely. ORANI was adopted for the Australia's tariff debate in 1970s.

2.2.3 World Bank version of the CGE modelling

Apart from the application of CGE modelling in Norway and Australia, World Bank is another institution that heavily rely on the CGE model for policy derivation. Lofgren and Diaz-Bonilla (2008), Cicowiez et al. (2008), and Lofgren (2010) illustrate the World Bank's programme for assessing the Millennium Development Goal (MDGs)'s progress. These goals were initially set at the UN Millennium Summit in 2000, in 2004 it found the Maquette for MDG Simulations (MAMS) framework for CGE modelling of the MDGs and established a pilot project in Ethiopia. The cross-country comparisons analysis shows that the achievement of the MDGs significantly relies on the initial situation of each country. This finding implies that pursuing goals for reducing poverty and improving human development would be more effective if countries set the goals based on their specific situation. The most desirable outcomes should be given by a relatively balanced development programme that public infrastructure and services of human development. The other conclusion that can be drawn from the analysis is that elements involved in human development programmes, for example, education and health care, bring about substantial demand for highly skilled labour and create troublesome distributional inequalities. The MAMS has also been adopted to evaluate the potential appreciation for currencies from foreign aid, which might give rise to reduced competitiveness.

Tarr (2007) performs a study on evaluating the effects of Russian accession to the World Trade Organization based on the World Bank CGE framework. In his model, the service products are produced by firms owned by the country and foreign-owned firms located within the country, and it is assumed that the technologies are superior in the foreign-owned firms. However, as they suffer a high discriminatory taxes policies and red-tape requirement, the home-owned firms can still survive. Foreign-owned firms weed out home-owned firms once the discrimination policies are lifted, large welfare benefits follow. The empirical work from the model shows that the leading benefit from the accession of WTO for Russia attributes to the free access of foreign direct investment, foreign service providers with more efficient technologies in this circumstance can spread their operations more easily. The simulations indicate a 5% of GDP welfare benefit produced by the improved service provision, and a 7% of GDP total gain due to all the derived benefits from the accession to WTO.

2.2.4 Global CGE models

Some contemporary issues that are targeted by CGE modellers including: bilateral and multilateral trade agreements, international financial imbalances, climate change, and immigration. These issues can be well addressed while evaluating them under a global context. One of the major multi-country models of this kind is the Global Trade Analysis Project (GTAP) build and run at Purdue University. Its global database covers 113 countries and 57 sectors, it includes the input-output table for each country, tariffs and other data relevant to the trade restrictions, trade and immigration flows, and greenhouse gas emission. Hertel (1997) and Hertel (1999) give a comprehensive description of this model, credits the enlightened influence that the GTAP has provided for trade negotiations and policy making and for climate policy negotiations.

The Distortion to Agricultural Incentives (DAI) database formed by Anderson and Martin (2005), Anderson et al. (2006) and Anderson et al. (2010) quantifies the import tariffs, exports and production subsidies and taxes for many economies and products. They perform a comparison between the GTAP and DAI database by using simulations regarding the trade-distorting policies generated by the LINKAGE (a global CGE model used by the World Bank to obtain the simulations of world economy's growth and trade related study). The results address a large range of variables incorporating poverty and welfare effects by region and country. An astonishing feature of the results is that agriculture is dominantly responsible for explaining the trade distortions.

2.3 The US trade background

2.3.1 Sectors in the US economy

According to Burfisher (2021), agricultural output only takes up approximately 1% of total US GDP (while services account for 81% of the total US GDP). It is crucial to identify the relative size of a sector in total GDP since the greater the size, the larger the impact of a shock from this sector on the economy. In the case of a relatively small size of the agricultural sector in the US economy, a policy shock rooted in the agricultural sector presumably would not cause a substantial effect on the US economy.

2.3.1.1 US agriculture sector

As the supplier of major food satisfy people's daily needs, agriculture plays a vital role in the US economy. The income per capita is negatively correlated with the fraction of the labours work in agriculture industry. Marion and MacDonald (2013) point out that 50% to 80% of the population in the poorest nations lives on farms, in contrast to less than 5% in Western Europe and about 2% in the US. In general, economic development closely rely on the performance of famers, which in turn rely on how agricultural industry is organised, its market structure, and the education institutions and related research that induce the improvement of technology. Substantial investment on education and research in agricultural sector made by Federal government has promoted productivity growth in the US agriculture.

Many of the farms are owned and operated by families, only a small quantity is owned or operated by large publicly owned firms. They generally operated as price-takers, with rather limited control over the prices of their products or the prices of the inputs they employed. Since farms might operate in competitive markets, the buyers they frequently encountered usually have certain level of monopsony power, and the providers of input factors usually have some monopoly power on the prices of the inputs. These family operated small businesses could meet significant financial risks due to prices' fluctuations affected by these powers and due to the production affected by environmental factors such as weather and disease.

Short-run supplies in agriculture sector are rather inelastic because farms' capital and labour commitment is conducted before the production process. Food is generally regarded as a necessity hence the demand is also relatively inelastic. Inelastic supply and demand give dramatic fluctuations when the unexpected supply or demand shocks present. Free entry and exit allow for elastic long-run supplies. Fast growth in productivity also promotes increases in supplies. Low growth rate of the domestic population and low-income elasticity of demand for majority of the products limit the growth in domestic demand for agricultural products. These long-run characteristics of supply and demand imply that real prices for agricultural products have declined gradually, causing further income risks to farmers have difficulties on accessing new cost saving technologies. The characteristics also proposing the crucial role of the foreign market in agriculture.

The US exports 20% of its agricultural production and this proportion occupied about 10% of total exports of the US. Field crops are significantly dependent on exports, almost three quarters of cotton and half of wheat is exported, and approximately 20% of corn and 30% soybean is exported. Although the agricultural exports exceed imports, the difference has been diminishing, with imports now accounting for 18% of total agricultural production. Tropical products that are not particularly planted in the US occupied large proportion of the imports, including bananas, coffee, cocoa, etc. International trade expands the sales of the agricultural products, but fluctuating exchange rates and macroeconomic developments in other regions also creates risks to exports and imports. Many international trade negotiations continuously focus on the disputes in agricultural sector, incorporating debates over subsidies offered to farmers in developed countries, restrictions in imports of agricultural products, and controversies over food safety.

2.3.1.2 US manufacture sector

As noted in Levinson (2013), the health of the US manufacturing industry has constantly been an issue of deep concern to Congress. The drop in employment in manufacture sector since the beginning of the 21st century has aroused special interest in Congress, which has led lawmakers to propose hundreds of bills aimed at supporting domestic manufacturing activities in plenty of methods in many sessions of Congress. Proponents of such measures often argue that the various measures taken by the United States in manufacturing are lagging behind other countries, and they believe that this gap can be mitigated or reversed through government policies.

After the US recession ended, the US share of global manufacturing activity fell from 28% in 2002 to 16.5% in 2011. By 2016, the US share climbed to over 18%, which is the greatest share since 2009. These estimates (based on the value of each nation’s manufacturing industry) are derived using US dollars; reduction in the U.S. share can be partially explained by a 23% depreciation of the U.S. dollar between 2002 and 2011, and the subsequent increase was partly due to a stronger U.S. dollar. China replaced the US as the biggest manufacturing economy in 2010. Similarly, China’s growth through this measure is partly due to the rise in the value of the renminbi, against the US dollar. Due to currency adjustments, the reporting scale of China's manufacturing industry declined in 2015 and 2016. Manufacturing output has grown slower in the US than that in China, South Korea, Germany, and Mexico, but faster than that in many European countries and Canada (this based on values measured in the local currency of each country adjusted for inflation).

Over the past 25 years, manufacturing employment rates in most major manufacturing countries have declined. In the US, employment in manufacturing has decreased since 1990, which is consistent with the changes in Western Europe and Japan, except for the timing of the decrease has varied from economy to economy. Real spending in Research and development (R&D) by US manufactures increased by 10.5% from 2010 to 2015. R&D spending by manufacturers in several other countries has grown even more faster. Compared with the value added in the manufacturing industry, manufacturers in many countries have expanded their R&D expenditures, but the R&D intensity of US manufacturers has not changed much since 2008. The majority of R&D taken by US manufacturers occurs in industries with high technology, for example, pharmaceutical, aircraft manufacturing, and electronics, while in contrary to US, most other countries largely spend their R&D expenditures on mid-technology industries such as machinery and automobile manufacturing.

2.3.1.3 US service sector

The role of services in employment is the easiest to explain. The US economy today is called the "service economy." This is because most of the working population is employed in the service industry. According to Haksever and Render (2013), by the mid-1990s, the proportion of service jobs had steadily increased to 76%, and by 2010 it had attained 84%. Many new jobs are generated in existing organisations when they expand, but other jobs are generated as new companies are founded. Service sector provides substantial opportunities for most new companies to be established. Approximately 73% of new private companies are service companies. In other words, the service industry is the "where the action is" and the place where the economy has the most powerful entrepreneurial spirit. The service sector also plays a significant role in US international trade. In the 1960s and 1970s, 22% of US exports are exports from service sector, however, this figure has reached about 30% in the 2000s. The US also imports services products, about 20% of imports are services. However, the most important feature is that since 1971, service exports have consistently outweighed service imports.

The link between the services sector and the return to skill has been widely documented in the literature. For example, Eckert (2019) document two salient features derived from the interaction between the services sector and changes in communication costs, and how this interaction leads to differences in the return on skills in the labour market. First, the ratio of the employment at the 90th percentile relative to the 10th percentile was 1.9 in service sector compared to this figure of 1.4 in commodity-producing sector in US 1980's labour market. These figures imply a significant difference in potential comparative advantage. Second, the skill-intensive degree of the service sector is significantly higher than that of the commodity production sector: from 1980 to 2010, the proportion of employees with a college degree is more than two and a half times that of the commodity-producing sector. The third fact amplifies the effect: service products are an indispensable intermediate input for other sectors of the economy, 40% of the service products are used only for commodity production.

In addition, the rising share of the service industry in GDP has two ways to weaken the impact of output growth on employment. In terms of the business cycle, Olney and Pacitti (2017) believe that the increase in the proportion of the service sector means that the recovery of employment after the economic recession is slower. There are two reasons for that: i) service producers do not need to replenish inventories when expected demand increases during the recovery; ii) many services are not tradable, which means that services exports are not as effective as commodity exports in promoting economic recovery. Olney and Pacitti use state-level data from US to conclude that a larger share of non-tradable services makes a significant contribution to a longer employment recovery period after a cycle trough.

2.3.2 Factor market in the US economy

Factor shares depict the relative importance of each factor employed in the production costs structure of a sector. Capital equipment, for example, account for a larger share of the factor costs of a capital-intensive automobile manufacturing industry than does labour. Factor shares are computed for each factor for each production process from data. The cost of a factor incorporates the rents and wages that the producer spends on each factor and taxes involved while using it, and the total costs of inputs should equal to the total value of output. The importance of the factor shares can be justified when a factor's relative price or the productivity is changed by some shocks. (Burfisher 2021) gives an example of wearing apparel production activity, which pays more costs on labour than it does on capital. If there is a fall in wages due to the increase in the labour supply, then the total factor costs in the apparel's industry will drop by proportionately more than in the automobile manufacturing industry. The proportionately larger amount of input cost savings in the apparel industry would result in a rise in its production and in its size compares to the automobile manufacturing industry, resting with the demand from the consumer.

While the broad range of agricultural goods produced in the US thanks to its ample arable land, it also equipped with abundant capital resources. Although its labour is not the cheapest, its world-leading education quality formed a labour pool filling with the most intelligent people in the world. These strengths in the factor market have made the US the largest economy in the world.

2.3.2.1 Land market in the US

Market forces, changes in agricultural plans, and changes in technology all affect the supply and demand of land employed for crop production (Nickerson and Borchers 2012). From 1949 to 1969, the arable land used for crops reduced by 54 million acres, and then reached a peak of 383 million acres in 1982, when the Government-acreage reduction programs did not cut the cropland acres. Despite the large fluctuations in commodity prices, the arable land employed for crops production has been relatively stable since 1980.

The elasticity of the total supply of farmland is one of the keys to understanding the extent to which changes in demand and supply of the cropland caused by policies will increase prices or increase crop yields. Estimating how the acreage responds to the changes in price has long been a focus in research of agricultural economics. For instance, Houck and Ryan (1972) investigate the acreage response of corn in the United States between 1948 and 1970. They study three different sets of variables that affect the area planted with corn: government policies, market influence, and various determinants from the supply side. The corn price in the previous crop year was applied as one of the variables serving as the market impact group. They discover that almost all changes in planted acreage can be explained by policy variables. Other variables have also been considered as the explanators of the variation in the usage of the agricultural land over the years. Tweeten and Quance (1969), and Lee and Helmberger (1985) include a variable characterised as output price relative to a variable input price index. Other variables include, for example, expected prices (Gardner 1976), expected net returns (Chavas and Holt 1990; Davison and Crowder 1991)), and acreage value (Bridges and Tenkorang 2009). Davidson and Crowder believe that compared with using price alone, explaining the usage of agricultural land by expected net returns is better, since net returns can explain variations in input prices. Barr et al. (2011) report the elasticity of land supply for the United States and Brazil. Estimates are directly based on recent changes in crop planting area and estimated changes in expected returns. The resulting estimates show that the land use elasticity is quite low in the United States.

