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The Effects of Iceberg Costs on the Volatility of Real Exchange Rates

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Abstract

The Effects of Iceberg Costs on the Volatility of Real Exchange Rates

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The fact that real exchange rates are highly volatile is one of the puzzles in international macroeconomics. Standard real business cycle models cannot explain this issue. This paper introduces the transportation costs in IRBC model to explain real exchange rates fluctuations. And this paper shows that a model with the high level of transportation costs and elasticity of substitution can reproduce high volatility of real exchange rates and explain other puzzles in international macroeconomics.

Keywords : real exchange rate, volatility, persistency, iceberg cost, elasticity of substitution, puzzle

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1. Real Exchange Rate Puzzle

The real exchange rate(RER) is the purchasing power of a currency relative to another. And it is based on the GDP deflator measurement of the price level in the domestic and foreign countries. If purchasing power parity(PPP) holds, the RER would be constant and equal to one. However the observed real exchange rates are not constant but fluctuate in data and the volatility and persistency of RER is much more severe than what the previous models explains. [Table 1] shows the volatility of RER of each country.

[Table 1] Means and Standard deviations of 24-month indexes of RER volatility quarterly observed from 1975I through 1984III[①]

Country	Mean	Deviation Standard
United States	0.014385	0.004338
Canada	0.010894	0.002743
Japan	0.024841	0.007401
Belgium	0.008003	0.003324
France	0.012243	0.003086
Germany	0.010561	0.003254
Italy	0.013041	0.006669
Netherlands	0.009277	0.002071
Sweden	0.027117	0.011389
Switzerland	0.016891	0.004513
United Kingdom	0.020012	0.003472

There have been a lot of discussions about this puzzle. Dornbush(1976) presented exchange rate overshooting theory explaining the volatility of exchange rate. This theory accounts for the

① See Peter B. Kenen and DaniRodrik(1986) volatility with the rigidity of price, but this model cannot explain the volatility of RER. And also, other basic international real business cycles models cannot fully resolve this puzzle. Heathcote and perri(2002) made a two-country, two-goods model and they tried to explain the volatility of RER with TFP shock. This model accounts for about 25% of the observed relative volatility of the RER.

There have been several kinds of way to explain this issue. Some papers stress the importance of stochastic trends. King et al(1991) , Engel and West(2005), Aguiar and Gopinath(2007) and so on use random walks shock or trend shocks to explain economic fluctuations. Rabanal, Rubio-Ramirez and Tuesta(2011) uses the cointegrated TFP process in model. In this model the shock is nonstationary so it can yield high volatility of RER. Recently some papers consider monetary shock or nominal rigidities

This paper goes back to the fundamental mechanism which is related to trade costs. This kind of discussion is documented by Obstfeld and Rogoff in 2001. They studied the trade costs which are considered a common cause of six puzzles. However they give individual explanations for each puzzle not a single model accounting for every feature. In this paper, a single model considering transportation costs which is often called 'iceberg costs' is introduced. And this paper follows the seminal work of Backus et al.(1992) and Baxter and Crucini(1993) which uses stationary TFP shock following VAR process. With this iceberg costs model, the volatility and persistency of RER and other features are discussed. Before we proceed to the model, we discuss the home bias in trade puzzle.

2. Home Bias in Trade Puzzle

In the model this paper presents, home and foreign final goods price is compared to determine the RER. And final goods are made of home and foreign intermediate goods. Therefore the price and volume of intermediate goods is critical factor in RER. In this case the phenomenon that final goods producers use their home made intermediate goods more than foreign made one is main key to explain the volatility of RER. We discuss this mechanism more in modeling section.

This feature is named as the home bias in trade puzzle. This issue is first documented by McCallum in 1995. In this paper, when other factors are controlled the volume of trade in country is approximately 20 times larger than the volume of trade between countries. To explain this issue, the theory that various kinds of trade walls are existing and this constrains the trade between countries is presented.

Mostly the previous IRBC models introduce home bias in trade effects as a parameter in production functions. However this paper minimizes this bias parameter and puts the trade costs in model. By using this mechanism, we can identify the whole effect of introducing the costs and avoid arbitrary estimation of home bias in trade. In discussing this features, several points discussed by Obsfeld and Rogoff(2001)are shown.

