Dynamics of Trade and Exchange Rate in Capital Accumulation and Welfare: Theory and Empirics

Keshab Bhattarai
University of Hull*

Sushanta Mallick
Queen Mary University of London†

December 22, 2010

Abstract

Role of real and nominal exchange rates in flows of goods and capital are evaluated theoretically using the Ricardian comparative static and dynamic general equilibrium models. Under free trade arrangements a low income country with lower wage cost and large endowment of labour has comparative advantage in trade and accumulates foreign and domestic capital. Efficiency gains from free trade enhance economic growth and welfare of households simultaneously in both low income and advanced economies. Empirically both static and dynamic general equilibrium models are solved and calibrated and tested with quarterly data over the time period 1995:1 to 2009:1 on China's relative wage cost, interest rate differential, and real effective exchange rate (REER), relative GDP and current account balance. Dynamic simulations are compared with predictions from a VAR model based on impulse responses and we show how shocks to relative wages and REER interact with relative GDP and US current account balance. Empirical findings support theoretical predictions that welfare of households in a low income country can catch up to that of a more advanced economy as the former develops dynamic comparative advantage and accumulates more capital through trade surplus to expand production of both tradable and non-tradable products. These findings are comparable to results in Turnovsky (1999) and Obstfeld-Rogoff (1996).

JEL Classification: P45, P51

KEY WORDS: Comparative advantage, growth, Exchange rate, China, US

*Business School, 125 Wharfe, HU6 7RX, UK. Phone 44-1482463207 Fax: 44-1482463484;Email: K.R.Bhattarai@hull.ac.uk

†School of Business and Management Mile End Road, London E1 4NS, UK phone: 44 (0)20 7882 7447 Fax: 44 (0)20 7882 3615; s.k.mallick@qmul.ac.uk

1 Introduction

International economic landscape has significantly changed in recent years after the expansion of G7 to G20 countries which gives greater importance to the emerging economies such as China and India in the process of negotiations and dialogues relating to the global economy. These emerging economies have been able to maintain the momentum of growth that has continued even during the financial crises and recessions of 2008/09. Comparative advantage in producing goods and direction of trade have changed dramatically in recent years. Thus it is in the interest of the more advanced economies to integrate them by broadening the dialogue in key economic and financial issues (G20). Benefits of such dialogue are obvious. According to WTO's current trade profile, US imports more than three times from China than it exports to China; nearly 17 percent of US total imports originate from China whereas only 5.6 percent of US exports go to China. More scientific analysis of trade and exchange rate is important in order to improve the ability of global negotiations and to engage these economies towards meaningful consensus. This requires a thorough analysis of the underlying causes of trade and capital flows which this paper aims to illustrate by developing Ricardian comparative static analysis and neoclassical dynamics supported by empirical evidence on the dynamics of trade and exchange rate between the US and China.

Analytical framework and empirical evidence are developed in three stages. First, a comparative static analysis with focus on underlying preferences and technology parameters are identified as causes of trade and the direction of welfare gains or losses in a two country trade under the Ricardian tradition. Second, comparative static analysis is supported by a dynamic optimisation model of trade and international capital flows. The predictions of these two theoretical models are tested empirically with long-run estimates, impulse responses and variance decompositions in a structural VAR model.

The rest of the paper is organized as follows. Section 2 develops the basic model with section 3 presenting the analytical results. Section 4 presents the dynamic version of the model with calibration results. Section 5 describes the data, and discusses the estimation methodology and empirical results. Finally, Section 6 concludes with the main findings of the paper and the policy implications.

2 Ricardian Model for Comparative Advantage

There are two countries indexed by j, producing two goods, manufacturing and services. Each of them have an option to be self reliant or to trade on the basis of comparative advantage. Under the ISI regimes countries favoured to be self reliant and infant industries were protected by tariffs and non-tariff barriers. After numerous rounds of trade negotiations under GATT/WTO over the years, all countries now have realised that the autarky solutions like this are economically inefficient. In contrast trade is mutually beneficial for trading nations and raises welfare in both countries. Aim of this section is to illustrate on these statements analytically and numerically with a small and transparent example. For this it is assumed that each country j specialises in commodities that it is more efficient and engages in trade. The exchange rate is determined by the relative prices of two commodities in the global market.

Preferences in country j are expressed by its utility function in consumption of good 1 and 2 , C_1^j and C_2^j respectively:

$$max \quad U^j = \left(C_1^j\right)^{\alpha^j} \left(C_2^j\right)^{1-\alpha^j} \tag{1}$$

Income of country j is obtained from the wage income in sector 1 and sector 2 plus the transfers to country j

$$I^j = w_1^j L_1^j + w_2^j L_2^j + TR^j \tag{2}$$

where L_1^j and L_2^j are labour employed in sector 1 and sector 2 w_1^j and w_2^j are corresponding wages respectively and TR^j is the transfer income.

Technology constraints in sector 1 in country j

$$X_1^j = a_1^j . L_1^j \tag{3}$$

where a_1^j is the productivity of labour in sector 1 in country j.

Technology constraints in sector 2 in country j

$$X_2^j = a_2^j . L_2^j \tag{4}$$

where a_2^j is the productivity of labour in sector 2 in country j.

Resource constraint in country j defined by the labour endowment as:

$$L^j = L_1^j + L_2^j \tag{5}$$

Production possibility frontier of country j now can be defined as

$$L^j = \frac{1}{a_1^j} . X_1^j + \frac{1}{a_2^j} . X_2^j \tag{6}$$

Given above preferences the demand for good 1 in country j is

$$C_1^j = \frac{\alpha^j . I^j}{P_1} \tag{7}$$

the demand for good 2 therefore is:

$$C_2^j = \frac{\left(1-\alpha^j\right) . I^j}{P_2} \tag{8}$$

Global market clearing for good 1

$$\sum_j^N C_{1,j} = \sum_j^N X_{1,j} \tag{9}$$

Global market clearing for good 2

$$\sum_{j}^{N} C_{2,j} = \sum_{j}^{N} X_{2,j} \tag{10}$$

Theoretically two trade arrangements are possible in this model. First one is an autarky equilibrium in which each country is separate and isolated from another. It produces just for its own consumption and no trade take place between these two countries. Such autarky solution is close to the production arrangement when countries were adopting ISI trade strategy.

Proposition 1 *Autarky solution is Pareto dominated by trade equilibrium for reasonable parameters of preferences and technology.*

This is proven below by analytical and numerical solutions.

3 Analytical solutions of autarky and specialisation

A Lagrangian function is used to express how each country j maximises welfare subject to its production possibility frontier constraint under the autarky equilibrium as:

$$£_j = X_{1,j}^{\alpha_j} X_{2,j}^{(1-\alpha_j)} + \lambda \left[L_j - \frac{1}{a_1^j} X_{1,j} - \frac{1}{a_2^j} X_{2,j} \right] \tag{11}$$

First order conditions with respect to X_1^j and X_2^j and λ as:

$$\frac{\partial £_j}{\partial X_{1,j}} = \alpha_j X_{1,j}^{\alpha_j - 1} X_{2,j}^{(1-\alpha_j)} - \frac{\lambda}{a_1^j} = 0 \tag{12}$$

$$\frac{\partial £_j}{\partial X_{2,j}} = (1-\alpha_j) X_{1,j}^{\alpha_j} X_{2,j}^{(-\alpha_j)} - \frac{\lambda}{a_2^j} = 0 \tag{13}$$

$$\frac{\partial £_j}{\partial \lambda} = L_j - \frac{1}{a_1^j} X_{1,j} - \frac{1}{a_2^j} X_{2,j} = 0 \tag{14}$$

From the first two first order conditions $\frac{\alpha_j X_{1,j}^{\alpha_j - 1} X_{2,j}^{(1-\alpha_j)}}{(1-\alpha_j) X_{1,j}^{\alpha_j} X_{2,j}^{(-\alpha_j)}} = \frac{\alpha_j}{(1-\alpha_j)} \frac{X_{2,j}}{X_{1,j}} = \frac{a_2^j}{a_1^j}$

$$X_{2,j} = \frac{(1-\alpha_j)}{\alpha_j} \frac{a_2^j}{a_1^j} X_{1,j} \tag{15}$$

optimal value of $X_{1,j}$ is found now putting this condition in the production possibility frontier constraint.

$$\frac{1}{a_1^j}X_{1,j} + \frac{1}{a_2^j}X_{2,j} = \frac{1}{a_1^j}X_{1,j} + \frac{1}{a_2^j}\frac{(1-\alpha_j)}{\alpha_j}\frac{a_2^j}{a_1^j}X_{1,j} = \frac{1}{a_1^j}X_{1,j}\left[1 + \frac{(1-\alpha_j)}{\alpha_j}\right] = L_j \tag{16}$$

$$X_{1,j} = \alpha_j a_1^j L_j \tag{17}$$

Similarly the optimal value of $X_{2,j}$ is found by

$$X_{2,j} = \frac{(1-\alpha_j)}{\alpha_j}\frac{a_2^j}{a_1^j}X_{1,j} = \frac{(1-\alpha_j)}{\alpha_j}\frac{a_2^j}{a_1^j}\alpha_j a_1^j L_j = (1-\alpha_j)\,a_2^j L_j \tag{18}$$

For each of j country amount produced depends on productivity and preferences parameters and the endowment of its labour input. The autarky welfare level is:

$$U^j = (X_{1,j})^{\alpha^j}(X_{2,j})^{1-\alpha^j} = \left(\alpha_j a_1^j L_j\right)^{\alpha_j}\left((1-\alpha_j)\,a_2^j L_j\right)^{(1-\alpha_j)} \tag{19}$$

Thus the level of welfare in country j is determined in terms of its preferences for consumption of good 1 and 2 as reflected by α_j and its own production technology as reflected in a_1^j and a_2^j.