2.3.2.2 Labour market in the US

Some key findings of the labour market in the US for the period 2000-2018 are summarised in Hamermesh (2019). On the favourable side, the unemployment rate is already lower than it was before the Great Depression. The job vacancy rate is currently at the highest level since the data has been collected and now above the hire rate. The labour participation rate of men and women aged between 20 and 54 has declined, so the number of labour force in 2018 has 6 million less than that was expected in 2000. Average real income and the real income of the median-income full-time employees have increased. Women's wages have climbed relative to men's earnings, but they are still slightly lower than men's.

On the negative side, even with full employment in 2018, the long-term unemployment rate is significantly higher than that during similar periods in past business cycles. The youth unemployment rate is still much higher than the adult average. Wage inequality has still been an issue and the gap has sustained to increase, and this enlarged gap centred in the upper half of the income distribution. Compared with those of white workers, the wages of African

American workers have declined and still much lower than the wages of white American workers.

2.3.2.3 Capital market in the US

According to Hennings (1990), “Capital goods are produced commodities which are required for production no matter how much or how little they are subject to wear and tear. A stock (at a point of time) of different capital goods is a capital”. In a Social Accounting Matrix (SAM) constructed for the US (Burfisher 2021), capital receives income from all three production activities (agriculture, manufacturing, and services): 53 billion dollars from employment in agriculture sector, 649 billion dollars from employment in manufacturing sector, and 2846 billion dollars from employment in services sector. From the perspective of disposition of factor income, capital pays income taxes of 294 billion dollars, depreciation accounts for 1260 billion dollars, this is the replacement cost of worn-out capital which is reported in the investment-savings account. The remaining income of capital is spent on the regional household account, worth 1994 billion dollars.

Changes in factor endowments can be a major shock because of their impact on the production capacity of an economy. From the perspective of public policy, what is usually more important is the distribution effect that occurs when changes in factor endowments result in an increase in wages or rents earned by certain factors but a decrease in earnings by other factors. A common assumption in the standard CGE model is that supplies of a country’s factor endowments are fixed. CGE modelers treat the analysis of shocks on factor endowments as a model experiment. These shocks come from many sources, shocks affect capital supply and demand, for example, could be foreign direct investment that rise the supply of capital, or war which decrease the supply of both capital and labour. It is normal to treat capital as internationally mobile.

2.3.3 Trade policy in the US

Although the abundance of its factor resources provides a wide range of products, the US also imports substantial varieties of goods and services, the purchase desire from the US consumers drives them to use their wealth to satisfy their needs and wants, while much of these is now supplied by other countries that are taking advantage of their large interior, cheap labour or other low-cost production inputs to establish their own comparative advantages.

2.3.3.1 Trade trends of the US

As noted in a report published by Congressional Research Service (2020), the United States is the largest economy, trading nation, and the source and destination of foreign direct investment in the world. The US trade is expanding all the time, and its markets and productive activities have become particularly more integrated with the emerging economies. The largest trading partners of the US in 2019 were Canada, Mexico, China, Japan, the United Kingdom and the European Union. The US has a long-term overall trade deficit and it comes from the gap between the goods trade deficit and the service trade surplus. Most economists believe that the effects of macroeconomic variables (for example, total savings and investment, dollar valuation and its role in world markets) on the determination of the US trade deficit are greater than the effects of trade policies or trade agreements on it.

2.3.3.2 Components of trade policy and policy tools of the US

Congress is responsible for the formulation of the goals of US trade negotiations, the establishment of trade laws, programs and agreements, and for the oversight of execution of trade functions performed by a series of federal agencies. According to statute, the United States Trade Representative (USTR) is the leading trade negotiator of the US and coordinates trade policies via an inter-agency procedure (provides formal public and private advice). The key components of the US trade policy including trade rules-setting, liberalisation, and enforcement; export promotion and controls; customs, trade remedies, trade adjustment; trade preferences; investments.

The US trade authorities created by Congress were adopted as the policy tools to address trade issues and were applied regularly in the 1980s, however their use reduced with the establishment of the WTO in 1995 and its enforceable dispute settlement system and the lifting of sets of trade barriers. The effectiveness of certain government tariff actions has been questioned by Congress. Tariffs have been imposed by US trading partners as a retaliation, they also negotiate exceptions in the method of quotas or other agreements, and make complaints to the WTO. In September 2020, Section 301 in the Trade Act of 1974 (tariffs on Chinese imports) was ruled by a WTO dispute panel due to its violation of WTO rules. Although the WTO agreements have stagnated, there has been a dramatic boost of bilateral and regional trade agreements, and more than 300 have come into force globally. The US has signed 14 Free Trade Agreements (FTAs) with 20 countries (ibid).

3 The Model

The main purpose of this study is to test which model fits the US economic facts better, one is the ‘gravity model’, which is widely recognised by economists who specialise in international trade study. Trade behaviour in this model is heavily rely on the forces from demand side, i.e. neighbour countries demand of imports and other countries demand of imports adjusted to transportation costs and border costs. The competition is highly imperfect, therefore the prices are set as a mark-up on costs by the supplier. Once the production and the trade pattern have been settled through the demand side, foreign direct investment will follow up which will further inducing the productivity. The other one is the ‘classical model’, which is developed by a group of trade theorists with great fame on their work on trade, beginning with Ricardo (1817). In the world of the classical model, the competition is high, the world prices are the same across countries with variation of transportation costs and other costs in association with trade barriers set by countries. All industries are featured with free entry and exist therefore the prices equal to average total costs. Capital is mobile across countries but other factors – unskilled labour, skilled labour and land, are immobile. In contrast to the gravity model, forces on supply side, factor supplies and productivity of those factors dominate the capability in each sector of an economy. Consumers using the resulting incomes to satisfy their expenditure on daily needs and the surplus over these demands is exported while the deficit will be imported in each sector. The trade pattern in turn is largely determined by the supply side.

The model used here is a CGE model based on Minford et al. (2015) in which four types of products, four inputs of production and four country blocs are identified. Three traded industries are identified here as agriculture, manufactures and services. The agricultural sector also contains other primary production, manufactures only account for the basic manufacturing work while manufactures with higher degree of complexity and technology are belongs to the services category. These industries intensively rely on the employment of land and both unskilled and skilled labour. Apart from these three traded industries, one non-traded sector is included in the model, where land and unskilled labour are intensively employed. Four inputs of production incorporate capital, unskilled labour, skilled labour and land, from which the capital is freely accessed across country borders, the rest of three inputs are immobile and therefore determine the comparative advantage of each country. Four country blocs include the US, the EU, the China and the Rest of the World (ROW).

The demand system specified in this study characterises the product differentiation in two ways: by product type and by different country origins. The elasticity of substitution specified in these two levels can thus take different values. This treatment is largely used in trade models as the demand can be derived for intermediate products by type, then demand for different country products can be derived. The market clearing for country product is achieved by the real exchange rate, which is the relative price of the origin's product. The market clearing condition states that Output = Aggregate Demand for Output+Real Exchange Rate(RXR)×Export(X)-Import(M). As CGE model requires Output = Aggregate Demand for Output, it must be the case that Real Exchange Rate(RXR)×Export(X)=Import(M), therefore the current account equilibrium condition pins down the real exchange rate, the ratio of home prices to foreign prices. Market clearing for product type level is achieved through different product type prices in the world economy.

Since the two-layered system would be too large to test, it will cause a lot of variability in the CGE model and influence the power of the test. The extra layer between intermediate and final goods, the retail demand is introduced to achieve a relative equivalent contrast. This specification allows the intermediate product CGE model to be the same across both versions of model, where the default assumption of perfect competition is satisfied. The geographical origin is imposed at this retail layer, it is assumed that all intermediate goods will be branded at the retail level. In all country bloc this branding is by geographical origin. The ROW in classical model branding intermediate products in an "origin-free" manner, this allows the unsold intermediate products from other countries can be sold in the ROW bloc at the prevailing price for the product type as perfect substitutes for products from other countries. This defends the perfect substitution of origin in the classic model. In the gravity model, the ROW retail demand is also branded by origin as specified for other origins, this ensures the imperfect substitutability by origin across the whole world market. The RXR for each country needs to move to maintain the current account equilibrium. To sum up, the perfect substitutability of origin in the classical model is defended by the residual "world market", the ROW, where unsold country products can be absorbed there at "world prices", but in the gravity model, all country blocs are homogeneous, they supply distinct country products. Therefore, there are two sets of firms in the model, one is the set of firms that sells intermediate products to the other set of firms, who is owned by the country suppliers as their marketing agents, this set of firms sells branded, distinct products to consumers.

The key problem is that how the essential gravity components are included when testing two versions of model. The gravity version of the CGE model differs the classical version in two main aspects: 1), as has been discussed above, the highly imperfect substitutivity between country products, therefore the real exchange rate, RXR, enters in the current account equilibrium condition in the gravity model. 2), the lager amount of trade, the larger size of the market and the profits to investment and the transfer of the knowledge. Therefore, trade determines FDI, and so productivity. The correspondence specification in the gravity model is that the productivity term is no longer the exogeneous process as it in the classical model, it is now determined by the size of trade.

Essentially the gravity model has used the Armington country-heterogeneity assumption as a way of generating the Tinbergen gravity regressions; to this assumption it has added a link from trade to productivity to account for the micro evidence that trade and productivity are correlated. However, the classical model relies on comparative advantage from the supply side to generate the reduced form trade relationships found in the data. This work shows that for the US the two models can both account for these relationships.

3.1 Final demand

Final demand are consumptions in their end use, they are not further combined or used into production of other goods and services. Domestic consumers choose their consumption according to different country origin of retail products in each sector. The retailers source the intermediate products and create bundles of them, these bundles are assigned with ‘brands’ to be distinguished with each other and consumers will not freely switch to other brands because of factors including habits, shortage of time etc. Each country produces a differentiated good due to the trade frictions, since the differentiation in transportation costs and tariffs applies between countries. The retail products are sold in imperfect competition market, a mark-up is adopted by the distributor to reflect the elasticity of substitution of the final good.

3.1.1 The model of consumption

The demand for each country brand is characterised by the Armington model (Armington 1969). Consumers from each country j maximise their utility through consumption of products from all countries i subject to total consumption demand:

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

$$s.t. p_j \cdot y_j = \sum p_i \cdot C_i \tag{2}$$

where σ is the elasticity of substitution between goods from different countries and v_i is a preference shifter, which is exogeneous, it represents for the share of expenditure country j spent on country i's product, therefore $\sum_1^N v_i = 1$. C_i is the quantity of a good from country i that is consumed by consumers in country j and p_i is the price of that good. $p_j \cdot y_j$ can be viewed as the total income in country j. The feasibility condition suggests that $\sum_{i,j=1}^N C_i = y_i$, which states the total consumption of good i is just equal the domestic production of that good.

The Lagrangian is then:

$$\mathcal{L} = \left(\sum v_i \cdot C_i^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}} - \lambda\left(\sum p_i \cdot C_i - p_j \cdot y_j\right) \tag{3}$$

The first order condition is thus:

$$\frac{\partial \mathcal{L}}{\partial C_i} = \frac{\sigma}{\sigma-1}\left(\sum v_i \cdot C_i^{\frac{\sigma-1}{\sigma}}\right)^{\frac{1}{\sigma-1}} \cdot \frac{\sigma-1}{\sigma} \cdot v_i \cdot C_i^{\frac{-1}{\sigma}} - \lambda p_i = 0 \tag{4}$$

$$\left(\sum v_i \cdot C_i^{\frac{\sigma-1}{\sigma}}\right)^{\frac{1}{\sigma-1}} \cdot v_i \cdot C_i^{\frac{-1}{\sigma}} = \lambda p_i \tag{5}$$

Multiplying equation (5) by C_i on both sides and summing over all i yields:

$$\left(\sum v_i \cdot C_i^{\frac{\sigma-1}{\sigma}}\right)^{\frac{1}{\sigma-1}} = \lambda \cdot p_j \cdot y_j \tag{6}$$

Since $p_j \cdot y_j = \sum p_i \cdot C_i$.

Equation (6) can be written as:

$$\lambda^{-1} \cdot U_j = p_j \cdot y_j \tag{7}$$

Therefore λ^{-1} is the price of one unit of utility in country j, this can be denoted as P_J. Recall U_j is the total utility that the household can afford given its income. Rearrange equation (5) gives:

$$C_i^{\frac{-1}{\sigma}} = \lambda \cdot p_i \left(\sum v_i \cdot C_i^{\frac{\sigma-1}{\sigma}}\right)^{\frac{-1}{\sigma-1}} \cdot v_i^{-1} \tag{8}$$

Raising each side to the power $1-\sigma$ and multiply by v_i on both sides:

$$v_i \cdot C_i^{\frac{\sigma-1}{\sigma}} = (\lambda \cdot p_i)^{1-\sigma} \left(\sum v_i \cdot C_i^{\frac{\sigma-1}{\sigma}}\right) \cdot v_i^{\sigma} \tag{9}$$

Summing over all i and solving for λ gives:

$$\lambda = \left(\sum v_i^{\sigma} \cdot p_i^{1-\sigma}\right)^{\frac{1}{\sigma-1}} \tag{10}$$

Therefore the price of a unit of utility is:

$$P_J = \lambda^{-1} = \left(\sum v_i^{\sigma} \cdot p_i^{1-\sigma}\right)^{\frac{1}{1-\sigma}} \tag{11}$$

This is the so-called Dixit-Stiglitz price index, which is an index of all varieties' prices, which can be interpreted as country J's price index.