3. The effects of introducing the iceberg costs

This paper refers to other papers[2][3] that discuss the iceberg costs. Mostly the iceberg costs are used in the following meaning. A cost of transporting a good that uses up only some fraction of the good itself, rather than using any other resources. Based on the idea of floating an iceberg, which is costless except for the amount of the iceberg itself that melts. It is a very tractable way of modeling transport costs since it impacts no other market.

When one producer in a country imports X units of a product, only μX units are arrived in the import country. This means that price of this product in both country cannot be same unless both country make same product in same technology. And if we assume that the transport market is competitive, then the cost of buying one unit in home price and the cost of buying $1/\mu$ unit of product in foreign country price are needed to be same. Therefore following equation holds.

$$P^{*} = \left(\frac{1}{\mu}\right) P \,,$$

P^{*}: the domestic price in home country ,

P : the domestic price in home country

This paper uses this equation in the model. Then next problem is how to estimate the value of μ. To get this value, a lot of factors should be considered. There are many kinds of costs in trade between countries.

② See Fabio Ghironi and Marc. J. Melitz(2004)
③ See Alfonso Irarrazabaly, Andreas Moxnesz, and Luca David Opromollax (2010)

First explicit cost is transportation cost. It depends on distance between countries, the kind of transportation method, weather condition, the level of developments in transports and so on. And also trade agreement that both country are engaging can be critical factor in estimating this cost. The trade barriers such as tariff, dumping, quarter in imports or exports and other restrictions are actual costs in traders.

And there are the implicit costs, especially time is critical one. People who buy some products in foreign country need to wait to receive those. This is some sort of costs because producers cannot change production line flexibly. And also asymmetric problems can be occurred. Buyer in home country cannot enough information about the products compared with home-made products.

Taking all factors discussed above in consideration is hard and exact estimation for this cost is not possible. In this paper, admitting a failure of accurate estimation, some possible levels of costs are put into the model. And we check the results of model as trade costs increase.

4. Estimates of the elasticity of substitution between imported and domestically produced commodities

One of the most important discussion in this paper is the elasticity of substitution between domestic intermediate goods and foreign intermediate goods. It is because the effect of trade costs on RER fluctuation is subject to this elasticity of substitution. This is defined as bellow.

$$\eta = \frac{\partial\left(\frac{Y_H}{Y_F}\right)\frac{P_F}{P_H}}{\partial\left(\frac{P_F}{P_H}\right)\frac{Y_H}{Y_F}}$$

As the elasticity of substitution increases, production mechanism is more sensitive to price of intermediate goods and this causes weights on the relative demand change more severely. This amplifies home bias effects and makes RER more volatile. Detail explanation about this process is presented in the results section.

Then we need to estimate the elasticity of substitution. The elasticity of substitution between domestic and imported goods has been the main objectof empirical study since the middle of last century. However these empiricalstudies have not delivered a consensus on its magnitude. These papers are divided between “elasticity pessimism” stemming from the earlier literature based on timeseries, and the “elasticity optimism” of the more recent studies using panel-basedeconometric methods. In other words, studies in the earlier literatureusually find very low elasticity estimates. However recent studies show higher ones.

Recently, Corbo and Osbat(2012) use bootstrap method to estimate the elasticity of substitution in Germany industries. The results are as follows.

[Table 2]Sector level results of the elasticity of substitution for the German economy[④]