Numerical version of this model is applied to China and the US taking the population as rough indicator of its resource in production. US has 365 million population and China has 1200 million population. US is more productive in producing services goods X_2 whereas China has more advantage in producing manufacturing goods X_1. Preferences are similar but technologies are different. These parameters are set out in Table 1.

Table 1: Parameters of the Autarky Model

	α	a_1	a_2	L
US	0.6	2	5	365
China	0.6	5	2	1200

Under the autarky equilibrium these two economies are completely isolated and produce only for domestic consumption. The optimal production and consumption and employment of labour for both sectors, prices of commodities and labour, and utility for the representative household are as given in Table 2. In per capita terms citizens of the US and China have welfare of 1.46 and 1.76 respectively.

Table 2: Parameters of the Autarky Model

	X_1	X_2	L_1	L_2	U	p_2
US	438	730	219	146	535.8	2.5
China	3600	960	720	480	2121.7	0.27

Each country produces both goods in no trade equilibrium which as explained here is very inefficient. Welfare can be improved by making these countries trade.

3.0.1 Analytical Solutions for Trade Equilibrium

A representative household in each country maximises its welfare subject to its budget constraint. Demand for goods are derived by standard constrained optimisation on supply side for each country j . Under trade equilibrium it is optimal for each country to specialise in goods in which it has comparative advantage. The optimisation problem and the first order conditions for constrained optimisation are given as follows:

$$£_j = X_{1,j}^{\alpha_j} X_{2,j}^{(1-\alpha_j)} + \lambda \left[I_j - P_1 X_{1,j} - P_2 X_{2,j} \right] \tag{20}$$

First order conditions:

$$\frac{\partial £_j}{\partial X_{1,j}} = \alpha_j X_{1,j}^{\alpha_j - 1} X_{2,j}^{(1-\alpha_j)} - \lambda P_1 = 0 \tag{21}$$

$$\frac{\partial £_j}{\partial X_{2,j}} = (1-\alpha_j) X_{1,j}^{\alpha_j} X_{2,j}^{(-\alpha_j)} - \lambda P_2 = 0 \tag{22}$$

$$\frac{\partial £_j}{\partial \lambda} = I_j - P_1 X_{1,j} - P_2 X_{2,j} = 0 \tag{23}$$

$$\frac{\alpha_j X_{1,j}^{\alpha_j - 1} X_{2,j}^{(1-\alpha_j)}}{(1-\alpha_j) X_{1,j}^{\alpha_j} X_{2,j}^{(-\alpha_j)}} = \frac{\alpha_j}{(1-\alpha_j)} \frac{X_{2,j}}{X_{1,j}} = \frac{P_1}{P_2} \tag{24}$$

$$X_{2,j} = \frac{(1-\alpha_j)}{\alpha_j} \frac{P_1}{P_2} X_{1,j} \tag{25}$$

$P_1 X_{1,j} + P_2 X_{2,j} = P_1 X_{1,j} + P_2 \frac{(1-\alpha_j)}{\alpha_j} \frac{P_1}{P_2} X_{1,j} = I_j$

$$X_{1,j} = \frac{\alpha_j I_j}{P_1};\ X_{2,j} = \frac{(1-\alpha_j) I_j}{P_2} \tag{26}$$

Global market clearing conditions for goods 1 and 2 are

$$\sum_j^N X_{1,j} = X_1 \tag{27}$$

$$\sum_j^N X_{2,j} = X_2 \tag{28}$$

Prices adjust until this equilibrium condition holds.

Under complete specialisation, country 1 US specialises in services X_2 and produces 1825 units of it. China specialises in manufacturing X_1 goods and produced 6000 units of it. It is easy to determine China's income if we choose good 1 as numeraire setting $P_1 = 1$.

$$I^c = P_1 X_1 = 1 \times 6000 = 6000 \tag{29}$$

Relative price of good 2, P_2 need to be determined to find the level of income in the US. This can be done using the global market clearing condition

$$\frac{\alpha^u . I^u}{P_1} + \frac{\alpha^c . I^c}{P_1} = 0.6\,(1825 \times P_2) + 0.6\,(6000) = 6000 \tag{30}$$

$$P_2 = \frac{6000 - 3600}{1095} = 2.192 \tag{31}$$

Now it is easy to determine the income of the US as:

$$I^u = P_2 X_2 = 365 \times 5 \times P_2 = 1825 \times P_2 = 1825 \times 2.192 = 4000.4 \tag{32}$$

Since income level for both China and the US are determined, it is now easy to determine the level of demand in both countries:

$$X_{1,u} = \frac{\alpha_u I_u}{P_1} = 0.6\,(4000.4) = 2401.6; \;\; X_{1,ch} = \frac{\alpha_{ch} I_{ch}}{P_1} = 0.6\,(6000) = 3600 \tag{33}$$

$$X_{2,u} = \frac{(1-\alpha_u)\, I_u}{P_2} = \frac{0.4\,(4000.4)}{2.192} = 730; X_{2,ch} = \frac{(1-\alpha_{ch})\, I_{ch}}{P_2} = \frac{0.6\,(6000)}{2.192} = 1462.3 \tag{34}$$

Solutions of both autarky and trade equilibria are given in Table 3 and 4. Given the preferences and technology specifications, with complete specialisation both countries gain from trade. Comparative static analysis of trade can be done changing the preference or technology parameters.

Table 3: Comparing Specialisation and Autarky Regimes

	Production				Consumption			
	Autarky		Trade		Autarky		Trade	
	X_1	X_2	X_1	X_2	C_1	C_2	C_1	C_2
US	438	730	0	1825	438	730	1600.2	730
China	3600	960	6000	0	3600	960	3600	1642.3

Gains from trade may be distributed differently across countries (Bhattarai and Whalley (2006)). Further there are opportunities for bargaining on the share of those gains particularly from dynamic strategic considerations and the basic elements required for such dynamic model is provided in the next section.

Table 4: Comparing Employment and Welfere under Specialisation and Autarky

Employment				Uitlity	
Autarky		Trade		Autarky	Trade
L_1	L_2	L_1	L_2	U	U
219	146	0	365	535.8	1169.1
720	480	1200	0	2121.7	2248

4 Dynamics of Two Country Two Commodity Model of Trade and Exchange Rate

Intuition from model 1 provides grounds for examining dynamic gains from trade and exchange rate in two country set up. Capital inflows and outflows and domestic and foreign interest rates and relative prices, and wage rates. trade balances and accumulation of net foreign assets feature prominently in this structure. Turnovsky (1999) has some structure of this type of model (see Obstfeld and Rogoff (1996) for comprehensive review of earlier models). Each country consumes goods produced at home (x) and produced abroad (y) and has a labour (l) along with capital stock (k) in production. Domestic and foreign wage and interest rates and relative prices are determined by the optimality conditions for both countries. Some structural features imposed on those optimal conditions will cause deviation from the optimal equilibrium.

Households in country j consume goods produced at home x^j and goods produced in foreign country y^j and receive utility from taking leisure l^j. Thus the intertemporal preference is represented by

$$max \int_0^{\infty} U\left(x^j, y^j, l^j\right) e^{-\beta t} \tag{35}$$

subject to the asset accumulation (budget) constraint as:

$$\frac{dB}{dt} = \overset{\bullet}{B} = F\left(k^j, l^j\right) - x^j - \dot{k}^j - r^j.B^j - \tau^j.p^j.y^j + T^j \tag{36}$$

where $F\left(k^j, l^j\right)$ is the production function, $\dot{k}^j$ is the investment, $r^j.B^j$ is the debt servicing, $\tau^j.p^j.y^j$ is tariff paid on imports of goods, T^j the amount of transfer of tariff revenue to household. Model requires initial conditions as $B_0^j = b_0^j$ and $K_0^j = k_0^j$ .For simplicity it is assumed that tariff revenues balance with transfer payments of households as:

$$p^j.\left(\tau^j - 1\right).y^j = T^j \tag{37}$$

Firm's problem in country j is to maximize its long run profit:

$$\max \int_0^{\infty} \left[F\left(k^j, l^j\right) - r^j.k^j - w^j.l^j\right] e^{-\int_0^t r^j(s)ds} dt \tag{38}$$

Investment adds to the capital stock as:

$$\dot{k}^j = I^j \tag{39}$$

Hamiltonian in country j problem taking above constraints is:

$$H = \int_0^\infty U\left(x^j, y^j, l^j\right) e^{-\beta t} + \lambda \int_0^\infty \left[F\left(k^j, l^j\right) - x^j - \dot{k}^j - r^j.B^j - \tau^j.p^j.y^j + T^j\right] \tag{40}$$

The optimal allocation of resources in this model require solving first order conditions (FOC) with respect to domestic and foreign goods leisure, and shadow prices as:

domestic good:

$$U_x^j(x) = \lambda^j \tag{41}$$

consumption of foreign good:

$$U_y^j(y) = \lambda p^j \tau^j \tag{42}$$

labour supply (leisure):

$$U_l^j(l) = -\lambda F_l\left(k^j, l^j\right) \tag{43}$$

shadow prices :

$$r^j = \beta^j - \frac{\dot{\lambda}^j}{\lambda^j} \tag{44}$$

In the production side the capital market equilibrium condition requires rental rate be equal to the interest rate as:

$$F_k^j\left(k^j, l^j\right) = r^j \tag{45}$$

and the boundary condition

$$\underset{t \to \infty}{lim} \lambda^j B^j e^{-\beta^j t} = 0 \tag{46}$$

Interest parity conditions link the interest rate and exchange rate of the US relative to china when trade is open between two countries.