Since all the countries are symmetric, the following first order condition also holds:

$$\frac{\partial \mathcal{L}}{\partial C_{i'}} = \frac{\sigma}{\sigma-1}\left(\sum v_{i'} \cdot C_{i'}^{\frac{\sigma-1}{\sigma}}\right)^{\frac{1}{\sigma-1}} \cdot \frac{\sigma-1}{\sigma} \cdot v_{i'} \cdot C_{i'}^{\frac{-1}{\sigma}} - \lambda p_{i'} = 0 \tag{12}$$

Equation (4) divided by equation (12) gives:

$$\left(\frac{v_i}{v_{i'}}\right)^{\sigma} = \left(\frac{C_i}{C_{i'}}\right) \cdot \left(\frac{p_i}{p_{i'}}\right)^{\sigma} \tag{13}$$

Multiplying equation (13) by $p_{i'}$ on both sides and summing over all i' reads the CES demand curve for country i's product:

$$C_i = v_i^{\sigma} \cdot \left(\frac{p_i}{P_J}\right)^{-\sigma} \cdot U_j \tag{14}$$

where equation (2) and equation (11) are used. The value of the total trade is thus:

$$X_i = p_i \cdot C_i = v_i^{\sigma} \cdot \left(\frac{p_i}{p_J}\right)^{1-\sigma} \cdot p_j \cdot y_j \quad (15)$$

The term U_j is the utility the household can afford, which equals to $\frac{p_j \cdot y_j}{P_J}$ – given country j's total income level $p_j \cdot y_j$. P_J, the consumer price index of country j, can be therefore interpreted as the price of unitary utility of country j. The price P_J can be further generalised as $P_J = p \cdot N^{\frac{1}{1-\sigma}}$ by assuming the world is symmetric, so that $p_i = p$ and $v_i = 1$ for all i. Here P_J is a decreasing function of N if $\sigma > 1$, the price of a unit of utility is decreasing as the variety of goods increases. Holding the income of the household constant, the household can buy more unit of utility if the price of unitary utility drops, thus the household is better-off if there are more varieties of goods available. This is known as the 'love of variety'. This property gives rise to trade, the consumer would like to consume goods from all of the world instead of spending on only one kind of good.

From the CES demand curve the model suggested, one can find out that the higher the preference shifter v_i (larger share in utility) is, the higher the quantity demand for goods from that country. Besides, good with higher price relative to the price of unitary utility $(\frac{p_i}{P_J})$ is demanded in lower quantity. Finally, an increase in income results in an increase of the consumption for all goods (U_j increases as $p_j \cdot y_j$ increase, this leads to the increase in C_i). The elasticity of substitution can be derived by writing the demand function in relative term and take logs of it with respect to the relative price. It is easily to show that the elasticity of demand is equal to σ and it is fixed when the quantities of goods demanded varies according to the CES nature of the preferences. The expenditure equations in our model are thus generated by taking logs of the demand curve showed above. These distribute all the US output to home, China, EU and ROW markets, and all the US demand can be allocated in the same way to all these markets:

$$E_A^{US} = 0.05 \cdot E_T^{US} + 835.01 - 5.0 \cdot (p_A^{US} - p_T^{US}) \tag{16}$$

$$E_S^{US} = 0.9 \cdot E_T^{US} - 1205.5 - 12.0 \cdot (p_S^{US} - p_T^{US}) \tag{17}$$

$$E_M^{US} = E_T^{US} - E_S^{US} - E_A^{US} \tag{18}$$

3.1.2 Import demand

The trade share bloc can be shaped by using the same logic discussed above. The US imports from China, EU and ROW are US demand for products from these areas:

$$\ln(M_i) = a_i + b_i \cdot \ln(E_T) + em_i \qquad i = EU, China, ROW \tag{19}$$

where M represents for the import and E_T is the expenditure on traded goods; em_i is the trade share error process, and a_i and b_i are estimated using OLS. The expression is necessarily simplified here since other trade barriers like tariffs can affect these demands, however the time series data of these is scarce therefore these effects are captured by the error terms in the equation.

3.1.3 Export demand

The US exports to China and EU are demand for the US products from these areas. The exports to ROW are equal to the remainder of the US total export to the world (the residual supply of the US traded production) as the current account balance needs to be satisfied. Since ROW acts as the residual world market in the classical model, it clears the world market without the intervention of the real exchange rate (RXR), RXR equals to 1 irrelevantly in the classical model. The resulting demand for the US exports is:

$$\ln(X_i) = c_i + d_i \cdot \ln(E_i) + ex_i \qquad i = EU, China \tag{20}$$

$$X_{ROW} = y_T - E_T - (X_{UK} + X_{EU} - M_{UK} - M_{EU} - M_{ROW}) \tag{21}$$

where X represents for the export, E_i is the expenditure on goods produced in other country blocs, and y_T is the output of traded goods; ex_i is the trade share error process, and c_i and d_i are estimated using OLS.

3.2 Supply

In the CGE model, the objective of the producers is to maximise their efficiency subject to the requirement of their technology embedded in their production process, this gives the demand of inputs and level of output. Outputs in our model are intermediate products, they will be further employed as inputs into final goods for retail consumption. They are divided into four types of products, agriculture, manufactures, services and nontraded output, and they are supplied in perfectly competitive markets.

3.2.1 Supply of intermediate goods

The technology is for simplicity expressed as a factor-neutral multiplicative term in the model's Cobb-Douglas production functions with constant returns to scale:

$$y = A \cdot N^{\alpha} \cdot H^{\beta} \cdot L^{\gamma} \cdot K^{1-\alpha-\beta-\gamma} \quad (22)$$

where A is a productivity multiplier factor, which is different across borders; α, β, and γ represent for factor shares and this set of values varies across sectors, depending on their intensity in producing each product; N, H, L, and K are notations of factors unskilled labour, skilled labour or human capital, land, and capital (physical), respectively. The model of US is calibrated as in Vanlentinyi and Herrendorf (2008), who measure the income shares of multiple inputs for the US economy at the sectoral level.

Sectoral price equations can be obtained by solving the cost minimisation problem of the intermediate goods producer (for each sector):

$$\min C = w \cdot N + h \cdot H + l \cdot L + r \cdot K \tag{23}$$

$$s.t. y = A \cdot N^{\alpha} \cdot H^{\beta} \cdot L^{\gamma} \cdot K^{1-\alpha-\beta-\gamma} \tag{24}$$

where w, h, l, and r are factor prices of unskilled labour, skilled labour, land, and capital respectively. The lagrangian reads:

$$\mathcal{L} = w \cdot N + h \cdot H + l \cdot L + r \cdot K - \mu\left(y - A \cdot N^{\alpha} \cdot H^{\beta} \cdot L^{\gamma} \cdot K^{1-\alpha-\beta-\gamma}\right) \tag{25}$$

The first order condition gives:

$$\frac{\partial \mathcal{L}}{\partial N} = w - \mu \cdot A \cdot \alpha \cdot N^{\alpha-1} \cdot H^{\beta} \cdot L^{\gamma} \cdot K^{1-\alpha-\beta-\gamma} = 0 \tag{26}$$

$$w = \mu \cdot A \cdot \alpha \cdot N^{\alpha-1} \cdot H^{\beta} \cdot L^{\gamma} \cdot K^{1-\alpha-\beta-\gamma} \tag{27}$$

$$\frac{\partial \mathcal{L}}{\partial H} = h - \mu \cdot A \cdot \beta \cdot N^{\alpha} \cdot H^{\beta-1} \cdot L^{\gamma} \cdot K^{1-\alpha-\beta-\gamma} = 0 \tag{28}$$

$$h = \mu \cdot A \cdot \beta \cdot N^{\alpha} \cdot H^{\beta-1} \cdot L^{\gamma} \cdot K^{1-\alpha-\beta-\gamma} \tag{29}$$

$$\frac{\partial \mathcal{L}}{\partial L} = l - \mu \cdot A \cdot \gamma \cdot N^{\alpha} \cdot H^{\beta} \cdot L^{\gamma-1} \cdot K^{1-\alpha-\beta-\gamma} = 0 \tag{30}$$

$$l = \mu \cdot A \cdot \gamma \cdot N^{\alpha} \cdot H^{\beta} \cdot L^{\gamma-1} \cdot K^{1-\alpha-\beta-\gamma} = 0 \tag{31}$$

$$\frac{\partial \mathcal{L}}{\partial K} = r - \mu \cdot A \cdot (1-\alpha-\beta-\gamma) \cdot N^{\alpha} \cdot H^{\beta} \cdot L^{\gamma-1} \cdot K^{-\alpha-\beta-\gamma} = 0 \tag{32}$$

$$r = \mu \cdot A \cdot (1-\alpha-\beta-\gamma) \cdot N^{\alpha} \cdot H^{\beta} \cdot L^{\gamma-1} \cdot K^{-\alpha-\beta-\gamma} \tag{33}$$

Equation (27) and (29) give:

$$\frac{w}{h} = \frac{\alpha}{\beta} \cdot \frac{H}{N} \tag{34}$$

$$H = \frac{w}{h} \cdot \frac{\beta}{\alpha} \cdot N \tag{35}$$

The representation of L and K can be derived use the same fashion:

$$L = \frac{w}{l} \cdot \frac{\gamma}{\alpha} \cdot N \tag{36}$$

$$K = \frac{w}{r} \cdot \frac{1-\alpha-\beta-\gamma}{\alpha} \cdot N \tag{37}$$

Substituting equation (35), (36), and (37) into equation (22), the production function becomes:

$$y = A \cdot N^{\alpha} \cdot \left(\frac{w}{h} \cdot \frac{\beta}{\alpha} \cdot N\right)^{\beta} \cdot \left(\frac{w}{l} \cdot \frac{\gamma}{\alpha} \cdot N\right)^{\gamma} \cdot \left(\frac{w}{r} \cdot \frac{1-\alpha-\beta-\gamma}{\alpha} \cdot N\right)^{1-\alpha-\beta-\gamma} \tag{38}$$

Solving for N gives:

$$N = \frac{y}{A} \cdot \frac{\alpha}{w} \cdot \frac{w^{\alpha} \cdot h^{\beta} \cdot l^{\gamma} \cdot r^{1-\alpha-\beta-\gamma}}{\alpha^{\alpha} \cdot \beta^{\beta} \cdot l^{\gamma} \cdot 1-\alpha-\beta-\gamma^{1-\alpha-\beta-\gamma}} \tag{39}$$

Using equation (35), (36), and (37) to solve for H, L, and K respectively:

$$H = \frac{y}{A} \cdot \frac{\beta}{h} \cdot \frac{w^{\alpha} \cdot h^{\beta} \cdot l^{\gamma} \cdot r^{1-\alpha-\beta-\gamma}}{\alpha^{\alpha} \cdot \beta^{\beta} \cdot l^{\gamma} \cdot 1-\alpha-\beta-\gamma^{1-\alpha-\beta-\gamma}} \tag{40}$$

$$L = \frac{y}{A} \cdot \frac{\gamma}{l} \cdot \frac{w^{\alpha} \cdot h^{\beta} \cdot l^{\gamma} \cdot r^{1-\alpha-\beta-\gamma}}{\alpha^{\alpha} \cdot \beta^{\beta} \cdot l^{\gamma} \cdot 1-\alpha-\beta-\gamma^{1-\alpha-\beta-\gamma}} \tag{41}$$

$$K = \frac{y}{A} \cdot \frac{1-\alpha-\beta-\gamma}{r} \cdot \frac{w^{\alpha} \cdot h^{\beta} \cdot l^{\gamma} \cdot r^{1-\alpha-\beta-\gamma}}{\alpha^{\alpha} \cdot \beta^{\beta} \cdot l^{\gamma} \cdot (1-\alpha-\beta-\gamma)^{1-\alpha-\beta-\gamma}} \tag{42}$$

The cost function is therefore:

$$C(w, r, l, h, y, \pi) = y \cdot \theta \cdot w^{\alpha} h^{\beta} l^{\gamma} r^{1-\alpha-\beta-\gamma} \cdot A^{-1} \tag{43}$$

where $\theta = \alpha^{-\alpha} \cdot \beta^{-\beta} \cdot \gamma^{-\gamma} \cdot (1-\alpha-\beta-\gamma)^{-(1-\alpha-\beta-\gamma)}$ is a parameter. The marginal cost of producing each product is also the price of each product in perfectly competitive market, thus:

$$p = MC = w^{\alpha} h^{\beta} l^{\gamma} r^{1-\alpha-\beta-\gamma} \cdot \pi^{-1} \tag{44}$$

where the term π^{-1} captures the product of parameter θ and the reciprocal of the productivity multiplier factor A^{-1}, it can be interpreted as the exogenous productivity error process. The price index for each sector can therefore be written accordingly:

$$p_M = w^{\alpha} h^{\beta} l^{\gamma} r^{1-\alpha-\beta-\gamma} \cdot \pi_M{}^{-1} \tag{45}$$

$$p_S = w^{\alpha} h^{\beta} l^{\gamma} r^{1-\alpha-\beta-\gamma} \cdot \pi_S{}^{-1} \tag{46}$$

$$p_A = w^{\alpha} h^{\beta} l^{\gamma} r^{1-\alpha-\beta-\gamma} \cdot \pi_A{}^{-1} \tag{47}$$

$$p_D = w^{\alpha} h^{\beta} l^{\gamma} r^{1-\alpha-\beta-\gamma} \cdot \pi_D{}^{-1} \tag{48}$$

where π_M, π_S, π_A, and π_D are exogenous productivity error processes specified for each sector. Parameters α, β, and γ take different values in different sectors. These equations give the world prices of traded goods and determine the prices of immobile factors. The domestic supplies of these immobile factors are induced by these derived factor prices. These resulting supplies of immobile factors then determine the output levels in each traded sector, while the output in nontraded sector is fixed by its demand, the production of traded goods that determined by the supplies of immobile factors are not used in the nontraded sector. The demand for products of traded sectors is then settled by the resulting total GDP.