	2SLS			Bootstrap								
Sec	#Partn	σ^	Std(σ^)	#Reps	Mean	Median	Mode	IQR	IQRnorm	Std	25%	75%
1511	68	4.3	5.3	5000	4.3	4.2	3.9	1.1	0.9	0.9	3.6	4.8
1512	103	7	12.8	5000	5.7	5.5	5.2	1.5	1	1.2	4.8	6.4
1513	118	4	4.1	5000	3.9	3.9	3.8	0.7	1	0.5	3.6	4.2
1514	91	2.6	1.6	5000	2.5	2.4	2.4	0.5	1.1	0.3	2.2	2.7
1520	48	1.9	1.1	5003	2.1	2	1.9	0.5	0.7	0.5	1.7	2.3
1531	77	4	4	5000	4.1	4	3.9	0.7	0.9	0.6	3.6	4.4
1532	46	3.2	2	5000	3.2	3.2	3.1	0.5	1	0.4	2.9	3.4
1533	49	2.9	1.6	5000	2.8	2.8	2.7	0.3	1	0.3	2.6	2.9
1541	69	2.4	1.4	5000	2.5	2.4	2.3	0.6	0.9	0.5	2.2	2.8
1542	46	2.9	1.1	5000	2.9	2.9	2.9	0.4	0.9	0.3	2.7	3.1
1543	84	3.6	3.7	5000	3.7	3.5	3.4	0.9	0.9	0.8	3.1	4.1
1549	96	8.4	18.9	5000	9.2	7.2	6.7	2.7	0	73.5	6.1	8.9
1551	81	3.2	3.3	5000	2.9	2.8	2.7	0.6	0.9	0.5	2.5	3.1
1552	73	3.5	3	5000	3.2	3.2	3.1	0.6	1	0.4	2.9	3.5
1553	61	6.8	8.3	5000	6.6	6.1	6	1.7	0.7	1.7	5.4	7.1
1554	75	3.9	6.6	5000	3.7	3.6	3.4	1	0.9	0.8	3.2	4.1
1600	52	6.4	10.9	5000	5.3	5	4.6	1.7	0.9	1.5	4.3	6.1
1711	107	3.8	3.6	5000	3.7	3.7	3.6	0.6	0.9	0.5	3.4	4
1721	109	11.2	27.1	5010	11.7	8.9	7.7	4.4	0.1	30.8	7.3	11.7
1722	86	3.7	3.4	5000	3.5	3.5	3.5	0.7	1	0.5	3.2	3.9
1729	77	3.8	3.8	5000	3.5	3.5	3.3	0.7	0.9	0.5	3.2	3.8
1730	103	5	0.4	5000	4.5	4.4	4.3	0.8	0.9	0.6	4.1	4.8
1810	147	3.1	2.3	5000	3.1	3.1	3.1	0.5	1	0.4	2.9	3.3
1911	75	6.4	12.1	5000	5.2	5	4.6	1.5	0.8	1.3	4.3	5.8
1912	97	27.9	280.2	5164	26.4	11	8.5	9.3	0	17	7.8	17.2
1920	91	5.5	6.5	5000	5.4	5.2	5	1.4	0.9	1.1	4.6	5.9
2010	93	3.5	2.6	5000	3.3	3.3	3.3	0.6	1	0.5	3	3.6
2021	68	1.5	0.4	5000	1.6	1.5	1.5	0.2	0.8	0.2	1.4	1.6
2022	80	3.8	3.7	5000	3.7	3.6	3.5	0.6	1	0.5	3.3	4
2023	91	2.6	2.1	5000	2.5	2.5	2.5	0.4	1	0.3	2.3	2.7
2029	122	3	2.1	5000	2.9	2.9	2.9	0.4	1	0.3	2.7	3.1
2101	72	2.7	1.3	5000	2.6	2.6	2.6	0.2	1	0.2	2.5	2.7
2102	85	3.5	3.3	5000	3.4	3.3	3.3	0.6	0.9	0.5	3.1	3.7
2109	82	2.5	1.4	5000	2.4	2.4	2.4	0.3	0.9	0.2	2.3	2.6
2211	98	3.9	3.1	5000	3.8	3.8	3.7	0.6	1	0.5	3.5	4.1
2212	71	4.1	3.4	5000	4	3.9	3.9	0.9	1	0.7	3.5	4.4
2221	94	3.5	3.7	5000	3.1	3.1	3	0.4	1	0.3	2.8	3.3
2222	67	4.4	6.4	5000	4.1	4	3.8	1	0.9	0.8	3.6	4.5
2310	19	2.7	0.3	5000	2.7	2.7	2.7	0.6	1	0.4	2.4	3
2320	40	2.4	0.1	5000	2.4	2.4	2.3	0.4	0.9	0.3	2.2	2.6

④ See Corbo and Osbat(2012)