Capital market equilibrium was given in the marginal productivity condition above, which implies from the interest rate parity condition

$$r^u = r^c + \frac{\dot{p}}{p} \tag{47}$$

where $\frac{\dot{p}}{p}$ is the relative price of goods x and y in the global market.

Further from the optimality conditions on shadow prices the marginal utility conditions in two countries are:

$$\lambda^u = \phi p \lambda^c \tag{48}$$

where ϕ is a constant.

Labour is mobile across sectors within a country but immobile between two countries. Wage rate within country j equals the marginal production of labour as:

$$F_l^j \left(k^j, l^j\right) = w^j \tag{49}$$

However for reasons of immobility across border China with abundant labour, labour endowment has lower wage rate than the US

$$F_l^c \left(k^c, l^c\right) = w^c < w^u = F_l^u \left(k^u, l^u\right). \tag{50}$$

Global goods market equilibrium condition is:

$$F_x^u \left(k^u, l^u\right) + F_x^c \left(k^c, l^c\right) = x^u + x^c + \dot{k}_x^u + \dot{k}_x^c \tag{51}$$

$$F_y^u \left(k^u, l^u\right) + F_y^c \left(k^c, l^c\right) = y^u + y^c + \dot{k}_y^u + \dot{k}_y^c \tag{52}$$

Capital in country j is owned by residents for foreigners and thus its composition is given by:

$$k^u = k_d^u + k_f^u \tag{53}$$

$$k^c = k_d^c + k_f^c \tag{54}$$

Wealth of country j similarly constitutes the wealth owned by its own residents and foreigners:

$$W^u = k_d^u + k_f^c \tag{55}$$

$$W^c = k_d^c + k_f^u \tag{56}$$

Net foreign asset position is given by the difference of how much capital is owned domestically relative to foreign investors:

$$B^u = k_d^u - k_f^u \tag{57}$$

$$B^c = k_d^c - k_f^c \tag{58}$$

There are taxes on capital income at home and abroad:

$$T^u = \tau^u.r^u.k_d^u. + \tau^u.r^u.k_f^u + \tau^u.r^c.k_f^c \tag{59}$$

$$T^c = \tau^c.r^c.k^c_{d}. + \tau^c.r^c.k^c_f + \tau^c.r^u.k^u_f \tag{60}$$

Above equilibrium conditions underpin the dynamics of the economy with the regular concavity or convexity conditions of the demand and production functions this system must converge to the steady state, the long run equilibrium of the economy.

Proposition 2 *Steady state and transitional dynamics of the economy are determined by relative prices of goods, factors and assets between trading nations.*

5 Steady State in the Neoclassical Model of Trade and Exchange

Steady state equilibrium of the dynamic model is pegged to the market equilibrium conditions in capital, labour and goods markets.

$$F^u_k\left(k^u, l^u\right) = r^u = F^c_k\left(k^c, l^c\right) = r^c = r \tag{61}$$

$$\frac{\dot{p}}{p} = \frac{\dot{\lambda^u}}{\lambda^u} - \frac{\dot{\lambda^c}}{\lambda^c} \tag{62}$$

These conditions imply that the Pareto optimal dynamic allocations and the steady state allocations implicitly could be stated for domestic and foreign goods for the US and China in terms of inter-temporal preferences and capital stock, which are given as:

$$\tilde{x^u} = x\left(\tilde{k^u}, \beta^u\right) \tag{63}$$

$$\tilde{y^u} = y\left(\tilde{k^u}, p, \tau^u, \beta^u\right) \tag{64}$$

$$\tilde{x^c} = x\left(\tilde{k^c}, \beta^c\right) \tag{65}$$

$$\tilde{y^c} = y\left(\tilde{k^c}, p, \tau^c, \beta^c\right) \tag{66}$$

Obviously further capital accumulation or the net accumulation of foreign asset in this model improves the level of demand for both domestic and foreign products. Thus this solution shows the interdependency among countries constituting the global economy.

6 Transitional Dynamics

It takes long time for the economy to converge to the steady state. The transition path towards the steady state is determined in terms of price adjustment equations, excess demand functions, or asset adjustment equations.

Price adjustment process in country j is given by:

$$\dot{\lambda}^j = \lambda^j \left[\beta^j - r^j \left(k^j, \lambda^j\right)\right] \tag{67}$$

Off the steady state, the excess supply function for the US and China are respectively as follows:

$$\dot{k}^u = \left[F\left(k^u, lu\right)\right] - x^u\left(\lambda^u\right) - x^c\left(\tau^c \lambda^u \phi\right) \tag{68}$$

$$\dot{k}^c = \left[F\left(k^c, l^c\right)\right] - x^c\left(\lambda^c\right) - x^u\left(\tau^u \lambda^c \phi\right) \tag{69}$$

Asset accumulation occurs due to trade surplus and returns on the previous investment as:

$$\overset{\bullet}{B}^c = r^c.B^c + x^c\left(\tau^c \lambda^u \phi\right) - \frac{\dot{\lambda}^c}{\lambda^u \phi} y\left(\frac{\tau^c \lambda^c}{\phi}\right) \tag{70}$$

In short, the long run equilibrium is given by the balance between the demand and supply and convergence between them. These conditions are smooth in good times but can be very wild as in the current economic crises when international demand or supply shocks hit these economies. How these shocks have affected these economies in the past and how are they likely to respond to them in future years in the real world situation will be studied on the basis of VAR model estimated from a quarterly dataset on relative wage cost, interest rate differential, real effective exchange rate, import prices, relative GDP and US current account balance, in the next section.

7 Empirical Analysis on Trade and Exchange rate

Empirical support for the dynamics of trade and exchange rates as proposed in the above models is found using a structural VAR models (see for example, Sim (1980, 1986), Bernanke(1986), Enders (1995), Garratt et al. (2003), and Rafiq and Mallick (2008)). Structural VAR is popular for this type of study as it allows to put restrictions based on the theoretical predictions in the above model. We limit our analysis to five variables that include relative wage between China and the US (w_{cu}), interest rate differential between China and the US (r_{cu}), Chinese real effective exchange rate (e), US relative GDP between China and the US (ry_{cu}) and the current account balance (CA_u) . The raw time series of these data are presented in Figure 1. When the Chinese economy has been growing rapidly, the exchange rate being fixed leads us to use China's real exchange rate rather than the nominal exchange rate. By doing so, we are also capturing the relative price effect. China's unit labour cost (ULC) is measured as total wage bill over real output (nominal output divided by CPI (1985=100)). Then relative wage is calculated by dividing ULC-China over ULC-US. Relative GDP on the other hand has been defined as Chinese GDP in dollar terms over US GDP. We calculate interest rate differential as the difference between Chinese average inter-bank rate and US 3-month Tbill rate. Current account balance for the US is used as the percentage of US nominal GDP. With these five variables, we formulate a first -order structural VAR of the following form:

$$\begin{bmatrix} b_{11} & b_{12} & b_{13} & b_{14} & b_{15} \\ b_{21} & b_{22} & b_{23} & b_{24} & b_{25} \\ b_{31} & b_{32} & b_{33} & b_{34} & b_{35} \\ b_{41} & b_{42} & b_{43} & b_{44} & b_{45} \\ b_{51} & b_{52} & b_{53} & b_{54} & b_{55} \end{bmatrix} \begin{bmatrix} w_{cu,t} \\ r_{cu,t} \\ e_{c,t} \\ ry_{cu,t} \\ CA_{u,t} \end{bmatrix} = \begin{bmatrix} b_{10} \\ b_{20} \\ b_{30} \\ b_{40} \\ b_{50} \end{bmatrix} + \begin{bmatrix} \gamma_{11} & \gamma_{12} & \gamma_{13} & \gamma_{14} & \gamma_{15} \\ \gamma_{21} & \gamma_{22} & \gamma_{23} & \gamma_{24} & \gamma_{25} \\ \gamma_{31} & \gamma_{32} & \gamma_{33} & \gamma_{34} & \gamma_{35} \\ \gamma_{41} & \gamma_{42} & \gamma_{43} & \gamma_{44} & \gamma_{45} \\ \gamma_{51} & \gamma_{52} & \gamma_{53} & \gamma_{54} & \gamma_{55} \end{bmatrix} \begin{bmatrix} w_{cu,t-1} \\ r_{cu,t-1} \\ e_{c,t-1} \\ ry_{cu,t-1} \\ CA_{u,t-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_{wt} \\ \varepsilon_{rt} \\ \varepsilon_{et} \\ \varepsilon_{ryt} \\ \varepsilon_{cat} \end{bmatrix} \tag{71}$$

where matrix notations can be employed for more exact representation.