The optimal supply in each sector (y_A, y_M, and y_S) can be solved by world prices (p_A, p_M, p_S and p_D), factor supplies (N, H and L), and factor prices (w, h, and l. The resulting output can be expressed as the following matrix with the calibrated value provided in Vanlentinyi and Herrendorf (2008):

$$\begin{pmatrix} y_M \\ y_S \\ y_A \end{pmatrix} = \begin{pmatrix} 0.47162 \cdot 0.2289p_D + 0.52528p_M & 0.47162 \cdot 0.2289p_D + 0.19138p_S & 0.47162 \cdot 0.2289p_D + 0.24237p_A \\ 0.20838 \cdot 0.2289p_D + 0.14472p_M & 0.20838 \cdot 0.2289p_D + 0.46862p_S & 0.20838 \cdot 0.2289p_D + 0.21763p_A \\ 0.05 \cdot 0.2289p_D + 0.03p_M & 0.05 \cdot 0.2289p_D + 0.06p_S & 0.05 \cdot 0.2289p_D + 0.18p_A \end{pmatrix}^{-1} \cdot \begin{pmatrix} N \cdot w \cdot {e_M}^{-1} \\ H \cdot h \cdot {e_S}^{-1} \\ L \cdot l \cdot {e_A}^{-1} \end{pmatrix} \quad (49)$$

where e_M, e_S, e_A, e_K are factor demand error processes. The solving process above made use of the factor demand equations, which comes from the producer's behaviour of maximise their profit, this will be discussed in the factor demand section in detail.

3.2.2 Supply of final goods

The intermediate goods discussed previously will be combined as inputs into retail goods for consumption. The final goods are differentiated according to product origin for each sector. While the intermediate output is sold in perfect competitive market, the final distribution is operated in an imperfect competitive market. Therefore the distributor adopt a mark-up on top of the cost reflecting the elasticity of substitution for retail products. The final good is simply a bundle of intermediate goods and this bundle will be 'branded' to become a distinct product so that the consumer will not replace this product by other substitutes easily.

The equilibrium price can be determined by solving the problem of the producer' profit maximisation problem. Suppose each distributor bundles its distinct product in each sector at a constant marginal cost C_i and they choose the quantity they sold to each destination to maximise its profit, subject to the CES demand curve for country i's product derived from the optimisation problem of the consumer:

$$\max \Pi = \sum (p_i \cdot C_i - MC \cdot C_i) \quad (50)$$

$$s.t.\ C_i = v_i^{\sigma} \cdot \left(\frac{p_i}{P_J}\right)^{-\sigma} \cdot U_j \quad (51)$$

where MC represents for the constant marginal cost. The implication of this constant marginal cost assumption is that every country can specify an optimisation problem for each destination individually.

Substitute equation (24) into equation (23), the first order condition gives:

$$\frac{\partial \Pi}{\partial p_i} = (1-\sigma) \cdot {p_i}^{-\sigma} \cdot {v_i}^{\sigma} \cdot {P_J}^{\sigma} \cdot U_j - {v_i}^{\sigma} \cdot {P_J}^{\sigma} \cdot U_j \cdot MC \cdot -\sigma \cdot {p_i}^{-\sigma-1} = 0 \quad (52)$$

$$p_i = \frac{\sigma}{\sigma - 1} \cdot MC \quad (53)$$

Therefore countries charge a constant mark-up $\frac{\sigma}{\sigma-1}$ over marginal cost for their heterogeneous products, and the mark-up drops when the elasticity of substitution rises, therefore a higher elasticity of substitution indicates a less heterogeneity.

3.3 Factors of production

There are four factors in the model, namely land, capital, unskilled labour and skilled labour. Labour has been differentiated in a way that they devote different shares in our four sectors and skilled labour is receiving higher wage than unskilled labour. Factor is crucial to the production process, it determines the attainable amount of production an economy can achieve. The first term should be discussed in a standard CGE model is the factor endowment, it shows the initial stock of all kinds of resources an economy possessed. Large range of shocks to the factor endowments can be noted, for example, immigration can increase the labour supply while the foreign direct investment provides a source of capital supply. Factor mobility is another term that worth to explore because of it affect the supply curve of each industry. It itself reveals how easier the factor supplies will shift in different sectors due to the change of wages and rents. Supply curves characterise the marginal costs of production, if, for example, it is easier to move factors across sectors, it would be easier for producers to use a relatively lower wages to induce workers to shift from one industry to another. It means that producer is able to produce a large quantity with just a little incremental increase in the wage costs. This implies a relatively elastic supply curve. In our model, capital is mobile across borders while land and both types of labour are immobile factors. It is a consideration of some restriction policies on immigration. The immobile factors are sometimes called sector-specific (in our case is country-specific) factor, it is 'specifically' used in a designated sector (country) and is hard to be moved to other sectors (countries). This implies that the wages or rents of the immobile factors can vary across different sectors (countries). Comparative advantage and development are vastly determined by these immobile factors.

3.3.1 Factor supply

For the majority of the new classical models, there is no explicit equations account for labour supply and labour demand, most of these equations are featured by some implicit equations for technology of production and labour market (Minford 1988). While in most CGE models the assumption of the factor supply illustrates a fixed endowment of factors, the setting of the factor supply here is based on (Minford 1983), a new classical model of the labour market, where the total hours of labour supply can be derived when the marginal net real wage equals to the marginal rate of substitution of leisure for goods. The net real wage here is defined as the real wage derived from the competitive market minus the unemployment benefits lost if employed and related tax expenditure if accept a job. It thus can be written as a function of real wage, real unemployment benefit, tax rate paid by employee and the size of the working-age population.

The supply side of the labour market is described as follows: a worker decides to work or exit the work by maximising the present value of their expected utility, given the wages, unemployment benefits, and taxes paid during employed. The quadratic utility function can be characterised as:

$$U_{it} = \left(\gamma_i I_{it} - \frac{\beta_i}{2}\pi_{it}^2 + \pi_{it}\{\alpha_i + v_{it} + D_t\}\right) \tag{54}$$

maximising this subject to

$$I_{it} = (1 - \pi_{it})w'_{ict} + \pi_{it}b_{it} \tag{55}$$

where π_{it} is defined as the proportion of hours the worker *i* is preparing to work during the current fiscal year, it can also be interpreted as the probability of a worker being unemployed when one implementing this cross-sectional analysis at a point in time. If he chooses to stay unemployed and enjoy the leisure he can obtain a real benefit b_{it}, and he can receive a real non-union wage $w_{ict} \times (1 - T_{Lt}) = w'_{ict}$ if he chooses to work, T_{Lt} is the direct tax rate; I_{it} is the worker's real net income; α_i is a dummy variable features some personal characteristics; v_{it} represents some random factors and D_t captures seasonal factors influencing the preferences. Substituting equation (28) into equation (27). The first order condition gives:

$$\frac{\partial U_{it}}{\partial \pi_{it}} = \gamma_i \cdot (b_{it} - w'_{ict}) - \beta_i \cdot \pi_{it} + (\alpha_i + v_{it} + D_t) = 0 \tag{56}$$

$$\pi_{it} = \frac{\gamma_i}{\beta_i}(b_{it} - w'_{ict}) + \frac{1}{\beta_i}(\alpha_i + v_{it} + D_t) \tag{57}$$

Translating such a cross-sectional analysis to a time series analysis requires to write unemployment $U_t = (1 - \pi_t)POP_t$ as a linear function of w_{ct}, b_t, T_t and finally the volume of the labour force POP_t.

This treatment is necessarily simplified here as it gives the factors an elasticity to their own price relative to their opportunity cost (Minford et al. 1997). Other factors can be generalised based on this treatment, for example, the supply of land is dependent on the price of land in productive use relative to its value when it is not in use, which in the model is assumed equals to the wage. The elasticity of land supply is set to be 0.5, that is, the percentage change in quantity of land supply due to a percentage change in the "relative price" is 0.5, which is inelastic. As noted previously, there are land planning controls in US, which are designed to help agriculture. Therefore, in the US context, the land supply is determined by the demand, which fixes output in agricultural sector exogenously.

The supply of skilled labour is closely related to education investment and other training methods. These education programs can be captured by the price of the skilled labour relative to the price of its alternative, wage of unskilled labour. The elasticity is also set to be 0.5. The supply of the unskilled labour has been detailed described above, the determinant is assumed to be the relative term between unemployment benefit and unskilled wage.

The immobile factor supply equations in the model are therefore:

$$N = e_N \cdot \left(\frac{w}{b}\right)^{0.1} \cdot POP^{0.5} \cdot G^{0.5} \quad (58)$$

$$H = e_H \cdot \left(\frac{h}{w}\right)^{0.1} \cdot G^{0.5} \quad (59)$$

$$L = l^{-1} \cdot (0.18 \cdot p_A \cdot y_A + 0.03 \cdot p_M \cdot y_M + 0.06 \cdot p_S \cdot y_S + 0.05 \cdot p_D \cdot y_D) \cdot e_A \quad (60)$$

where N, H, and L are notations of factors unskilled labour, skilled labour or human capital, and land respectively; w, h, and l are the prices of factors, while w is the wages of unskilled labour, h stands for the skilled wages or rent on human capital, and l is the rent on land; b, POP, and G are exogeneous variables that capture rate of unemployment benefit, working population, and the fraction of government expenditure in GDP, respectively; p_A, p_M, p_S, and p_D are price indexes of each sector: agriculture, manufacturing, services, and non-traded; y_A, y_M, y_S, and y_D are output of each sector; finally, e_N, e_H, and e_A are factor supply error processes.

3.3.2 Factor demand

The demand for factors used in the production is derived by analysing the supply side of the economy, linking all the sectors through exploring their demands for inputs used in the production of intermediate goods. In the CGE model, producers maximise their efficiency subject to their capability of producing, as they determine their choice of inputs and level of output, given the prices of the input and product together with the technological strength. Since the world market for the intermediate output is perfectly competitive, individual producers have no ability to affect the market prices of inputs and outputs, therefore the intermediate outputs are sold at the marginal cost and each firm can earn zero profits. The production process also features constant returns to scale, an expansion of the inputs in the same scale leads to an expansion of the output in the same scale.

The technology in the model is characterised by the Cobb-Douglas production function and it is applied to all country blocs, each sector maximises its profit:

$$\Pi = p \cdot y - w \cdot N - h \cdot H - l \cdot L - r \cdot K \tag{61}$$

given the Cobb-Douglas technology:

$$y = A \cdot N^{\alpha} \cdot H^{\beta} \cdot L^{\gamma} \cdot K^{1-\alpha-\beta-\gamma} \tag{62}$$

where A is a productivity multiplier factor, which is different across borders; α, β, and γ represent for factor shares and this set of values varies across sectors, depending on their intensity in producing each product. The profit maximisation problem for the sectoral producer is thus:

$$Max\ \Pi = p \cdot y - w \cdot N - h \cdot H - l \cdot L - r \cdot K \tag{63}$$

$$s.t. y = A \cdot N^{\alpha} \cdot H^{\beta} \cdot L^{\gamma} \cdot K^{1-\alpha-\beta-\gamma} \tag{64}$$

Substituting equation (37) into equation (36) and the first order condition finds:

$$\frac{\partial \Pi}{\partial N} = A \cdot p \cdot \alpha \cdot N^{\alpha-1} \cdot H^{\beta} \cdot L^{\gamma} \cdot K^{1-\alpha-\beta-\gamma} - w = 0 \tag{65}$$

$$\frac{\partial \Pi}{\partial H} = A \cdot p \cdot \beta \cdot H^{\beta-1} \cdot N^{\alpha} \cdot L^{\gamma} \cdot K^{1-\alpha-\beta-\gamma} - h = 0 \tag{66}$$

$$\frac{\partial \Pi}{\partial L} = A \cdot p \cdot \gamma \cdot L^{\gamma-1} \cdot N^{\alpha} \cdot H^{\beta} \cdot K^{1-\alpha-\beta-\gamma} - l = 0 \tag{67}$$

$$\frac{\partial \Pi}{\partial K} = A \cdot p \cdot (1-\alpha-\beta-\gamma) \cdot K^{-\alpha-\beta-\gamma} \cdot N^{\alpha} \cdot H^{\beta} \cdot L^{\gamma} - r = 0 \tag{68}$$