2330	8	-	-	-	-	-	-	-	-	-	-	-
2411	105	2.1	1	5000	2.1	2.1	2	0.2	0.9	0.2	1.9	2.2
2412	41	2.4	1.4	5000	2.5	2.4	2.4	0.4	1	0.3	2.2	2.6
2413	78	4.7	0.6	5000	4.7	4.6	4.5	1.1	1	0.9	4.1	5.2
2422	63	3.3	2.9	5000	3.2	3.2	3.2	0.5	1	0.4	3	3.4
2423	76	3.1	3.7	5000	3	2.9	2.7	0.8	0.8	0.7	2.5	3.3
2424	92	3.2	2	5000	3	3	2.9	0.4	0.9	0.3	2.8	3.2
2429	103	3	0.3	5000	2.9	2.8	2.7	0.5	0.9	0.4	2.6	3.1
2430	63	3.8	3.6	5000	3.7	3.6	3.4	0.9	1	0.7	3.2	4.1
2511	74	3.4	4.1	5000	3	2.9	2.9	0.7	0.9	0.6	2.6	3.3
2519	79	3.2	2.4	5000	3	3	3	0.4	1	0.3	2.8	3.2
2520	122	4	5.3	5000	3.8	3.7	3.6	0.7	0.9	0.6	3.3	4.1
2610	99	3.1	3.8	5000	2.9	2.8	2.7	0.7	0.9	0.6	2.5	3.2
2691	100	3.2	2.2	5000	3	3	2.9	0.3	1	0.2	2.8	3.1
2692	57	3.3	1.6	5000	3.2	3.2	3.2	0.4	1	0.3	3	3.4
2693	55	3.2	3	5000	3.1	3	2.8	0.8	1	0.6	2.7	3.5
2694	38	3	1.3	5000	2.9	2.9	2.9	0.3	1	0.2	2.7	3
2695	54	2.5	1.7	5000	2.4	2.4	2.4	0.4	0.9	0.3	2.2	2.6
2696	81	2.1	0.9	5000	2.1	2	2	0.1	1	0.1	2	2.1
2699	75	2.6	1.7	5000	2.5	2.4	2.4	0.4	0.9	0.3	2.3	2.7
2710	87	3.3	2.8	5000	3.1	3.1	3	0.5	1	0.4	2.8	3.3
2720	102	3.8	3.2	5000	3.8	3.8	3.8	1	1	0.7	3.3	4.3
2811	81	3	2.5	5000	3	3	2.9	0.5	1	0.4	2.7	3.2
2812	62	4.5	7.7	5000	4	3.8	3.5	1.1	0.7	1.1	3.3	4.4
2813	38	3.8	5.4	5000	3.8	3.6	3.3	1.3	0.9	1.1	3	4.3
2893	109	3.8	5	5000	3.7	3.6	3.5	1	0.8	0.8	3.2	4.1
2899	122	3.2	2	5000	3.1	3.1	3.1	0.4	1	0.3	2.9	3.3
2911	84	7.9	25.7	5000	6.4	5.8	5.3	2	0.6	2.4	5	7
2912	113	2.4	1.9	5000	2.4	2.4	2.4	0.4	1	0.3	2.2	2.6
2913	99	15.9	93.9	5032	14.3	10	8.3	6.1	0.1	30.1	7.8	13.9
2915	73	3.3	2.8	5000	3.3	3.2	3.1	0.7	0.9	0.5	3	3.6
2919	107	7.6	20.7	5002	7.3	6.4	5.9	2.6	0.4	4.5	5.3	7.9
2921	64	2.4	1.8	5000	2.4	2.3	2.3	0.5	1	0.4	2.1	2.6
2922	76	3.1	3.6	5000	3.1	2.9	2.7	0.8	0.7	0.8	2.6	3.4
2923	54	3.9	4.6	5000	3.7	3.6	3.4	0.8	0.9	0.7	3.2	4
2924	88	3.6	3.3	5000	3.4	3.4	3.4	0.5	1	0.4	3.2	3.7
2925	75	5.9	1.6	5011	6.9	5.4	4.5	3.1	0.2	12.2	4.3	7.4
2926	81	3.3	3.8	5000	3	2.9	2.8	0.6	0.9	0.5	2.6	3.2
2927	48	2.4	2.1	5000	2.2	2.2	2.1	0.3	0.9	0.2	2	2.3
2929	105	4.7	8.9	5000	4.4	4.1	3.9	1.2	0.8	1.2	3.6	4.9
2930	72	6.5	16.3	5000	6	5.6	5.3	2	0.8	1.8	4.8	6.8
3000	132	4.2	8	5000	3.8	3.7	3.6	0.8	0.9	0.6	3.3	4.1
3110	117	1.9	0.1	5000	1.8	1.8	1.8	0.2	0.9	0.1	1.7	1.9
3120	100	6.7	12.7	5014	9.1	6.7	5.4	4.5	0.1	22.6	4.8	9.3
3130	71	3.2	0.2	5000	3.2	3.1	3	0.7	0.9	0.6	2.8	3.5
3140	39	2.2	2.2	5000	2.2	2.2	2.2	0.4	1	0.3	2	2.4
3150	83	8.2	2.9	5036	10.9	6.1	5.5	4.2	0.1	27.3	5.1	9.2
3190	77	2.4	2.6	5000	2.5	2.4	2.3	0.6	0.7	0.7	2.1	2.8
3210	71	9.4	4.1	5716	21	5.8	4.6	4.3	0	25.7	4.4	8.7
3220	100	2.9	2	5000	2.8	2.8	2.8	0.3	1	0.2	2.7	2.9
3230	84	2.5	2.7	5000	2.4	2.4	2.4	0.3	1	0.2	2.3	2.6
3311	93	5.7	15.3	5005	6.1	4.9	4	2.8	0.2	10	3.8	6.6
3312	115	6.2	22.1	5056	8.7	5	4.2	2.9	0	77.1	4	6.9
3313	62	5.5	13.8	5000	4.5	4	3.6	1.5	0.5	2.4	3.4	4.9
3320	92	2.4	2.4	5000	2.2	2.1	2.1	0.5	0.9	0.4	2	2.4
3410	102	68.1	1599.8	6114	35.7	14.4	12.2	10.3	0	77.6	11	21.4
3420	67	3.1	2.8	5000	3.1	3.1	3	0.7	1	0.5	2.7	3.4
3430	123	2.4	2.1	5000	2.4	2.3	2.3	0.3	1	0.2	2.2	2.5
3511	44	5.3	4.9	5000	4.7	4.7	4.6	0.9	1	0.7	4.3	5.2