$$X_t = \begin{bmatrix} w_{cu,t} \\ r_{cu,t} \\ e_{c,t} \\ ry_{cu,t} \\ CA_{u,t} \end{bmatrix};\ X_{t-1} = \begin{bmatrix} w_{cu,t-1} \\ r_{cu,t-1} \\ e_{c,t-1} \\ ry_{cu,t-1} \\ CA_{u,t-1} \end{bmatrix};\ \varepsilon_t = \begin{bmatrix} \varepsilon_{wt} \\ \varepsilon_{rt} \\ \varepsilon_{et} \\ \varepsilon_{ryt} \\ \varepsilon_{cat} \end{bmatrix} \tag{72}$$

or compactly the path of X_{it} is affected by both contemporaneous and lagged effects of X_{jt} as measured by Γ_0 and Γ_1 and its own past values .Consider

$$X_t = B^{-1}\Gamma_0 + B^{-1}\Gamma_1 X_{t-1} + B^{-1}\varepsilon_t \tag{73}$$

$$B^{-1} = \begin{bmatrix} b_{11} & b_{12} & b_{13} & b_{14} & b_{15} \\ b_{21} & b_{22} & b_{23} & b_{24} & b_{25} \\ b_{31} & b_{32} & b_{33} & b_{34} & b_{35} \\ b_{41} & b_{42} & b_{43} & b_{44} & b_{45} \\ b_{51} & b_{52} & b_{53} & b_{54} & b_{55} \end{bmatrix}^{-1} \quad \Gamma_0 = \begin{bmatrix} b_{10} \\ b_{20} \\ b_{30} \\ b_{40} \\ b_{50} \end{bmatrix};$$

$$\Gamma_1 = \begin{bmatrix} \gamma_{11} & \gamma_{12} & \gamma_{13} & \gamma_{14} & \gamma_{15} \\ \gamma_{21} & \gamma_{22} & \gamma_{23} & \gamma_{24} & \gamma_{25} \\ \gamma_{31} & \gamma_{32} & \gamma_{33} & \gamma_{34} & \gamma_{35} \\ \gamma_{41} & \gamma_{42} & \gamma_{43} & \gamma_{44} & \gamma_{45} \\ \gamma_{51} & \gamma_{52} & \gamma_{53} & \gamma_{54} & \gamma_{55} \end{bmatrix}$$

The reduced form of this VAR system is then given by:

$$X_t = A_0 + A_1 X_{t-1} + e_t \tag{74}$$

where $A_0 = B^{-1}\Gamma_0,\ A_1 = B^{-1}\Gamma_1,\ e_t = B^{-1}\varepsilon_t$

Reduced form is estimated with the available data; then structural shocks are retrieved using $e_t = B^{-1}\varepsilon_t$ This requires estimation of the variance covariance matrix of the error term

$$\sum = \begin{bmatrix} \sigma_{11} & \sigma_{12} & \sigma_{13} & \sigma_{14} & \sigma_{15} \\ \sigma_{21} & \sigma_{22} & \sigma_{23} & \sigma_{24} & \sigma_{25} \\ \sigma_{31} & \sigma_{32} & \sigma_{33} & \sigma_{34} & \sigma_{35} \\ \sigma_{41} & \sigma_{42} & \sigma_{43} & \sigma_{44} & \sigma_{45} \\ \sigma_{51} & \sigma_{52} & \sigma_{53} & \sigma_{54} & \sigma_{55} \end{bmatrix} \tag{75}$$

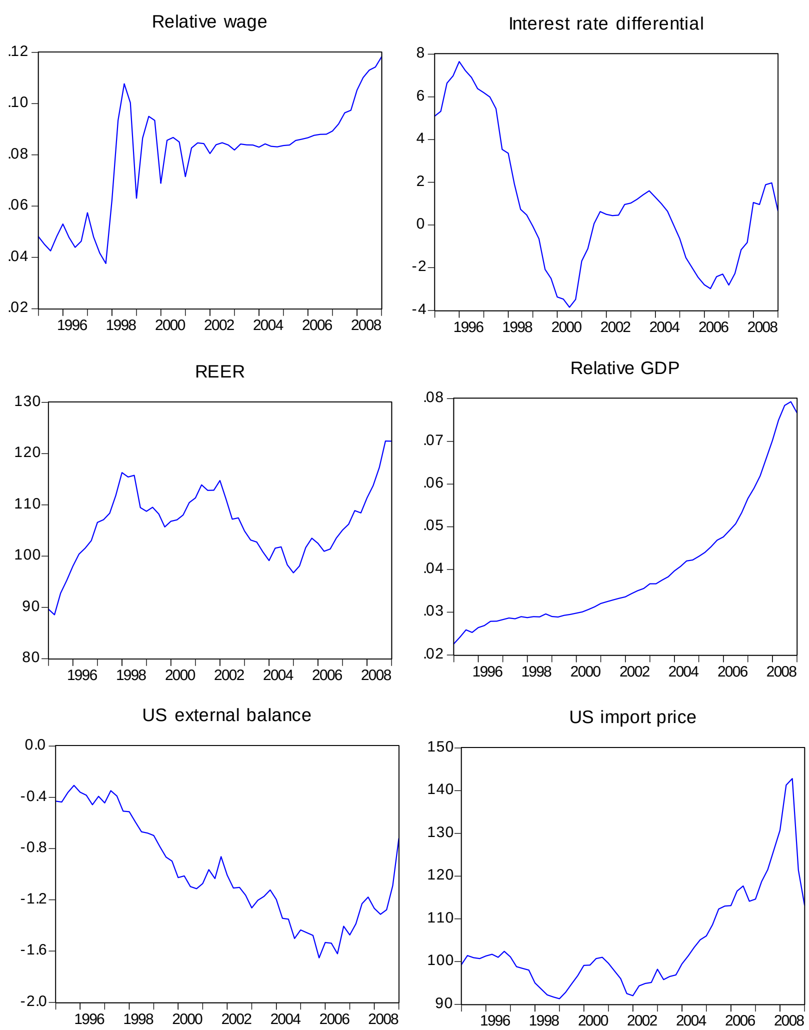
where $\sigma_{ij} = \frac{1}{T}\sum_{t=1}^{T} e_{ij}e_{ij}^{'}$

VAR is a-theoretic. In order to understand the long-run dynamics, we perform impulse response shock analysis, as the results from impulse responses are more informative than the estimated VAR regression coefficients (see Stock and Watson, 2001). It is customary to impose restrictions on coefficients based on prior economic theory. These restrictions can be on parameters, variance covariance matrices or symmetry.

$$\begin{bmatrix} a_{11} & 0 & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} & 0 \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} \end{bmatrix} \begin{bmatrix} w_{cu,t} \\ r_{cu,t} \\ e_{c,t} \\ ry_{cu,t} \\ CA_{u,t} \end{bmatrix} = \begin{bmatrix} \varepsilon_{wt} \\ \varepsilon_{rt} \\ \varepsilon_{et} \\ \varepsilon_{pmt} \\ \varepsilon_{cat} \end{bmatrix} \tag{76}$$

Quarterly observations from 1995-Q1 to 2009-Q1 are used to estimate the model with two optimal lags. All the data have been gathered from Datastream and the variables are plotted in Figure 1. Since there is evidence of a structural break around 1994Q1 in China (see for example Baak (2008)), our sample in this paper starts from 1995Q1. Furthermore there is unavailability of quarterly data for the variables involved in this paper prior to 1995Q1.

Figure 1: Plot of time series used in the VAR



7.1 Impulse response Analysis

The VAR is formulated with the following ordering: relative wage, interest rate differential, Chinese REER, relative GDP, and US current account balance. Shocks are extracted by applying a recursive identification structure with the above ordering. All the estimations have been carried out using RATS econometric software.

$$\begin{bmatrix} w_{c,t} \\ r_{c,t} \\ e_{c,t} \\ ry_{u,t} \\ CA_{u,t} \end{bmatrix} = \begin{bmatrix} \overline{w}_{c,t} \\ \overline{r}_{c,t} \\ \overline{e}_{c,t} \\ \overline{ry}_{u,t} \\ \overline{CA}_{u,t} \end{bmatrix} + \sum_{i=0}^{\infty} \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} \\ a_{41} & a_{42} & a_{43} & a_{44} & a_{45} \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} \end{bmatrix} \begin{bmatrix} e_{1t-i} \\ e_{2t-i} \\ e_{3t-i} \\ e_{4t-i} \\ e_{5t-i} \end{bmatrix} \quad (77)$$