Solving equation (38) as an example reads:

$$w = A \cdot p \cdot \alpha \cdot N^{-1} \cdot N^{\alpha} \cdot H^{\beta} \cdot L^{\gamma} \cdot K^{1-\alpha-\beta-\gamma} \tag{69}$$

$$w = A \cdot p \cdot \alpha \cdot N^{-1} \cdot y \tag{70}$$

The demand for unskilled labour is thus:

$$N = \frac{\alpha \cdot p \cdot y}{w} \cdot A \tag{71}$$

The demand for other factors can be derived similarly:

$$H = \frac{\beta \cdot p \cdot y}{h} \cdot A \tag{72}$$

$$L = \frac{\gamma \cdot p \cdot y}{l} \cdot A \tag{73}$$

$$K = \frac{(1-\alpha-\beta-\gamma) \cdot p \cdot y}{r} \cdot A \tag{74}$$

Thus the total demand for each factor is obtained by aggregating the sectoral demand for each factor:

$$N = N_A + N_M + N_S + N_D$$
$$= w^{-1} \cdot (\alpha_A \cdot p_A \cdot y_A + \alpha_M \cdot p_M \cdot y_M + \alpha_S \cdot p_S \cdot y_S + \alpha_D \cdot p_D \cdot y_D) \cdot e_M \tag{75}$$

$$H = H_A + H_M + H_S + H_D$$
$$= h^{-1} \cdot (\beta_A \cdot p_A \cdot y_A + \beta_M \cdot p_M \cdot y_M + \beta_S \cdot p_S \cdot y_S + \beta_D \cdot p_D \cdot y_D) \cdot e_S \tag{76}$$

$$L = L_A + L_M + L_S + L_D$$
$$= l^{-1} \cdot (\gamma_A \cdot p_A \cdot y_A + \gamma_M \cdot p_M \cdot y_M + \gamma_S \cdot p_S \cdot y_S + \gamma_D \cdot p_D \cdot y_D) \cdot e_A \tag{77}$$

$$K = K_A + K_M + K_S + K_D$$
$$= k^{-1} \cdot ((1-\alpha_A-\beta_A-\gamma_A) \cdot p_A \cdot y_A + (1-\alpha_M-\beta_M-\gamma_M)$$
$$\cdot p_M \cdot y_M + (1-\alpha_S-\beta_S-\gamma_S) \cdot p_S \cdot y_S + (1-\alpha_D-\beta_D-\gamma_D)$$
$$\cdot p_D \cdot y_D) \cdot e_K \tag{78}$$

where e_M, e_S, e_A, e_K are factor demand error processes.

3.4 Setting up the Gravity version of model

The gravity model has a similar market structure as in the classical model but with some assumptions that reflect the ‘gravity’ components. These assumptions include imperfect competition, limited commodity origin substitutability, and an effect of trade intensity to productivity. Under the specification of the gravity model, demand forces dominate the supply side of the economy – neighbours demand for imports and the rest of world demand for imports adjusted for trade barriers which can be characterised by transportation costs and border costs. Competition is highly imperfect therefore the prices are set as a mark-up over the costs and they barely move. After demand fix the trade and output, productivity will be boosted by the innovation via the channel of foreign direct investment.

The gravity model has two main differences comparing to the specification of the classical model while testing. First difference attributes to the introduction of the real exchange rate (RXR) term in the trade share equation. Trade share equations depict the trade patterns in the gravity model, imperfect competition states the dominance of the demand and trade share equations give this demand. Since RXR represents for the price of a domestic basket of goods relative to the price of a foreign counterpart and prices are not determined in the world market anymore, it is necessary to include this term in the trade share equations – it moves to satisfy current account balance. Therefore equations of the trade share bloc are the same as those in the classical model except that the term RXR enters into the equations and the export to ROW is no longer the residual supply of the US production, it is now determined by the import demand from the rest of world. The US import demand for its trading partners are thus:

$$\ln\left(\frac{M_i}{E_T}\right) = cm_i + \psi RXR + e_{M,i} \qquad i = EU, CH, ROW \tag{79}$$

Other country blocs demand for the US exports are:

$$\ln\left(\frac{X_i}{E_i}\right) = cx_i + \psi RXR + e_{X,i} \qquad i = EU, CH, ROW \tag{80}$$

The impacts of trade barriers like tariffs and transport costs are contained in the exogenous error processes $e_{M,i}$ and $e_{X,i}$ due to the lack of time series data. The parameters in the trade share equations are estimated by OLS using the data and the estimated equations are employed to bootstrap the import share data M_i/E_T and export share data X_i/E_i. The elasticity of demand to RXR is set at $\psi = 1$ for import and $\psi = -1$ for export.

The gravity model also deviates from the classical model in the determination of the productivity. In the gravity model, exports plus the imports (the total trade size) affects the foreign direct investment which in turn affect the productivity – this can be seen from the deepen relationships with foreign firms because of the enhancing trade relationships. Following this specification, the productivity in each sector are no longer the exogeneous error processes but contain the effect of the total trade term T and it is defined as:

$$\begin{aligned} T = \frac{Total\,Trade}{E_{US}} &= \frac{M_{CH} + M_{EU} + M_{ROW} + X_{CH} + X_{EU} + X_{ROW}}{E_{US}} \\ &= \frac{E_T}{E_{US}} \cdot \frac{M_{EU}}{E_T} + \frac{E_T}{E_{US}} \cdot \frac{M_{CH}}{E_T} + \frac{E_T}{E_{US}} \cdot \frac{M_{ROW}}{E_T} \\ &+ \frac{E_{EU}}{E_{US}} \cdot \frac{X_{EU}}{E_{EU}} + \frac{E_{CH}}{E_{US}} \cdot \frac{X_{CH}}{E_{CH}} + \frac{E_{ROW}}{E_{US}} \cdot \frac{X_{ROW}}{E_{ROW}} \end{aligned} \tag{81}$$

where $Total\,Trade = M_{EU} + M_{CH} + M_{ROW} + X_{EU} + X_{CH} + X_{ROW}$, and $\frac{E_T}{E_{US}} = 0.8137$ (estimated by the data), $\frac{E_{EU}}{E_{US}}, \frac{E_{CH}}{E_{US}}, \frac{E_{ROW}}{E_{US}}$ are fixed by the sample mean. The productivity term in each sector is now:

$$\Delta \ln(\pi_{i,t}) = c_{1i} + v_i \cdot \Delta T + \varepsilon_{i,t} \qquad i = M, S, A, D \tag{82}$$

where $\varepsilon_{i,t}$ characterise the trade share error processes in gravity model for each sector. Since the presenting of a mark-up due to the imperfect competition, there is a real devaluation across all traded sectors. Therefore the RXR, reflecting this devaluation, moves to solve the current account equilibrium:

$$RXR \cdot (X_{EU} + X_{CH} + X_{ROW}) = M_{EU} + M_{CH} + M_{ROW} \qquad (83)$$

It shall be noted that the different specification of RXR in the two rival models is crucial to the model behaviours, while RXR moves in the gravity version of the model to solve for the current account balance, it remains the value of one in the classical model as ROW there acting as the residual world market to clear the market automatically.

3.5 Estimation of VAR used in Part-of-model test

As has been described previously, in order to test the US part of the full world model, we need to simulate the US model as a part of the world trade model to be tested and simulate world prices and other countries' GDPs from a VAR model, where this VAR model represents the reduced form of the unknown true world model. The specification of the VAR can be represented as follows:

$$\begin{pmatrix} p_{A,t} \\ p_{M,t} \\ p_{S,t} \\ y_{China,t} \\ y_{EU,t} \\ y_{ROW,t} \end{pmatrix} = \begin{pmatrix} c_1 \\ c_2 \\ c_3 \\ c_4 \\ c_5 \\ c_6 \end{pmatrix} + \begin{pmatrix} \varphi_{11}\varphi_{12}\varphi_{13}\varphi_{14}\varphi_{15}\varphi_{16} \\ \varphi_{21}\varphi_{22}\varphi_{23}\varphi_{24}\varphi_{25}\varphi_{26} \\ \varphi_{31}\varphi_{32}\varphi_{33}\varphi_{34}\varphi_{35}\varphi_{36} \\ \varphi_{41}\varphi_{42}\varphi_{43}\varphi_{44}\varphi_{45}\varphi_{46} \\ \varphi_{51}\varphi_{52}\varphi_{53}\varphi_{54}\varphi_{55}\varphi_{56} \\ \varphi_{61}\varphi_{62}\varphi_{63}\varphi_{64}\varphi_{65}\varphi_{66} \end{pmatrix} \begin{pmatrix} p_{A,t-1} \\ p_{M,t-1} \\ p_{S,t-1} \\ y_{China,t-1} \\ y_{EU,t-1} \\ y_{ROW,t-1} \end{pmatrix} + \begin{pmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \\ \varepsilon_{3,t} \\ \varepsilon_{4,t} \\ \varepsilon_{5,t} \\ \varepsilon_{6,t} \end{pmatrix} \qquad (84)$$

The vector of variables in the VAR is expected to be cointegrated, therefore the errors should all be AR(1) process and stationary. The results of the ADF test on the errors in the VAR are summarised in table 5-6, all the errors are stationary, ensuring a cointegration relationship among variables included in the VAR.

Table 3-1 ADF test on the errors in the VAR

ADF test	**Stationary**	**Trend stationary**	**Nonstationary**
p_A			√

	p_M		√
	p_S		√
	y_{China}		√
	y_{EU}		√
	y_{ROW}		√
Residuals			
	ε_1	√	
	ε_2	√	
	ε_3	√	
	ε_4	√	
	ε_5	√	
	ε_6	√	

After confirming the vector of variables are cointegrated, the results of estimation of φ matrix can be shown in table 5-7:

Table 3-2 Estimation of φ matrix

	$p_{A,t-1}$	$p_{M,t-1}$	$p_{S,t-1}$	$y_{China,t-1}$	$y_{EU,t-1}$	$y_{ROW,t-1}$	$constant$
p_A	0.7152	-0.1739	-0.7234	-0.0027	0.0068	0.0019	-15.0301
p_M	0.0308	0.8421	-0.1622	-0.0006	0.0012	0.0005	-0.6819
p_S	0.0873	-0.0516	0.4495	-0.0027	0.0022	0.0015	-15.1136
y_{China}	6.9738	-16.7192	-11.1908	0.9775	0.1252	0.0540	-769.6021
y_{EU}	3.1827	-23.3962	-50.5110	-0.2845	1.1383	0.2171	-825.1045
y_{ROW}	-14.9323	36.2681	30.0989	0.2409	-0.0700	0.8481	1079.3501

3.6 Data

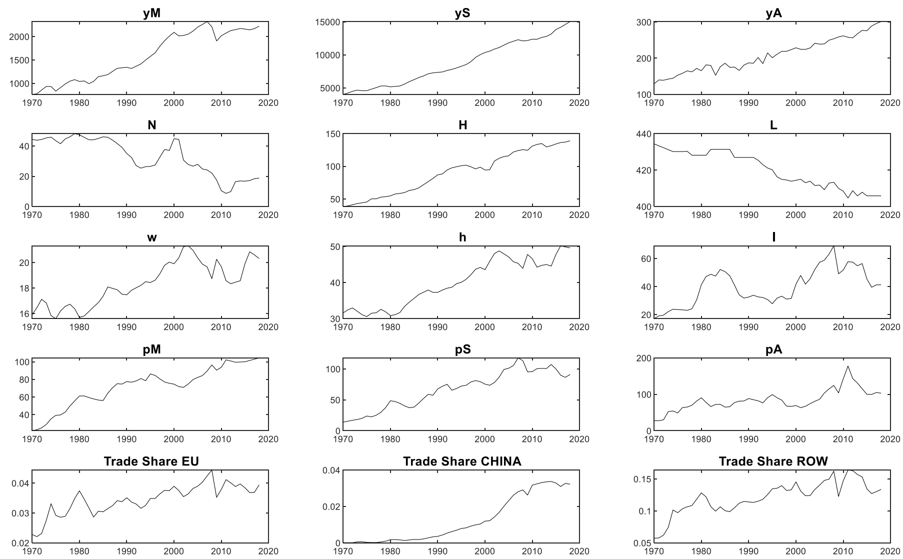
The sources of the data can be summarised as follows; a complete description of the data used in the model can be found in the Appendix B Data description:

1) Output by sector: Agriculture, Industry, Service, Nontraded - sources are: FAOSTAT, OECD Statistics; World Bank; AMECO database. 2) Trade data (export and import data) by sector: Agriculture, Industry, Service - sources are: FAOSTAT; BEA - US department of commerce. 3) Population and employment

- sources are: BLS; AMECO database. 4) Earnings of skilled workers: Ratio of skilled earning to unskilled earnings (Decile9/Decile5) - Source: OECD Statistics. 5) Goods price index: Agriculture, Industry, Service, Nontraded - Sources are: World Bank Commodity Price Data (The Pink Sheet); OECD Statistics; BEA - National Income and Product Accounts; BLS. 6) Rent on land (£ per hectare) - source: Board of Governors of the Federal Reserve System (US). 7) Real interest rate - source: AMECO database. 8) other world data: source as for UK.

All data are annual data from 1970 to 2018.