3520	52	3.4	0.5	5000	3.3	3.2	3	0.9	0.9	0.7	2.8	3.7
3530	86	16	63.9	5293	27.7	10.7	8.5	9	0	93.1	8.1	17.1
3610	128	6.6	12.7	5000	5.5	5.2	4.9	1.4	0.8	1.2	4.6	6.1
3691	136	2	1.4	5000	1.9	1.8	1.8	0.2	0.9	0.2	1.8	2
3693	69	5.5	8	5000	4.8	4.6	4.3	1.3	0.9	1.1	4.1	5.3
3694	89	3.9	7.3	5000	2.9	2.7	2.6	0.7	0.7	0.7	2.5	3.2
3699	116	5.5	8.1	5000	5.2	5.1	4.9	1.3	0.9	1	4.5	5.8

Referring to this data, the values of elasticity of substitution are distributed from 1.5 to 14.4 depending on the industry. This paper uses these values in modeling and sees how the RER fluctuation and other features change as the elasticity of substitution varies. And it use 3 as the benchmark value of the elasticity of substitution to see the results of other features.

5. The Model

This chapter presents a standard two-country, two-good IRBC model, which is similar to the model in Heathcote and Perri (2002) and also Rabanal, Rubio-Ramirez and Tuesta(2011). The main difference in model between those papers and my paper is adopting transportation costs. The main direction is explaining real exchange rate volatility in IRBC model with iceberg costs. And also this paper discusses the persistency of RER, consumption real exchange rate anomaly, the Feldstein-Horioka puzzle and the international consumption correlations puzzle.

In this paper, we assume the problem faced by each country households and firms is symmetric. And in each country, there are one final good producer and one intermediate good producer. The latter one produces single kind of intermediate products and these products are used to produce home final goods and foreign final goods. So these are traded across the countries. A single final good is produced by a competitive firm that uses home intermediate goods and foreign intermediate goods. And only final goods are used for consumption and investment. And only non-contingent international riskless bonds are available. These are traded in units of domestic intermediate goods. In each period t, there are finitely many events s_t, the economy experiences one of these events with history $s^t = (s_0, \dots, s_t)$. And in each period the probability of any particular history s^t is $\pi(s^t)$ and s_0 is given.