Errors of the reduced form equations are related to the structural parameters as:

$$\begin{bmatrix} e_{1t} \\ e_{2t} \\ e_{3t} \\ e_{4t} \\ e_{5t} \end{bmatrix} = \begin{bmatrix} b_{11} & b_{12} & b_{13} & b_{14} & b_{15} \\ b_{21} & b_{22} & b_{23} & b_{24} & b_{25} \\ b_{31} & b_{32} & b_{33} & b_{34} & b_{35} \\ b_{41} & b_{42} & b_{43} & b_{44} & b_{45} \\ b_{51} & b_{52} & b_{53} & b_{54} & b_{55} \end{bmatrix}^{-1} \begin{bmatrix} \varepsilon_{wt} \\ \varepsilon_{rt} \\ \varepsilon_{et} \\ \varepsilon_{pmt} \\ \varepsilon_{cat} \end{bmatrix} \quad (78)$$

Introducing more simplifying assumptions:

$$\begin{bmatrix} w_{c,t} \\ r_{c,t} \\ e_{c,t} \\ pm_{u,t} \\ CA_{u,t} \end{bmatrix} = \begin{bmatrix} \overline{w}_{c,t} \\ \overline{r}_{c,t} \\ \overline{e}_{c,t} \\ \overline{pm}_{u,t} \\ \overline{CA}_{u,t} \end{bmatrix} + \sum_{i=0}^{\infty} \begin{bmatrix} \phi_{11} & \phi_{12} & \phi_{13} & \phi_{14} & \phi_{15} \\ \phi_{21} & \phi_{22} & \phi_{23} & \phi_{24} & \phi_{25} \\ \phi_{31} & \phi_{32} & \phi_{33} & \phi_{34} & \phi_{35} \\ \phi_{41} & \phi_{42} & \phi_{43} & \phi_{44} & \phi_{45} \\ \phi_{51} & \phi_{52} & \phi_{53} & \phi_{54} & \phi_{55} \end{bmatrix} \begin{bmatrix} \varepsilon_{wt} \\ \varepsilon_{rt} \\ \varepsilon_{et} \\ \varepsilon_{pmt} \\ \varepsilon_{cat} \end{bmatrix} \quad (79)$$

where $\phi_i = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} \\ a_{41} & a_{42} & a_{43} & a_{44} & a_{45} \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} \end{bmatrix} \begin{bmatrix} b_{11} & b_{12} & b_{13} & b_{14} & b_{15} \\ b_{21} & b_{22} & b_{23} & b_{24} & b_{25} \\ b_{31} & b_{32} & b_{33} & b_{34} & b_{35} \\ b_{41} & b_{42} & b_{43} & b_{44} & b_{45} \\ b_{51} & b_{52} & b_{53} & b_{54} & b_{55} \end{bmatrix}^{-1} \quad \phi_{i,j}(n)$ are impulse response coefficients for equation n. More compactly this can be represented as:

$$x_t = \mu + \sum_{i=0}^{\infty} \phi_i(i) \epsilon_{t-i} \quad (80)$$

Given the higher US imports (more than three times the amount they export), incurring a huge overall trade deficit, there is a growing pressure on China to raise the value of its currency, particularly from the US. This concern can be assessed via a structural VAR exercise whether the deficit is due to relative domestic demand or relative prices (real exchange rate). We therefore have used relative GDP and REER as a relative price variable. The impulse responses of REER shocks on relative GDP show that REER appreciation harms Chinese exports thereby helping US GDP increase faster than Chinese GDP, thereby leading to a decline in relative GDP between the two countries. This suggests that Chinese yuan real appreciation is required to ensure sustainability, as relative GDP shocks only lead to short-run appreciation in REER (see Figure

4). Xu (2008) reports a statistically significant long-run relationship between the RMB/dollar exchange rate and the US trade deficit with China, suggesting a need for China to adjust its exchange rate policy to help reduce the ever mounting US trade deficit.

Table 1: Matrix of long-run effects

Shocks in ⟶	rw	ird	$reer$	ry	cab
rw	3.2255*	0.3625	1.2820	-3.2287*	-1.3144
ird	-0.0257	0.0579	0.0007	0.0378	0.0326*
$reer$	-2.2766*	0.0241	1.1561*	1.2616	1.1909*
ry	0.8502	1.4324	1.0553	-1.9516*	-0.1373
cab	-0.6550	3.7211	2.3668	-4.2768*	4.1669*

:

Table 2: Matrix of Short-run effects

Shocks in ⟶	rw	ird	$reer$	ry	cab
rw	0.7758*	0.0000	0.0000	0.0000	0.0000
ird	0.0005	0.005*	0.0000	0.0000	0.0000
$reer$	-0.1080	-0.0349	1.5472*	0.0000	0.0000
ry	-0.002	-0.0003	-0.0114	0.0626*	0.0000
cab	-0.6583	2.6703	0.4887	-1.5658*	6.4793*

Impulse responses for the empirical model are presented in Figures 2 to 5. IRD appears to be purely exogenous, as none of the included variables significantly influence it in the long-run. This result is in line with earlier evidence that in China, interest rates have not been an important monetary policy tool (see Mehrotra, 2007). In the long-run, China's interest rate differential with the US and REER shocks are positively related, while China's REER responds positively to shocks in all the four variables in the short-run, except the relative wage shock to which the REER responds negatively, which can happen via price adjustment by Chinese exporters (given fixed nominal exchange rate) on the back of lower profit mark-up in order to maintain its market share in the US. Under an unanticipated RMB real appreciation; the impulse responses suggest that Chinese GDP decline more than the US GDP. To prevent such outcome, it is likely that Chinese exporters could change their export prices via adjusting profit margins in order to offset the impact of real currency appreciation (see Bergin and Feenstra, 2009; Witte, 2009).