Figure 3-1 Plot of actual data



4 Testing Methods: Indirect Inference Wald Test

4.1 The indirect inference method of model evaluation

According to Le et al. (2016), indirect inference preserves the basic idea of evaluating the early RBC models – contrasting the moments produced by data simulated from the model against the actual data, to assess a calibrated or estimated (or partly estimated) model. The auxiliary model can be viewed as an extension of this process, establish this general but formal model, in fact the conditional mean of the data distribution, and compare the features of the simulated data estimated model and the actual data estimated model. These features can also take the form of moments and other measures derived from the data and the model simulations if needed. This comparison is performed through the 'Indirect Inference Wald' test which involved with the calculation of the Wald statistics. If the null hypothesis cannot be rejected, the structural model is correct, it means that the simulated data and the descriptors estimated using these data will not be significant from those generated from the actual data.

The structural shocks suggested by the estimated model are obtained to create the simulated data by bootstrapping the structural model using these shocks. Certain number of simulated data sets will be generated through repeating the above process, the distribution of data descriptors derived from those simulated data sets will then be applied to compare with the data descriptors derived from the actual data. This test tells that whether the actual US history can be displayed at a certain selected probability test level, where the probability is derived from the distribution of likely histories established by differentiated US shocks and actual world situation. Following this basis of the test, the Wald statistic is calculated as below:

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

Where a_T is derived from the estimation of the data descriptors using actual data, $\overline{a_S(\theta_0)}$ stands for the expected value of the distribution of the estimates of the data descriptors generated from the simulated data and θ_0 represents for the vector of parameters of our trade model when it is not significantly different from the true model (the null hypothesis is not rejected). $W(a_S(\theta_0))$ is the variance-covariance matrix of the distribution of a_S, the estimation of the auxiliary model when the simulated data is used.

The procedures of the practical application of the Indirect Inference Wald test by bootstrapping can be illustrated as follows: the first step is to estimate the errors of the structural model $x_t(\theta_0)$, using the real data and the vector of the 'true' model parameters θ_0. These estimations of the structural errors are independent and their number should be less than or equal to the number of endogenous variables. In the case where the equation does not incorporate expectations, the error can naturally be estimated from the equation and data. The second step conveys the derivation of the simulated data. On the null hypothesis we have two sets of structural errors, $\{\pi_{i,t}\}_{t=1}^{T}$, the productivity error processes and $\{e_{i,t}\}_{t=1}^{T}$, the factor supply and factor demand error processes. As noted earlier, the model errors will be either non-stationary or trend stationary and will also be autocorrelated. They need to be estimated as AR(1), AR(1) with trend or AR(1) on their first difference process, depends on what stationarity property they have. Then the simulated data is derived by drawing the bootstrapped disturbances in terms of the time vector to retain simultaneity if there is any, and solving the structural model. Repeat this process independently if N samples of bootstrapped simulations are needed. The final step shows the computation of the Wald statistic. The estimation of the auxiliary model involves the application of the actual data and the simulated data (N samples in total), the resulting estimates are a_T and $a_S(\theta_0)$, the estimated coefficients of the auxiliary model using actual data and simulated data respectively. Then we need to estimate the distribution of $a_T - \overline{a_S(\theta_0)}$ and its variance-covariance matrix $W(a_S(\theta_0))$ by bootstrapping $a_S(\theta_0)$. This bootstrapping process involve with drawing N samples by bootstrapping the structural model, and use each of the sample to estimate the auxiliary model to obtain N values of $a_S(\theta_0)$. The covariance of the simulated variables can be derived from the bootstrapped samples. The obtained set of N vectors of $a_S(\theta_0)$ characterises the sampling variation delivered by the structural model, the estimates of its mean, variance-covariance matrix and confidence limits can be computed directly from it. The variance-covariance matrix can be thus calculated as:

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

where $\overline{a_k} = \frac{1}{N}\sum_{k=1}^{N} a_k$ is the mean value of the N vectors of the estimated coefficients of the auxiliary model using simulated data. The value of this calculation is then be used to compute the Wald statistic as:

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

The bootstrap distribution of the Wald can also be estimated from the N samples. The position of the Wald statistic in the bootstrap distribution of the Wald statistic can be displayed based on how the data lies, this is the Wald percentile. The overall measure of the test, how the model fits the data, can be interpreted by the Wald p-value. This is produced by calculate the equivalent t-statistics, which is computed by normalising the Mahalanobis Distance derived from the same joint distribution.

4.2 The Auxiliary model

Trade models are designed to answer questions like how trade structure affect output in each sector, which sector will experience larger grow or contract in its output, and how the trade behaviour revealed between countries. One can also use trade models to explain the economic behaviour in factor markets, such as trends in labour supply and wages. All of these trends can be accommodated by the auxiliary model. The role of the auxiliary model is to depict the data behaviour. In testing the US trade model here, the auxiliary model is established with a set of regression equations that includes variables that can depict the country trade trends. The data of these variables are all non-stationary, it is possible to form a cointegration relationship that can relate these series through their common trends. Thus in the auxiliary model, a set of descriptive cointegration relationships can be built to join the selected endogenous variables and exogenous variables to form a long term relationship.

The testing procedure focuses on evaluating the simulation performance of the model against the real data behaviour, this requires a rigorous selection of the variables that can reflect trade behaviour from the model. As more features are included, i.e., more variables are included in the auxiliary model, the power of the indirect inference test tends to infinity. One can of course include all the trade features in the auxiliary model to allow more trends to be compared, but only a model that very close to the real world will not be rejected, which is unrealistic from the modelling perspective. Therefore the selection of the features that are included in the auxiliary model should consider the power of the test in a way that a good but not excessive power can be achieved in the test.

Here in testing our model, two data movements are considered as the main focus, one is the output share defined as the manufactures output divided by service output, the other is the trade shares (for each country bloc) defined as the sum of the export and import (for each country bloc) divided by the US output. The reason of choosing these two shares is that output share can explain the country's output structure and trade share can show the direction of the trade flow. These trends are accompanied by: i) the relative world prices and relative productivity of manufactured goods and services, with raw materials as the numeraire; ii) the relative factor supplies of land, unskilled and skilled labour in the US. Equations in the auxiliary model are specified as follows:

$$TS_{EU} = a_1 + a_{11} \cdot \frac{\pi_M}{\pi_S} + a_{12} \cdot \frac{N}{H} + a_{13} \cdot \log(GDP_{EU}) + a_{14} \cdot \log(GDP_{China}) + a_{15} \cdot \frac{w}{h} + \varepsilon_1$$

$$TS_{CH} = a_2 + a_{21} \cdot \frac{\pi_M}{\pi_S} + a_{22} \cdot \frac{N}{H} + a_{23} \cdot \log(GDP_{EU}) + a_{24} \cdot \log(GDP_{China}) + a_{25} \cdot \frac{w}{h} + \varepsilon_2$$

$$OS_{US} = a_3 + a_{31} \cdot \frac{\pi_M}{\pi_S} + a_{32} \cdot \frac{N}{H} + a_{33} \cdot \log(GDP_{EU}) + a_{34} \cdot \log(GDP_{China}) + a_{35} \cdot \frac{w}{h} + \varepsilon_3$$

$$TS_{ROW} = a_4 + a_{41} \cdot \frac{\pi_M}{\pi_S} + a_{42} \cdot \frac{N}{H} + a_{43} \cdot \log(GDP_{EU}) + a_{44} \cdot \log(GDP_{China}) + a_{45} \cdot \frac{w}{h} + \varepsilon_4$$

where OS_{US} stands for output share and it equals to $\frac{y_M}{y_S}$, manufacturing output divided by service output; TS_{EU}, TS_{CH} and TS_{ROW} are trade shares of each country bloc, they equal to $\frac{M_{EU}+X_{EU}}{GDP_{US}}$, $\frac{M_{CH}+X_{CH}}{GDP_{US}}$ and $\frac{M_{ROW}+X_{ROW}}{GDP_{US}}$ respectively, where elements in the numerator are total trade and element in the denominator is the US output. Variables on the right-hand side include $\frac{\pi_M}{\pi_S}$, US relative productivity of manufacturing sector and services sector; $\frac{N}{H}$, US relative factor share, it is the supplies of skilled labour relative to supplies of unskilled labour; finally, GDP_{EU} and GDP_{CH} are output of the EU and the China. The key coefficients a_{ij}s can thus be used to account for the trade behaviour for a country we are interested in through the relationships derived from the data.

4.3 The part-of-model test

The part-of-model test (Minford et al. 2019) allows the testing of a subset of the equations embedded in the model, this method is adopted here in order to test the US part of the full world model. It takes the effects of shocks from other parts of the full world model into account when testing the US trade model on its own. Minford and Xu (2018) test a CGE trade model using indirect inference on UK facts, where the world prices and other countries' GDPs are treated as exogenous. This treatment is based on the fact that its GDP only accounts for approximately 4% of the world GDP; it is thus reasonable to omit its effect on world prices and GDPs of other countries. However, as a large continental country, US economy has a non-negligible effect on them. The application of the part-of-model test addresses this problem by simulating the US model as a part of the world trade model to be tested and simulating world prices and other countries' GDPs from a Vector Autoregression (VAR) model. This VAR model represents the reduced form of the unknown true world model. Hence failure to meet the test can only come from the US model part of the full global model.

Its implementation in testing the US model starts with bootstrapping the shocks from the VAR. This generates simulated world prices and other countries' GDPs, these simulated world variables are then introduced into the US model, together with the model's simulated shocks. The simulated US variables derived from solving the model are employed to produce the auxiliary model which account for the behaviour implied by both the US model and the full world model. If the model is rejected through the indirect inference test, the US model is not correctly specified as the world prices and other countries' GDPs are adhering to the true unknown world model. According to Minford et al (2019), this test is unbiased with the full-model test, and it also provide significant power of the test.

5 Empirical Results

5.1 Indirect Inference Wald test result

The interpretation of the test results is organised in terms of the general steps of implementing the Indirect Inference Wald test.

Firstly, estimate the errors of the structural model $x_t(\theta_0)$, using the real data and the vector of the 'true' model parameters θ_0. For both the classical and gravity trade model specified in the model section, the structural errors are $\pi_{i,t}$, the productivity error processes; $e_{i,t}$, the factor supply and factor demand error processes; $em_{i,t}$ and $ex_{i,t}$, trade share error processes. These structural errors are extracted, given the parameter values specified in the model and the collected actual data. The stationarity property of these errors is tested using ADF and KPSS tests (Table 5-1), and appropriate process is estimated based on the stationarity test result.

Table 5-1 ADF test on model residuals

ADF test	**Stationary**	**Trend stationary**	**Nonstationary**
ln (π_M) manufacture productivity error			√
ln (π_S) service productivity error			√
ln (π_A) agriculture productivity error			√
ln (π_D) nontraded 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_K) capital demand error			√
ln (e_N) manufacture factor supply error			√
ln (e_H) service factor supply error			√
em_{UK} trade share error	√		

em_{EU} trade share error	√
em_{ROW} trade share error	√
ex_{UK} trade share error	√
ex_{EU} trade share error	√
ex_{ROW} trade share error	√

Secondly, obtaining the simulated data for both classical model and the gravity model. Since the specifications of the trade share bloc are different for these two rivalry models, we start from explaining the behaviour in classical model. In classical model, trade share errors are stationary therefore they are assumed to follow an AR(1) process based on the ADF test results provided in Table 5-1:

$$em_{i,t} = c_{1i} + \rho_{1i}(em_{i,t-1}) + \varepsilon_{mi,t} \qquad i = UK, EU, ROW$$

$$ex_{i,t} = c_{2i} + \rho_{2i}(ex_{i,t-1}) + \varepsilon_{xi,t} \qquad i = UK, EU$$

where $\varepsilon_{mi,t}$ and $\varepsilon_{xi,t}$ are model innovations and are serial independent, they are bootstrapped to generate the bootstrapped trade share errors. Then the trade share data is generated through the trade share equations specified for the classical trade model.

Other variables in the classical trade model are bootstrapped accordingly. This process starts with obtaining the implied model residuals π_i and e_i from the model equations. According to the ADF test on the model residuals reported in Table 5-1, all the productivity errors and factor demand and supply errors are nonstationary except for service factor demand error. As a result, the service factor demand error $\ln(e_s)$ is assumed to follow an AR(1) process with an constant, and the first difference of the rest of residuals are assumed to follow an AR(1) process with drift:

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

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

$$\ln(e_{i,t}) = c_{3i} + \rho_{3i}\ln(\pi_{i,t-1}) + \eta_{i,t} \qquad i = S$$

The above AR(1) processes are estimated to generate the bootstrapped productivity errors π_i and factor share errors e_i. Other endogenous variables can be bootstrapped through model solving process.