5.1. Households

The representative household of the home country solves

$$\max_{\{C(s^t),L(s^t),X(s^t),K(s^t),D(s^t)\}} \sum_{t=1}^{\infty} \beta^t \sum_{s^t} \frac{\pi(s^t)\left(\left(C(s^t)^{\tau}(1-L(s^t)^{1-\tau})\right)^{1-\sigma}\right)}{1-\sigma} \tag{1}$$

subject to the following budget constraint and the law of motion for capital as below.

$$\begin{aligned} W(s^t)L(s^t) + R(s^t)K(s^{t-1}) + \frac{P_H(s^t)}{P(s^t)}\left(D(s^{t-1}) - \Phi\left(D(s^t)\right)\right) \\ \geq C(s^t) + X(s^t) + \frac{P_H(s^t)}{P(s^t)}\bar{Q}(s^t)D(s^t) \end{aligned} \tag{2}$$

$$K(s^t) = (1-\delta)K(s^{t-1}) + X(s^t) \tag{3}$$

In the same way, the representative household of the foreign country solves

$$\max_{\{C(s^t),L(s^t),X(s^t),K(s^t),D(s^t)\}} \sum_{t=1}^{\infty} \beta^t \sum_{s^t} \frac{\pi(s^t)^*\left(\left(C^*(s^t)^{\tau}(1-L^*(s^t)^{1-\tau})\right)^{1-\sigma}\right)}{1-\sigma} \tag{4}$$

subject to the following budget constraint and the law of motion for capital as below.

$$\begin{aligned} W^*(s^t)L^*(s^t) + R^*(s^t)K^*(s^{t-1}) + \frac{P_H^*(s^t)}{P^*(s^t)}\left(D^*(s^{t-1}) - \Phi\left(D^*(s^t)\right)\right) \\ \geq C^*(s^t) + X^*(s^t) + \frac{P_H^*(s^t)}{P^*(s^t)}\bar{Q}^*(s^t)D^*(s^t) \end{aligned} \tag{5}$$

$$K^*(s^t) = (1-\delta)K^*(s^{t-1}) + X^*(s^t) \quad (6)$$

The following notations are used: $\beta \in (0,1)$ is the discount factor, $L(s^t) \in (0,1)$is the fraction of time allocated to work in the home country, $C(s^t) \geq 0$ is in units of consumption of the final good, $X(s^t) \geq 0$ are units of investment, and $K(s^t) \geq 0$ is the capital stock in the home country at the beginning of period $t+1$. $P(s^t)$is the price of the home final good in the home country. $P^*(s^t)$is the price of the foreign final good in the foreign country. $P_H(s^t)$is the price of the home intermediate good in the home country. $P_H^*(s^t)$is the price of the home intermediate good in the foreign country. $P_F(s^t)$is the price of the foreign intermediate good in the foreign country. $P_F^*(s^t)$is the price of the foreign intermediate good in home country. $W(s^t)$is the hourly wage in the home country measured in units of the final good. $R(s^t)$is the home country rental rate of capital measured in units of the final good. $D(s^t)$is the holdings of the internationally traded riskless bond that pays one unit of home intermediate good in period $t+1$. And $\overline{Q}(s^t)$ is bond price measured in units of the home intermediate good. The function $\Phi(\cdot)$ is the cost of holding bonds measured in units of the home intermediated good. And all notations with * stand for foreign country.

And this paper sets cost of holding bonds as follows

$$\Phi\big(D(s^t)\big) = \frac{\phi}{2}A(s^{t-1})\left[\frac{D(s^t)}{A(s^{t-1})}\right]^2 \quad (7)$$

5.2. Iceberg cost

This section introduces transportation cost which is usually called 'Iceberg Costs' before we set up the firm's optimization problems. In this paper, we assume that there is iceberg in the ocean and each country's intermediate producer needs ship to transport their products across the country. So during transportation, some part of products is missing and firms take this transportation cost. In this paper, we assume that a firm in home country needs to buy more than one unit to receive exact one unit after transportation and this fixed discount ratio is applied to any firm in the economy and denoted by μ $(1 > \mu > 0)$

Under this assumption, we can derive relationship between home price and foreign price. If the transportation market is competitive, the cost of buying one unit of foreign product in home country equals the cost of buying $1/\mu$ unit of foreign product in foreign country. Therefore the following equations hold.

$$P_H^* = \left(\frac{1}{\mu}\right) P_H \tag{8}$$

$$P_F^* = \left(\frac{1}{\mu}\right) P_F \tag{9}$$

With iceberg costs, we set up the firm optimization problems.

5.3. Firms

In this section the final and intermediate goods producer problem with iceberg costs is presented.