Figure 2: IRFs for relative wage shocks

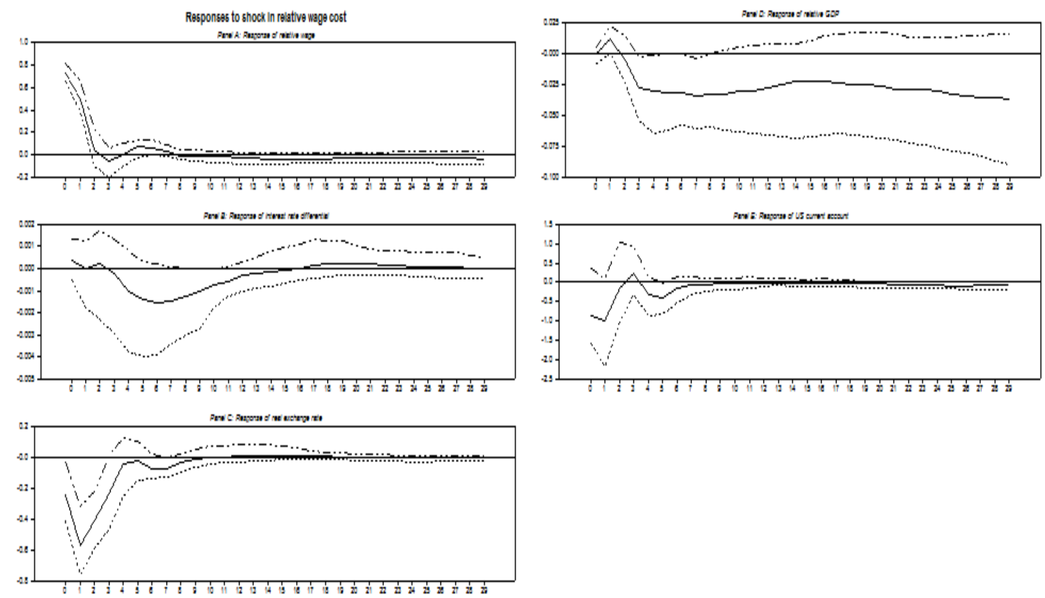


Figure 3: IRFs for shocks in interest rate differential

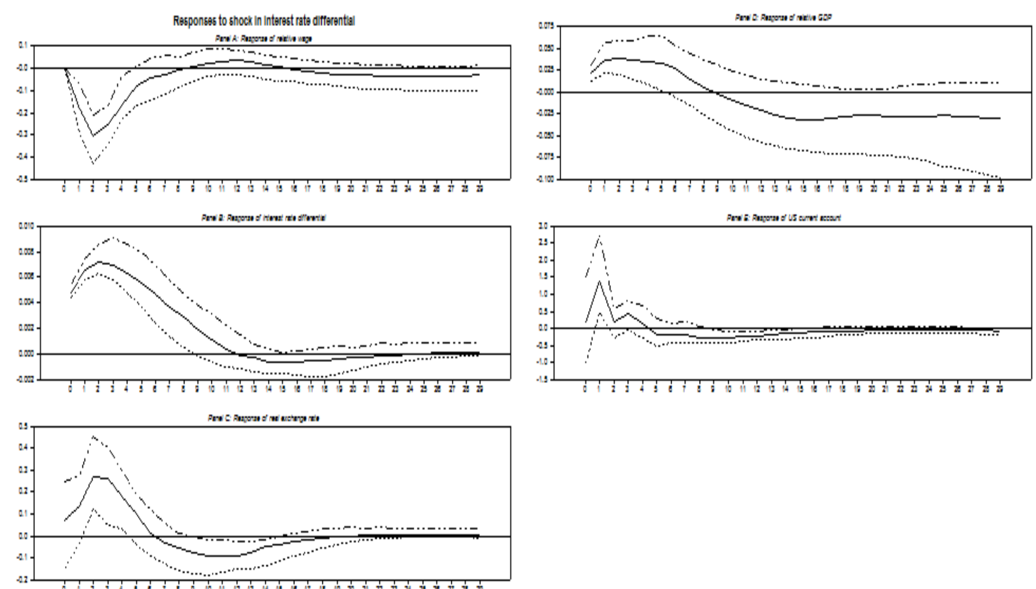
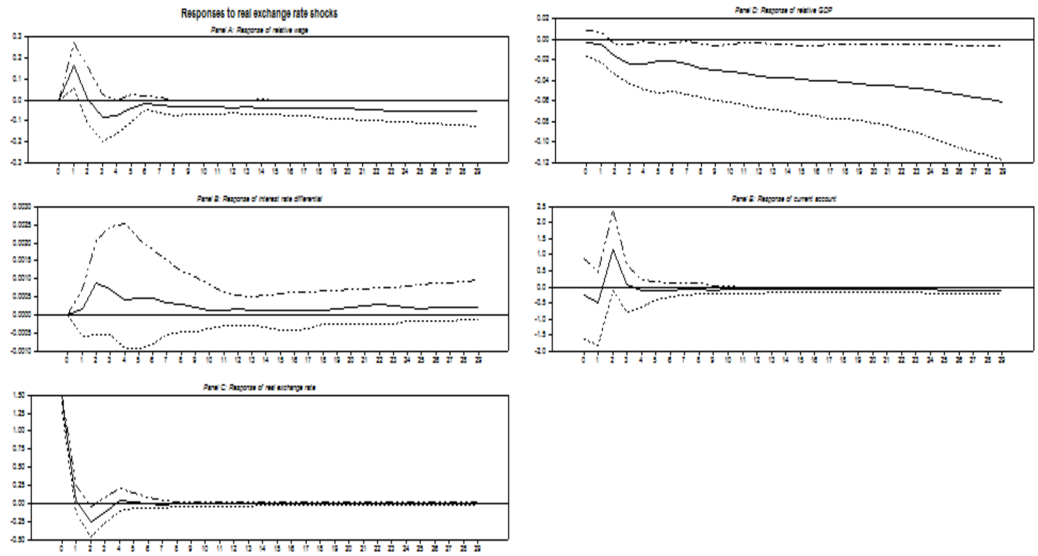


Figure 4: IRFs for Chinese REER shocks



As an important international competitiveness indicator, REER can provide a reliable gauge of price competitiveness about the relative profitability of Chinese traded goods. The results in Figure 4 imply that there could be loss in competitiveness due to RMB appreciation, leading to a decline in Chinese GDP relative to the US. On the other hand, following a shock to relative GDP as in Figure 5, relative wage in China increases, thus lowering China's trade competitiveness and thus helping improve US current account balance. Thus lower production cost remains the key to China's trade competitiveness with the US. From Figure 6, it is clear that US current account balance can improve if it is accompanied by China's REER appreciation and an increase in China's relative wage.

Figure 5: IRFs of relative GDP shocks

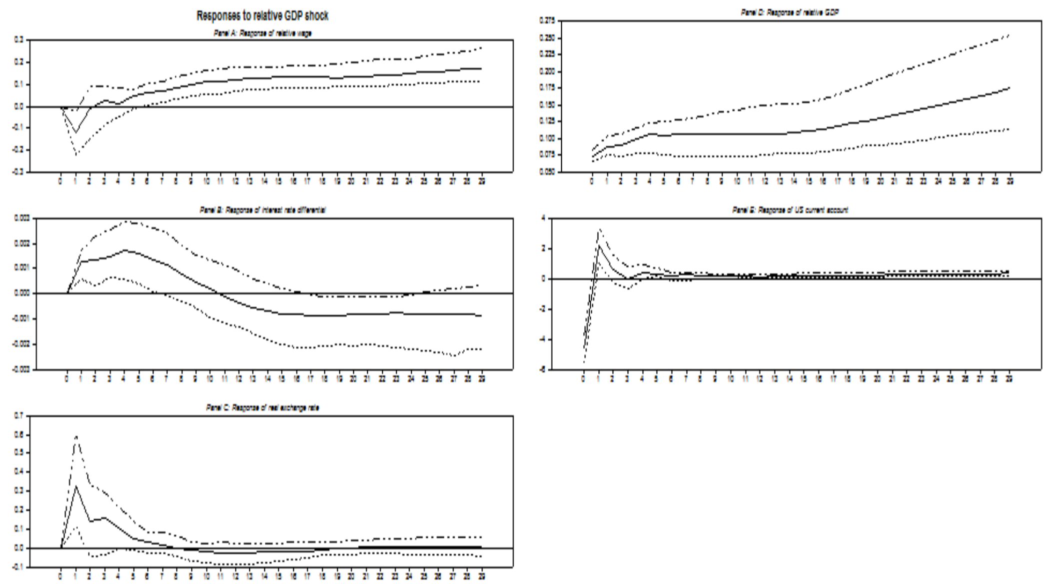
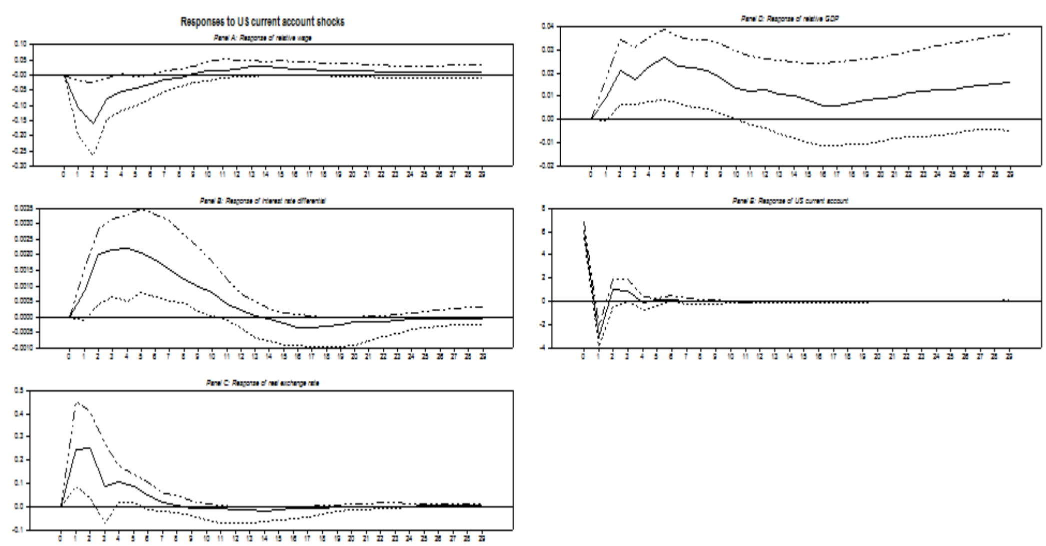
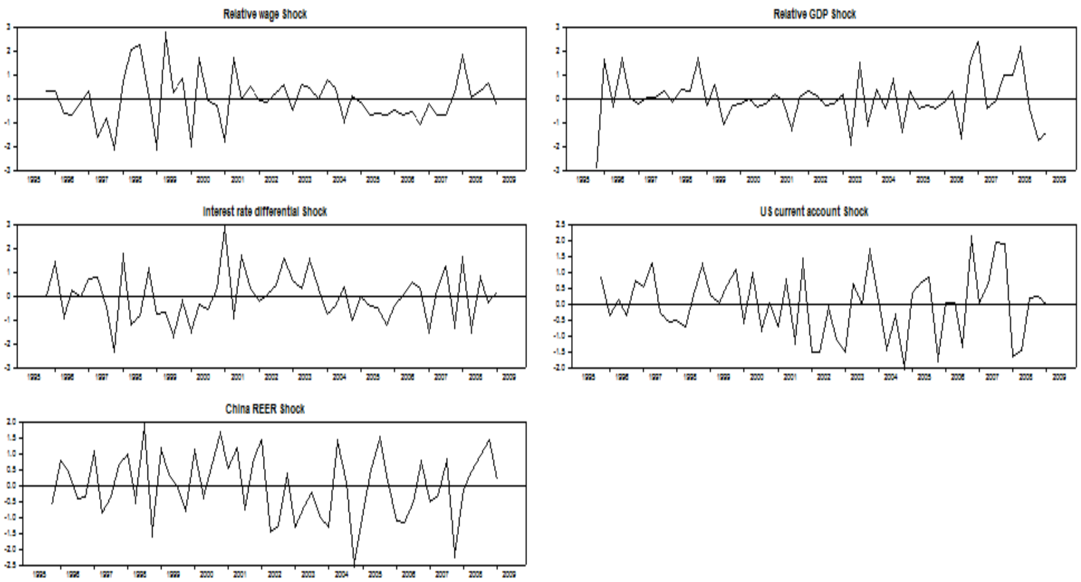


Figure 6: IRFs for shocks in US current account balance



The derived structural shocks are shown in Figure 7. Estimated structural shocks do tend to capture the turning points.