In the gravity model, two particular specifications that depart from the classical model need to be clarified. As illustrated in the model section, the first difference is considering the specification of the productivity errors. They are driven by total trade term T, the total trade share in GDP, which represents the trade effect on productivity. Here it is assumed a semi-elasticity of 2 for all three traded sectors: agricultural, manufacturing and services, there will be a 2% increase in each sector with regards to an absolute increase of 1 in T. The treatment of the factor share errors are identical to that in the classical model, they are stationary and follow an AR(1) process except for the service factor demand residual. The resulting model residuals in the gravity model are thus estimated as follows:

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

$$\Delta\ln(\pi_{i,t}) = c_{2i} + \rho_{2i}\Delta\ln(\pi_{i,t-1}) + \epsilon_{i,t} \qquad i = D$$

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

$$ln(e_{i,t}) = c_{3i} + \rho_{3i} ln(e_{i,t-1}) + \emptyset_{3i} * t + \eta_{i,t} \qquad i = S$$

where $v_i = 2$ captures the semi-elasticity for all the traded sectors. The estimation process is exactly the same as that of the classical model: estimating the above equations delivers the bootstrapped productivity errors π_i and factor share errors e_i, and the rest of the endogenous variables are bootstrapped by solving the model. As discussed in the model section, the second difference is that all trade shares are affected by the real exchange rate, although the effect of the RXR is included, the ADF test shows that the trade share errors are also stationary in the gravity model and therefore they are assumed to follow an AR(1) process with a constant:

$$em_{i,t} = c_{1i} + \rho_{1i} em_{i,t-1} + \varepsilon_{mi,t} \qquad i = CH, EU, ROW$$

$$ex_{i,t} = c_{2i} + \rho_{2i} ex_{i,t-1} + \varepsilon_{xi,t} \qquad i = CH, EU, ROW$$

The above AR(1) processes are estimated and the bootstrapped trade share data is drawn from the equations in trade share bloc in the gravity model. Table 5-2 summarises the estimated coefficients for all the error processes discussed above:

Table 5-2 Estimated coefficients for the error process

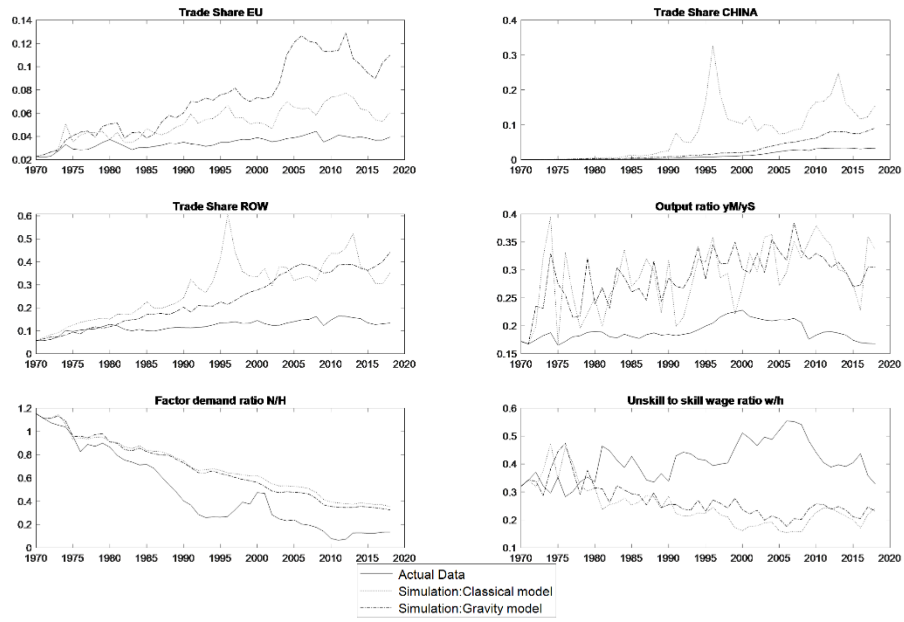
Estimates	Classical trade model		Gravity model		
	ρ	c	ρ	c	v
$\Delta\ln(\pi_M)$	0.1274	0.0100		0.0066	2.0
$\Delta\ln(\pi_S)$	-0.3721	0.0066		0.0023	2.0
$\Delta\ln(\pi_A)$	-0.4276	0.0230		0.0165	2.0
$\Delta\ln(\pi_D)$	-0.1937	0.0053	-0.2171	0.0068	
$\Delta\ln(e_M)$	0.2941	-0.0234	0.3183	-0.0227	
$\ln(e_S)$	0.5039	-0.0803	0.3930	-0.1190	
$\Delta\ln(e_A)$	-0.1525	-0.0022	-0.0960	0.0016	
$\Delta\ln(e_N)$	0.3373	-0.0181	0.3325	-0.0181	
$\Delta\ln(e_H)$	-0.0076	0.0267	-0.0280	0.0270	
em_{CH}	0.8389	0.0274	0.9238	-0.2597	
em_{EU}	0.5468	0.0027	0.8250	-0.6340	
em_{ROW}	0.7472	0.0067	0.7817	-0.5063	
ex_{CH}	0.8008	0.0346	0.8058	-0.8766	
ex_{EU}	0.3223	2.265e-05	0.5210	-1.8801	
ex_{ROW}			0.6492	-1.3101	

Finally, calculating the Wald statistic and presenting the Indirect Inference Wald test results (number of bootstraps: 5000). The test result indicates that both classical and gravity model pass the test for the US facts with a very close probability (see table 5-3). Figure 5-1 shows the comparison of the trends among the actual data, the average of the simulations generated by the classical model, and the average of the simulations generated the gravity model, this might provide some explanations regarding to the test result. As shown from the figure, comparing with the actual data, the performance of the average simulations provided by the two models do not show much differences in factor demand ratio and unskilled to skilled wage ratio; the variation trends of both simulations are overlapping in the output ratio but with slight differences in the magnitude; classical model provides a better simulation to mimic the actual EU trade share data while gravity model is superior in modelling the China trade share behaviour; as for the ROW trade share, both models show an upward trend but simulations from the classical model are more volatile than that from the gravity model. However these comparisons can only partly explain the test result, since the Indirect Inference Wald test is relied on the joint distribution of the estimated coefficients derived from the auxiliary model when using the simulated data, implying the dependence on all the simulated data and not the average of them.

Table 5-3 Indirect Inference Wald test results

	Equations in auxiliary model	P-value
Classical trade model	1), 2), 3), 4)	0.070
Gravity model	1), 2), 3), 4)	0.070

Figure 5-1 Plot of actual and simulated data



In order to check for any possible threshold that can distinguish two models regarding to their modelling ability, we perform the following experiments, eliminating two “gravity effects” one by one: the first difference between the classical model and the gravity model is the specification in the trade share equation, this is due to the assumption of imperfect competition in the gravity model; the second is that in the gravity model, the term “total trade share” defined in the model section has an effect on sectoral productivity (dT effect). The results are summarised in table 5-4:

Table 5-4 Indirect Inference Wald test results: dT effect

Gravity model	Equations in auxiliary model	P-value
With classical trade share equations	1), 2), 3), 4)	0.14
No dT effect	1), 2), 3), 4)	0.03
	1), 2), 3)	0.06

As can be seen from the results, if the equations in trade share bloc in the gravity model are replaced by the classical trade share equations, the p-value raises to 0.14. This implies that the assumption of the imperfect substitutability (heterogeneity by country origin) is less proper than perfect substitutability as in the classical model. By dropping the heterogeneity characteristic in the gravity model, the model passes the test fairly easy. If the link from the trade shares to productivity is dropped, the gravity model is rejected at p-value equals to 0.03 when all the equations in the auxiliary model are used, but passes the test at p-value equals to 0.06 when only three equations are used.

One last experiment can be conducted to check for that the assumption of the heterogeneity is relatively less proper than the assumption of goods homogeneity specified in the classical model is to reduce the quantitative size of the effect of the imperfect competition assumption, doubling the elasticity of *RXR* on trade shares, ψ, the trade elasticity. The comparison is shown in table 5-5: the weaker version of the gravity model (ψ=2.0) passes the test at a slightly higher probability 0.08, which suggests that less heterogeneity, the closer the model to the data. This is consistent with the result drawn from the previous experiment when the trade share equations in the gravity model are replaced by the classical trade share equations. The result also indicates that the probability of passing the model is not very sensitive to the change of the degree of heterogeneity – modifying the value of the trade elasticity does not cause much variation of the p-value.

Table 5-5 Indirect Inference Wald test results: different trade elasticities

Gravity model	Equations in auxiliary model	P-value
Strong gravity model (ψ=1.0)	1), 2), 3), 4)	0.07
Weak gravity model (ψ=2.0)	1), 2), 3), 4)	0.08

A Monte Carlo experiment can be adopted to assess the power of the Indirect Inference Wald test irrespective of how many regressions are used in the auxiliary model. The more regressions included the higher the test power. However, the power should not be so large that only models very close to the truth can pass the test. Table 4-1 shows the result regarding to the power of Indirect Inference Wald test reported in Chen et al. (2021), it reveals how frequently the true models of the UK, and the US are rejected when these two models become falser. They find the power is substantial but not excessive when they use all regressions in the auxiliary model. This experiment starts from falsifying all parameters by $x\%$ positively and negatively. Then the "True" can be obtained by creating 1000 samples from the classical model, they test both the true and falsified models on these samples to identify the frequency of rejection. For the UK model, the test rejects model with 3% falsified parameters almost all the time, any model with more than 3% falsified parameters is rejected 100% of the time. In other words, if a model is not rejected by this test, it must be very close to the real world. For the US model, where the part-of-model test is applied, although the power declined from the test of UK, it is significant and appropriate when all the regressions are used, and the figure climbs sharply as the percent mis-specified exceeds 5%.

Table 5-6 Power of Indirect Inference Wald test

Percent Mis-specified	Rejection Rates at 95% Confidence Level	
	UK	US
True	5.00%	5.00%
1%	40.5%	6.4%
3%	99.9%	15.8%
5%	100%	27.6%

7%	100%	43.5%
10%	100%	74.5%
15%	100%	90.7%
20%	100%	91.4%

All the experiments implemented above demonstrate that the two models do not essentially depart heavily from each other. The magnitude of the gravity effects constructed in this computable general equilibrium model is not that significant. The fluctuation of the total trade shares is not enough to have much impact on productivity, and the interferences from demand shocks to the current account equilibrium do not cause *RXR* to change much therefore the move in the trade shares in the gravity model is much similar to that in the classical model.

5.2 Welfare calculation and policy implication

Since both models passed the test, they are ready to be applied to derive some policy implications. Table 5-8 shows the simulations of a 10% tariff raised in agricultural and manufacturing sectors. Similar as the test results, the simulations produced by these two models do not diverge greatly. They both indicate an approximately 10% welfare loss from an increase in tariffs imposed by the US government, where the percentage change in welfare contains the percentage loss of total output, the percentage loss of consumer surplus (this is given by percentage rise in CPI times 0.5), and the gain or loss in terms of trade (this is given by the percentage change in RXR term times import share of GDP). In the gravity model, there is a counteracting benefit from RXR, which implies a gain on terms of trade. When the US as a large importing country imposes a tariff on a good imported, the foreign price will fall in correspondence to this. Since the US imports of this good takes a significant proportion of the world demand for this good, the reduced demand from the US imports due to the effective tariff would cut down the world demand for this good. The profit-seeking firms from the rest of the countries have to lower the production and price to clear the market. This gives a gain on terms of trade in the gravity model as the terms of trade by definition represents the ratio between the price of products that a country export and the price of its import products. Since the price of its imports will fall, the implementation of the tariff will improve the terms of trade of the US.

Table 5-7 Effects of 10% tariff on food and manufacturing

	Base Run	10% tariff on food and manufacturing		(% change)	
		Gravity	Classical	Gravity	Classical
y(GDP)	19350	17252	17719	-10.84	-8.43
y_A	301	301	301	0.00	0.00
y_M	2222	4687	4769	110.94	114.63
y_S	13223	9050	9348	-31.56	-29.30
y_D	3604	3213	3300	-10.85	-8.44
E_A	1875	1789	1808	-4.59	-3.57
E_M	1714	1629	1648	-4.96	-3.85
E_S	12632	11095	11437	-12.17	-9.46
w	20.6117	23.295	24.0125	13.02	16.50
h	57.747	47.5188	49.1422	-17.71	-14.90
l	42.3535	43.6624	58.8143	3.09	38.87
N	18.8	19	19.1	1.06	1.60
H	139.1	134.8	134.8	-3.09	-3.09

L	405.9	339.2	260.4	-16.43	-35.85
K	4042.9	3532.2	3649.2	-12.63	-9.74
p(CPI)	0.9369	0.9479	0.9543	1.17	1.86
p_A	0.9876	1.0863	1.0863	10.00	10.00
p_M	1	1.1	1.1	10.00	10.00
p_S	0.872	0.872	0.872	0.00	0.00
p_D	0.9848	1.0295	1.0674	4.54	8.39
RXR	99.1205	109.81	99.1205	10.78	0.00
welfare				-10.09	-9.36

The base run is based on year 2018 data. Welfare is captured by the percentage loss of total output, the percentage loss of consumer surplus, and the gain or loss in terms of trade. The formular is thus: $welfare = \%\Delta y - \%\Delta p \cdot 0.5 + \%\Delta RXR \cdot \frac{M}{y}$, where M represents for import.

6 Conclusions

The identification problem might arise from the estimated relationship using gravity equations because these relationships can be used to work backwards to build other CGE models that can also generate such relationships. In order to test different CGE structural models, it is necessary to make empirical comparisons based on the ability of different models to match the regression on endogenous variables. Two rival versions of the CGE trade models have been described in this study, one is derived from the classical theory of comparative advantage, the other is featured by the elements in recent gravity theory. These two models have been tested by indirect inference method against US time-series trade facts. It is a method that allows the use of small samples of data and can powerfully reject a model that is not correctly specified. The test procedure mainly focuses on a comparison between real data behaviour and simulated data behaviour by using an 'auxiliary model'.