Figure 7: Derived structural shocks



8 Variance Decomposition

Let us start from the reduced form:

$$X_t = A_0 + A_1 X_{t-1} + e_t \tag{81}$$

from successive iteration this reduces to

$$E_t X_{t+n} = \left(I + A_1 + A_1^2 + A_1^3 + ... + A_1^{n-1}\right) A_0 + A_1^n X_t + e_t \tag{82}$$

Forecast error is given by

$$\left(e_{t+n} + A_1 e_{t+n-1} + A_1^2 e_{t+n-2} + ... + A_1^{n-1} e_{t+1}\right) A_0 + A_1^n X_t \tag{83}$$

$$X_{t+n} - E_t X_{t+n} = \sum_{i=0}^{n-1} \phi_i(i) \epsilon_{t+n-i} \tag{84}$$

Taking only one equation

$w_{t+n} - E_t w_{t+n} = \phi_{11}(0)\epsilon_{wt+n} + \phi_{11}(1)\epsilon_{wt+n-1} + ... + \phi_{11}(n-1)\epsilon_{wt+1} + \phi_{12}(0)\epsilon_{rt+n} + \phi_{12}(1)\epsilon_{rt+n-1} + ... + \phi_{12}(n-1)\epsilon_{rt+1}$

$+\phi_{12}(0)\epsilon_{et+n} + \phi_{12}(1)\epsilon_{et+n-1} + ... + \phi_{12}(n-1)\epsilon_{et+1}$

$+\phi_{12}(0)\epsilon_{pmt+n} + \phi_{12}(1)\epsilon_{pmt+n-1} + ... + \phi_{12}(n-1)\epsilon_{pmt+1}$

$+\phi_{12}(0)\epsilon_{cat+n} + \phi_{12}(1)\epsilon_{cat+n-1} + ... + \phi_{12}(n-1)\epsilon_{cat+1}$

Variance of n-step ahead forecast error is

$$\begin{aligned}\sigma(n)_w^2 = {} & \sigma_w^2\left[\phi_{11}(0)+\phi_{11}(1)+...+\phi_{11}(n-1)\right]+\sigma_r^2\left[\phi_{12}(0)+\phi_{12}(1)+...+\phi_{12}(n-1)\right]+ \\ & \sigma_e^2\left[\phi_{12}(0)+\phi_{12}(1)+...+\phi_{12}(n-1)\right]+\sigma_{pm}^2\left[\phi_{12}(0)+\phi_{12}(1)+...+\phi_{12}(n-1)\right]+ \\ & \sigma_{CA}^2\left[\phi_{12}(0)+\phi_{12}(1)+...+\phi_{12}(n-1)\right] \qquad (85)\end{aligned}$$

Variance decomposition in terms of variances of shocks ϵ_{wt} , ϵ_{rt}, ϵ_{et}, ϵ_{pmt} and ϵ_{cat}.

$$\begin{aligned}\sigma(n)_w^2 = {} & \frac{\sigma_w^2\left[\phi_{11}(0)+\phi_{11}(1)+...+\phi_{11}(n-1)\right]}{\sigma(n)_w^2}+\frac{\sigma_r^2\left[\phi_{12}(0)+\phi_{12}(1)+...+\phi_{12}(n-1)\right]}{\sigma(n)_w^2}+ \\ & \frac{\sigma_e^2\left[\phi_{12}(0)+\phi_{12}(1)+...+\phi_{12}(n-1)\right]}{\sigma(n)_w^2}+\frac{\sigma_{pm}^2\left[\phi_{12}(0)+\phi_{12}(1)+...+\phi_{12}(n-1)\right]}{\sigma(n)_w^2}+ \\ & \frac{\sigma_{CA}^2\left[\phi_{12}(0)+\phi_{12}(1)+...+\phi_{12}(n-1)\right]}{\sigma(n)_w^2} \qquad (86)\end{aligned}$$

Thus the variance decomposition is finding the proportion of variance explained by a variable's own shock(ϵ_{wt}) versus the variance explained by shock to the other variables ϵ_{rt}, ϵ_{et}, $\epsilon_{pmt}$and ϵ_{cat}. The variance decomposition for the empirical model is presented in Table 3. In the variance decomposition analysis, nearly 75% of the variation in US current account balance is explained by its own shocks, and relative GDP explains 29% of the variation in relative wage. As nearly 25% of the variation in US current account balance is explained by interest rate differential (11%), REER (5%), relative GDP (6%) and China's wage cost (3%), this could suggest that China's exchange rate appreciation might not solve the enlarging US current account deficits. However from the long-run and short-run parameter estimates, higher relative GDP of China does have a significant effect on lowering current account balance, and from variance decomposition results, 12% of the variation in relative GDP is on the back of China's relatively lower wage cost. Figure 2 shows that following a relative wage shock, relative GDP declines with either loss of income for the low-wage country or the rise in income for the high-wage country.

Table 3: Variance Decompositions ($k = 30$)

Shocks in ↓	rw	ird	$reer$	ry	cab
rw	0.43891	0.03664	0.21193	0.12387	0.02668
ird	0.14291	0.75010	0.03689	0.09665	0.11266
$reer$	0.08287	0.03193	0.64079	0.11419	0.04616
ry	0.28609	0.06602	0.03465	0.63737	0.06095
cab	0.04923	0.11531	0.07573	0.02791	0.75355

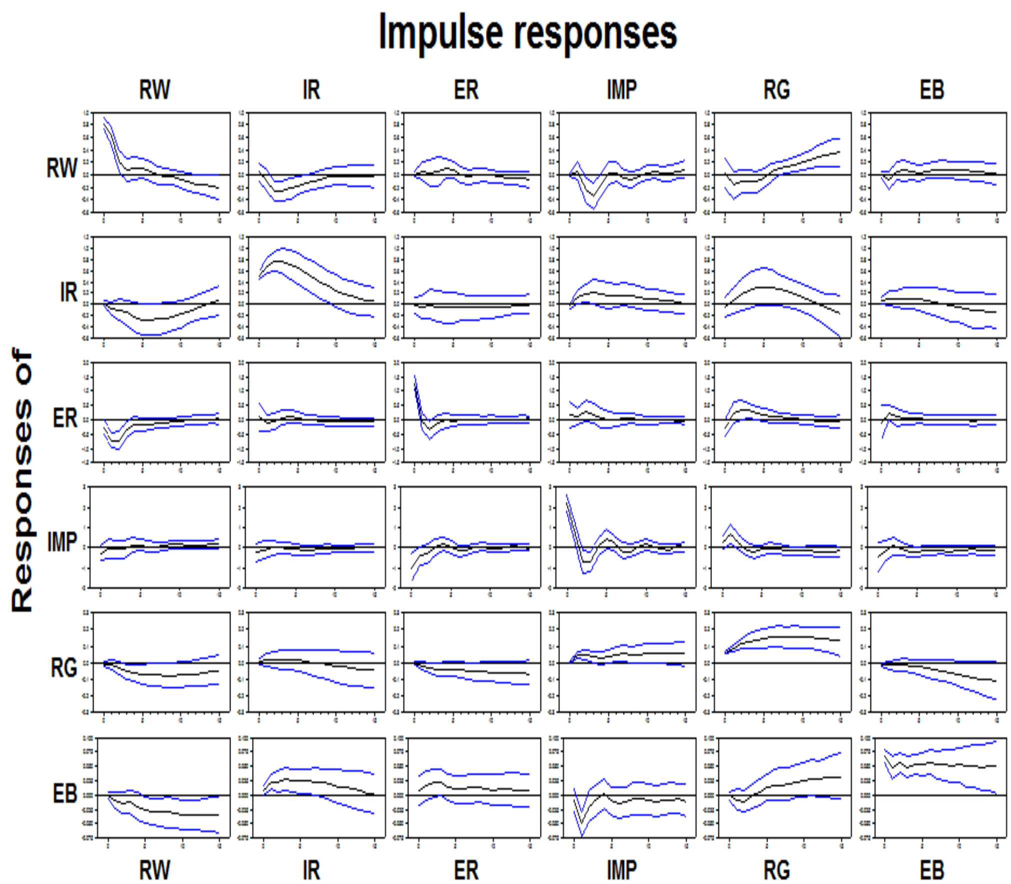
To further validate this result, a 6-variable VAR has been formulated by adding US import price as another variable in the VAR, following an over-identified SVAR strategy (Sims-Zha) and impose the restrictions in the matrix below:

$$\begin{bmatrix} 1 & a_{12} & 0 & 0 & a_{15} & 0 \\ 0 & 1 & a_{23} & 0 & a_{25} & 0 \\ a_{31} & a_{32} & 1 & a_{34} & a_{35} & a_{36} \\ a_{41} & 0 & a_{43} & 1 & 0 & a_{46} \\ a_{51} & a_{52} & 0 & 0 & 1 & a_{56} \\ 0 & 0 & a_{63} & a_{64} & 0 & a_{66} \end{bmatrix}$$

The technique draws a set of posterior samples from the VAR coefficients and computes impulse responses for each sample. These samples are then summarized to compute MC-based estimates of the responses using the error band methods in Sims and Zha (1999). The confidence bands are drawn by taking draws from the posterior distribution and identifying the shocks. The bands are modelled as the 16 and 84 percentile quantities for the response, which if the distribution is normal, these quantiles would correspond to a one standard deviation band as recommended by Sims and Zha (1999)[1]. These responses further help pinpoint the effects of different shocks, consistent with the earlier results from recursive factorisation (see figure 7). The results further pinpoint how China's heavily managed exchange rate contributes to its huge trade surplus with the United States. The fixed peg currency regime of China could act as a form of "exchange rate protection", alongside China's comparative advantage coming from lower relative wage cost, which remain central to any explanation of global imbalances. With import prices as an additional variable in an over-identified SVAR, we show that higher import price shock (4th column, Figure 7) could immediately worsen US current account balance if China's fixed peg is replaced, but it will help improve the US external balance in the medium run.