As a large continental country, US economy has a non-negligible effect on the behaviour of the rest of the world - world prices and GDPs of other countries therefore cannot be treated as exogenous. The application of the part-of-model test address this problem by simulating the US model as a part of the world trade model to be tested and simulate world prices and other countries' GDPs from a VAR as the reduced form of the unknown true world model. Hence failure to meet the test can only come from the US model part of the full global model.

Empirical findings show that both versions of model pass the test with close probabilities. The US seems to have close ties to the neighbouring economies modelled in the Gravity version and this will not compromise the model's ability to match its trade facts. Two additional experiments further imply that the assumption of the imperfect substitutability (heterogeneity by country origin) is less proper than perfect substitutability as in the classical model, and the probability of passing the model is not very sensitive to the change of the degree of heterogeneity. Tariff simulation indicates an approximately 10% welfare loss from an increase in tariffs imposed by the US government, this implies that protection harms welfare, to a similar extent in both versions of the trade model we have examined.

Appendix A: Listing of variables

y_A	US agriculture output, real, billion dollars, constant 2015
y_M	US manufacturing output, real, billion dollars, constant 2015
y_S	US service output, real, billion dollars, constant 2015
y_D	US non-traded output, real, billion dollars, constant 2015
y	US GDP, real, billion dollars, constant 2015
G	Government expenditure/GDP
BOP	US balance of payment, real, billion dollars, constant 2015
p_A	agriculture price index, 2015=100
p_M	manufaturing price index, 2015=100
p_S	service price index, 2015=100
p	US 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 physical capital, 2015=100
RXR	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 population, million persons
b	unemployment benefit, real, billion dollars, constant 2015
X_{EU}	export to EU, real, billion dollars, constant 2015
X_{China}	export to China, real, billion dollars, constant 2015
X_{ROW}	export to ROW, real, billion dollars, constant 2015
M_{EU}	import from EU, real, billion dollars, constant 2015
M_{China}	import from China, real, billion dollars, constant 2015
X_{ROW}	import from ROW, real, billion dollars, constant 2015
E	Expenditure on US goods
E_A	Expenditure on US agricultural products
E_M	Expenditure on US manufacturing products
E_S	Expenditure on US services products

E_T	Expenditure on US traded products

Appendix B: Data description

Variables	Sources	Processing information
Price Indices		
- agricultural	World Bank Commodity Price Data (The Pink Sheet)	base year: 2015/ world price
- manufacturing	OECD Statistics - Prices and PPP	base year: 2015/ US price
- services	BEA - National Income and Product Accounts	base year: 2015/ US price
- nontraded	BLS - Producer Price Index by Commodity for Machinery and Equipment: Construction Machinery and Equipment	base year: 2015/ US price
- US CPI	OECD Statistics	base year: 2015/ US price
- China CPI	FRED	base year: 2015/ China price
- EU CPI	OECD Statistics	base year: 2015/ EU price/partly approxy by Europe data (growth rate) and Canada data
Price of input factors		
- Decile9/Decile5	OECD Statistics	skilled wage = Decile9/Decile5 * Unskilled wage
-Unskilled wage	Organization for Economic Co-operation and Development (hourly earnings for manufacturing)	
- Skilled wage	Calculated by the above two data sets	
- rent on land	Board of Governors of the Federal Reserve System (US), retrieved from FRED/ OECD Statistics	rent flows from the 1st source (millions of dollars), land from the 2nd source (thousand hectares), using these two sets to calculate rent on land, dollars per hectare
- return on capital	AMECO database	
Input factors		
- working population	AMECO database/ World Bank - school	working population from the 1st source, using this multiplies the school

- unskilled labour	enrollment, tertiary (% of gross)	enrollment, tertiary (% of gross) to obtain the amount of Skilled Labour. Unskilled labour = working population - skilled labour/ million persons
- skilled labour		
- land	OECD Statistics - agricultural land	million hectares
- capital	AMECO database - Gross fixed capital formation at current prices	using US CPI to convert it to constant 2015/ billion dollars
Output		
- agricultural	FAOSTAT	value of agricultural production (Net)/ billion dollars/ constant 2015
- manufacturing	OECD Statistics/ World Bank	value added/ billion dollars/ constant 2015
- services	AMECO database	value added/ billion dollars/ constant 2015
- nontraded	calculated	$y_D = y - y_A - y_M - y_S$
- US GDP	FRED	billion dollars/ constant 2015
- China GDP	World Bank data/ Statistics Times	billion dollars/ constant 2015
- EU GDP	World Bank data/ Statistics Times	billion dollars/ constant 2015
- World GDP	World Bank data/ IMF - World Economic Outlook	billion dollars/ constant 2015
Unemployment benefit	BEA - Personal current transfer receipts: Government social benefits to persons: Unemployment insurance	billion dollars/ constant 2015
Government expenditure	FRED	using this divided by GDP
Trade bloc		
- balance on current account	BEA - National Income and Product Accounts	billion dollars/ constant 2015
- export to China/EU/ROW	IMF - Direction of Trade Statistics	billion dollars/ constant 2015
- import from China/EU/ROW	IMF - Direction of Trade Statistics	billion dollars/ constant 2015
- real exchange rate	Bruegel datasets/ IMF - International Financial Statistics	Real Effective Exchange Rate (REER), 67 of trading partners considered/ base year: 2015

Expenditure		
- agricultural	OECD - National Accounts, 5. Final consumption expenditure of households	only use the fraction of sectoral expenditure on total consumption
- manufacturing		
- services		
Trade by sector		
- agricultural export	FAOSTAT	billion dollars/ constant 2015
- manufacture export	calculated	total export - agricultural export - services export
- services export	BEA - U.S department of commerce	billion dollars/ constant 2015
- agricultural import	FAOSTAT	import (foods, feeds, beverages) + nondurable petroleum and products
- manufacturing import	calculated	total import - agricultural import - services import
- services import	BEA - U.S department of commerce	billion dollars/ constant 2015
- total export	BEA - U.S department of commerce	billion dollars/ constant 2015
- total import	BEA - U.S department of commerce	billion dollars/ constant 2015

Appendix C: Model listing

Prices for each sector: solve for w, h, l and p_D respectively.

$$p_M = w^{0.52528} \cdot h^{0.14472} \cdot l^{0.03} \cdot (p_M \cdot r)^{0.3} \cdot \pi_M^{-1}$$

$$p_S = w^{0.19138} \cdot h^{0.46862} \cdot l^{0.06} \cdot (p_M \cdot r)^{0.28} \cdot \pi_S^{-1}$$

$$p_A = w^{0.24237} \cdot h^{0.21763} \cdot l^{0.18} \cdot (p_M \cdot r)^{0.36} \cdot \pi_A^{-1}$$

$$p_D = w^{0.47162} \cdot h^{0.20838} \cdot l^{0.05} \cdot (p_M \cdot r)^{0.27} \cdot \pi_D^{-1}$$

$$\ln(w) = (\frac{1}{0.52528}) \cdot \{\ln(p_M \cdot \pi_M) - 0.14472 \cdot \ln(h) - 0.03 \cdot \ln(l) - 0.3 \cdot \ln\,(p_M \cdot r)\}$$

$$\ln(h) = (\frac{1}{0.46862}) \cdot \{\ln(p_S \cdot \pi_S) - 0.19138 \cdot \ln(w) - 0.06 \cdot \ln(l) - 0.28 \cdot \ln\,(p_M \cdot r)\}$$

$$\ln(l) = (\frac{1}{0.18}) \cdot \{\ln(p_A \cdot \pi_A) - 0.24237 \cdot \ln(w) - 0.21763 \cdot \ln(h) - 0.36 \cdot \ln\,(p_M \cdot r)\}$$

π_M, π_S, π_A, π_D are exogenous productivity error processes.

Factor demands:

$$N = w^{-1} \cdot (0.24237 \cdot p_A \cdot y_A + 0.52528 \cdot p_M \cdot y_M + 0.19138 \cdot p_S \cdot y_S + 0.47162 \cdot p_D \cdot y_D) \cdot e_M$$

$$H = h^{-1} \cdot (0.21763 \cdot p_A \cdot y_A + 0.14472 \cdot p_M \cdot y_M + 0.46862 \cdot p_S \cdot y_S + 0.20838 \cdot p_D \cdot y_D) \cdot e_S$$

$$L = l^{-1} \cdot (0.18 \cdot p_A \cdot y_A + 0.03 \cdot p_M \cdot y_M + 0.06 \cdot p_S \cdot y_S + 0.05 \cdot p_D \cdot y_D) \cdot e_A$$

$$K = k^{-1} \cdot (0.36 \cdot p_A \cdot y_A + 0.30 \cdot p_M \cdot y_M + 0.28 \cdot p_S \cdot y_S + 0.27 \cdot p_D \cdot y_D) \cdot e_K$$

e_M, e_S, e_A, e_K are factor demand error processes

$$y_M = (\frac{1}{0.52528 \cdot p_M}) \cdot (\frac{N \cdot w}{e_M} - 0.47162 \cdot p_D \cdot y_D - 0.19138 \cdot p_S \cdot y_S - 0.24237 \cdot p_A \cdot y_A)$$

$$y_S = (\frac{1}{0.46862 \cdot p_S}) \cdot (\frac{H \cdot h}{e_S} - 0.20838 \cdot p_D \cdot y_D - 0.14472 \cdot p_M \cdot y_M - 0.21763 \cdot p_A \cdot y_A)$$

y_A Exogenous process

Factor supplies:

$$N = e_N \cdot (\frac{w}{b})^{0.1} \cdot POP^{0.5} \cdot G^{0.5}$$

$$H = e_H \cdot (\frac{h}{w})^{0.1} \cdot G^{0.5}$$

$$L = l^{-1} \cdot (0.18 \cdot p_A \cdot y_A + 0.03 \cdot p_M \cdot y_M + 0.06 \cdot p_S \cdot y_S + 0.05 \cdot p_D \cdot y_D) \cdot e_A$$

L is supplied according to demand through planning system, agricultural production is thus fixed exogenously.

$$y_D = 0.1862 \cdot E$$

$$y = y_A + y_M + y_S + y_D$$

$$E = y$$

$$E_T = E - y_D - BOP$$

$$E_M^{US} = E_T^{US} - E_S^{US} - E_A^{US}$$

$$E_S^{US} = 0.9 \cdot E_T^{US} - 1205.5 - 12.0 \cdot (p_S^{US} - p_T^{US})$$

$$E_A^{US} = 0.05 \cdot E_T^{US} + 835.01 - 5.0 \cdot (p_A^{US} - p_T^{US})$$

$$p = p_M \cdot \left(\frac{E_M^{base}}{E^{base}}\right) + p_S \cdot \left(\frac{E_M^{base}}{E^{base}}\right) + p_A \cdot \left(\frac{E_M^{base}}{E^{base}}\right) + p_D \cdot (\frac{E_M^{base}}{E^{base}})$$

$$p_M = p_M^{World} \cdot (1 + T_M)$$

$$p_S = p_S^{World} \cdot (1 + T_S)$$

$$p_A = p_A^{World} \cdot (1 + T_A)$$

$$p_T = p_M \cdot \left(\frac{E_M}{E_T}\right) + p_S \cdot \left(\frac{E_S}{E_T}\right) + p_A \cdot \left(\frac{E_A}{E_T}\right)$$

Classical trade share bloc:

$$\ln(M_i) = a_i + b_i ln(E_T) + em_i \qquad i = China, EU, ROW$$

$$\ln(X_i) = c_i + d_i ln(E_i) + ex_i \qquad i = China, EU$$

$$X_{ROW} = Y_T - E_T - (X_{China} + X_{EU} - M_{China} - M_{EU} - M_{ROW})$$

Gravity trade share bloc:

1) US import demand for trade bloc i, where $i = China, EU, ROW$

$$\ln\left(M_i/E_T\right) = cm_i + \varphi RXR + e_{M,i}$$

2) Trade bloc i demand for US exports, where $i = China, EU, ROW$

$$\ln\left(X_i/E_i\right) = cx_i + \varphi RXR + e_{X,i}$$

Total trade term that affects productivity:

$$T = \frac{Total\,Trade}{E_{US}}$$

$$= \frac{E_T}{E_{US}} \cdot \frac{M_{EU}}{E_T} + \frac{E_T}{E_{US}} \cdot \frac{M_{China}}{E_T} + \frac{E_T}{E_{US}} \cdot \frac{M_{ROW}}{E_T} + \frac{E_{EU}}{E_{US}} \cdot \frac{X_{EU}}{E_{EU}} + \frac{E_{UK}}{E_{US}} \cdot \frac{X_{China}}{E_{China}} + \frac{E_{ROW}}{E_{US}} \cdot \frac{X_{ROW}}{E_{ROW}}$$

where $Total\,Trade = M_{EU} + M_{UK} + M_{ROW} + X_{EU} + X_{UK} + X_{ROW}$, and $\frac{E_T}{E_{US}} = 0.8137$, $\frac{E_{EU}}{E_{US}}, \frac{E_{UK}}{E_{US}}, \frac{E_{ROW}}{E_{US}}$ are fixed by the sample mean.

$$RXR \cdot \left(X_{EU} + X_{China} + X_{ROW}\right) = M_{EU} + M_{China} + M_{ROW}$$

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