[1] Sims and Zha (1999) found that the impulse responses from a VAR have highly asymmetrical distributions. As a result, the use of one or two standard error bands can give a misleading impression about the shape. Hence, Sims and Zha (1999) argue in favour of fractiles with 16 and 84 percentiles.

Figure 7: IRFs from over-identified SVAR



9 Conclusion

Role of real and nominal exchange rates in flows of goods and capital are evaluated theoretically using the Ricardian comparative static and dynamic general equilibrium models. Under free trade arrangements a low income country with lower wage cost and large endowment of labour has comparative advantage in trade and accumulates foreign and domestic capital. Efficiency gains from free trade enhance economic growth and enhance welfare of households simultaneously in both low income and advanced economies. Empirically both static and dynamic general equilibrium models are solved and calibrated and tested with quarterly data over the time period 1995:1 to 2009:1 on China's relative wage cost, interest rate differential, and REER (with US import price in an overidentified VAR), China's relative GDP and the US current account balance. Decomposition of the variance of shocks and impulse response analysis are used to examine the size and the speed of adjustments to shocks. Dynamic simulations are compared with VAR predictions and impulse response analyses to show how shocks to China's wages and exchange rates interact with import prices and current account balance in the US. Empirical findings support theoretical predictions that welfare of households in a low income country can catch up to that of a more advanced economy as the former develops dynamic comparative advantage and accumulates more capital through trade surplus to expand its production of both tradable and non-tradable products. These findings are comparable to results in Turnovsky (1999) and Obstfeld-Rogoff (1996). In the long-run, China's interest rate and exchange rate shocks are positively related, while China's REER responds negatively to US import price shocks, which can happen via price adjustment by Chinese exporters (given fixed nominal exchange rate) on the back of lower wage cost in order to maintain its market share in the US. This suggests that although China's fixed peg makes the Renminbi undervalued, yet changes in the REER bear little on the US external balance, thus attributing the real shocks (relative wage and relative GDP) as the key determinants of persistent external imbalance in the US.

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A Appendix

Detailed derivation of structural coefficients.

$$
\begin{bmatrix} w_{cu,t} \\ r_{cu,t} \\ e_{c,t} \\ ry_{cu,t} \\ CA_{u,t} \end{bmatrix}
=
\begin{bmatrix} b_{11} & b_{12} & b_{13} & b_{14} & b_{15} \\ b_{21} & b_{22} & b_{23} & b_{24} & b_{25} \\ b_{31} & b_{32} & b_{33} & b_{34} & b_{35} \\ b_{41} & b_{42} & b_{43} & b_{44} & b_{45} \\ b_{51} & b_{52} & b_{53} & b_{54} & b_{55} \end{bmatrix}^{-1}
\begin{bmatrix} b_{10} \\ b_{20} \\ b_{30} \\ b_{40} \\ b_{50} \end{bmatrix}
+
\begin{bmatrix} b_{11} & b_{12} & b_{13} & b_{14} & b_{15} \\ b_{21} & b_{22} & b_{23} & b_{24} & b_{25} \\ b_{31} & b_{32} & b_{33} & b_{34} & b_{35} \\ b_{41} & b_{42} & b_{43} & b_{44} & b_{45} \\ b_{51} & b_{52} & b_{53} & b_{54} & b_{55} \end{bmatrix}^{-1}
\begin{bmatrix} \gamma_{11} & \gamma_{12} & \gamma_{13} & \gamma_{14} & \gamma_{15} \\ \gamma_{21} & \gamma_{22} & \gamma_{23} & \gamma_{24} & \gamma_{25} \\ \gamma_{31} & \gamma_{32} & \gamma_{33} & \gamma_{34} & \gamma_{35} \\ \gamma_{41} & \gamma_{42} & \gamma_{43} & \gamma_{44} & \gamma_{45} \\ \gamma_{51} & \gamma_{52} & \gamma_{53} & \gamma_{54} & \gamma_{55} \end{bmatrix}
+ \tag{A.1}
$$

$$
\begin{bmatrix} b_{11} & b_{12} & b_{13} & b_{14} & b_{15} \\ b_{21} & b_{22} & b_{23} & b_{24} & b_{25} \\ b_{31} & b_{32} & b_{33} & b_{34} & b_{35} \\ b_{41} & b_{42} & b_{43} & b_{44} & b_{45} \\ b_{51} & b_{52} & b_{53} & b_{54} & b_{55} \end{bmatrix}^{-1}
\begin{bmatrix} \varepsilon_{wt} \\ \varepsilon_{rt} \\ \varepsilon_{et} \\ \varepsilon_{pmt} \\ \varepsilon_{cat} \end{bmatrix} \tag{A.2}
$$

$$
\begin{bmatrix} a_{10} \\ a_{20} \\ a_{30} \\ a_{40} \\ a_{50} \end{bmatrix}
=
\begin{bmatrix} b_{11} & b_{12} & b_{13} & b_{14} & b_{15} \\ b_{21} & b_{22} & b_{23} & b_{24} & b_{25} \\ b_{31} & b_{32} & b_{33} & b_{34} & b_{35} \\ b_{41} & b_{42} & b_{43} & b_{44} & b_{45} \\ b_{51} & b_{52} & b_{53} & b_{54} & b_{55} \end{bmatrix}^{-1}
\begin{bmatrix} b_{10} \\ b_{20} \\ b_{30} \\ b_{40} \\ b_{50} \end{bmatrix}
;
\begin{bmatrix} e_{1t} \\ e_{2t} \\ e_{3t} \\ e_{4t} \\ e_{5t} \end{bmatrix}
=
\begin{bmatrix} b_{11} & b_{12} & b_{13} & b_{14} & b_{15} \\ b_{21} & b_{22} & b_{23} & b_{24} & b_{25} \\ b_{31} & b_{32} & b_{33} & b_{34} & b_{35} \\ b_{41} & b_{42} & b_{43} & b_{44} & b_{45} \\ b_{51} & b_{52} & b_{53} & b_{54} & b_{55} \end{bmatrix}^{-1}
\begin{bmatrix} \varepsilon_{wt} \\ \varepsilon_{rt} \\ \varepsilon_{et} \\ \varepsilon_{pmt} \\ \varepsilon_{cat} \end{bmatrix} \tag{A.3}
$$

$$
\begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} \\ a_{41} & a_{42} & a_{43} & a_{44} & a_{45} \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} \end{bmatrix}
=
\begin{bmatrix} b_{11} & b_{12} & b_{13} & b_{14} & b_{15} \\ b_{21} & b_{22} & b_{23} & b_{24} & b_{25} \\ b_{31} & b_{32} & b_{33} & b_{34} & b_{35} \\ b_{41} & b_{42} & b_{43} & b_{44} & b_{45} \\ b_{51} & b_{52} & b_{53} & b_{54} & b_{55} \end{bmatrix}^{-1}
\begin{bmatrix} \gamma_{11} & \gamma_{12} & \gamma_{13} & \gamma_{14} & \gamma_{15} \\ \gamma_{21} & \gamma_{22} & \gamma_{23} & \gamma_{24} & \gamma_{25} \\ \gamma_{31} & \gamma_{32} & \gamma_{33} & \gamma_{34} & \gamma_{35} \\ \gamma_{41} & \gamma_{42} & \gamma_{43} & \gamma_{44} & \gamma_{45} \\ \gamma_{51} & \gamma_{52} & \gamma_{53} & \gamma_{54} & \gamma_{55} \end{bmatrix} \tag{A.4}
$$

$$
\begin{bmatrix} w_{c,t} \\ r_{c,t} \\ e_{c,t} \\ pm_{u,t} \\ CA_{u,t} \end{bmatrix}
=
\begin{bmatrix} \overline{w}_{c,t} \\ \overline{r}_{c,t} \\ \overline{e}_{c,t} \\ \overline{pm}_{u,t} \\ \overline{CA}_{u,t} \end{bmatrix}
+ \sum_{i=0}^{\infty}
\begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} \\ a_{41} & a_{42} & a_{43} & a_{44} & a_{45} \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} \end{bmatrix}
\begin{bmatrix} b_{11} & b_{12} & b_{13} & b_{14} & b_{15} \\ b_{21} & b_{22} & b_{23} & b_{24} & b_{25} \\ b_{31} & b_{32} & b_{33} & b_{34} & b_{35} \\ b_{41} & b_{42} & b_{43} & b_{44} & b_{45} \\ b_{51} & b_{52} & b_{53} & b_{54} & b_{55} \end{bmatrix}^{-1}
\begin{bmatrix} \varepsilon_{wt} \\ \varepsilon_{rt} \\ \varepsilon_{et} \\ \varepsilon_{pmt} \\ \varepsilon_{cat} \end{bmatrix} \tag{A.5}
$$