5.3.1. Final Good Producers

The final good in the home country is produced with home intermediated goods and foreign intermediate goods. The production technology is described below.

$$Y(s^t) = \left(\omega^{\frac{1}{\theta}} Y_H^{\frac{\theta-1}{\theta}} + (1-\omega)^{\frac{1}{\theta}} \mu^{\frac{\theta-1}{\theta}} Y_F^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}} \qquad (10)$$

In this production function, $Y_H(s^t)$ denotes the amount of home intermediate goods production sold to the home final goods producer and $Y_F(s^t)$ is the amount of foreign intermediate production which is scheduled to be sold to the home final goods. However after transportation, there is a loss in products so final goods producer in home country can only input the μ proportion of originally produced intermediate goods. And parameter ω stands for the fraction of home intermediate goods used for the production of the home final good. This paper sets the value of ω nearly 0.5 so that we control the primary home bias effect on production. If ω is exactly 0.5, then RER is always one and we cannot get any effect of transportation cost and other variable.And parameterθ denotes the elasticity of substitution between home and foreign intermediate goods. Therefore the final good producer in the home country faces the following problems

$$\max_{Y(s^t)\geq 0, Y_H(s^t)\geq 0, Y_F(s^t)\geq 0} P(s^t)Y(s^t) - P_H(s^t)Y_H(s^t) - P_F^*(s^t)\mu Y_F(s^t) \qquad (11)$$

And foreign final producer's problem is

$$\max_{Y^*(s^t)\geq 0, Y_H^*(s^t)\geq 0, Y_F^*(s^t)\geq 0} P^*(s^t)Y^*(s^t) - P_H^*(s^t)\mu Y_H^*(s^t) - P_F(s^t)Y_F^*(s^t) \tag{12}$$

subject to the following production function.

$$Y^*(s^t) = \left(\omega^{\frac{1}{\theta}} Y_F^{*\frac{\theta-1}{\theta}} + (1-\omega)^{\frac{1}{\theta}} \mu^{\frac{\theta-1}{\theta}} Y_H^{*\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}} \tag{13}$$

5.3.2. Intermediate Good Producers

The intermediate goods producer in the home country uses home labor and capital to produce home intermediate good and sells the intermediate products to the final good producers. The intermediate good producers have the production function below.

$$Y_H(s^t) + Y_H^*(s^t) = A(s^t)^{1-\alpha} K(s^{t-1})^{\alpha} L(s^t)^{1-\alpha} \tag{14}$$

$$Y_F(s^t) + Y_F^*(s^t) = A^*(s^t)^{1-\alpha} K^*(s^{t-1})^{\alpha} L^*(s^t)^{1-\alpha} \tag{15}$$

And the intermediate goods producers maximize profit taking prices of all goods and factors inputs as given.

$$\begin{aligned}\max_{L(s^t)\geq 0, K(s^{t-1})\geq 0} & P_H(s^t)Y_H(s^t) + P_H(s^t)Y_H^*(s^t) - P(s^t)[W(s^t)L(s^t) \\ & + R(s^t)K(s^{t-1})]\end{aligned} \tag{16}$$

$$\begin{aligned}\max_{L^*(s^t)\geq 0, K^*(s^{t-1})\geq 0} & P_F(s^t)Y_F(s^t) + P_F(s^t)Y_F^*(s^t) - P^*(s^t)[W^*(s^t)L^*(s^t) \\ & + R^*(s^t)K^*(s^{t-1})]\end{aligned} \tag{17}$$

5.4. The Processes for TFP

This section introduces TFP impulse, and in this paper, stationary shock processes are assumed. If some productivity shock occurs in one country, then this shock spreads to the other country in next periods. TFP processes for both country is described as below

$$A(s^t) = \rho A(s^{t-1}) + \rho^* A^*(s^{t-1}) - \epsilon(s^t) \quad (18)$$

$$A^*(s^t) = \rho A^*(s^{t-1}) + \rho^* A(s^{t-1}) - \epsilon^*(s^t) \quad (19)$$

where $\epsilon(s^t) \sim N(0,\sigma), \epsilon^*(s^t) \sim N(0,\sigma^*)$, $0 < \rho, \rho^* < 1,\ 0 < \rho + \rho^* < 1$.

5.5. Equilibrium

This section describes the set of equilibrium conditions.

5.5.1. Households Equilibrium Conditions

From the households maximization problems, we can derive equilibrium conditions as follows.

$$U_C(s^t) = \lambda(s^t) \quad (20)$$

$$\frac{U_L(s^t)}{U_C(s^t)} = W(s^t) \quad (21)$$

These equations are labor supply conditions. $U_C(s^t)$ is marginal utility of consumption and $U_L(s^t)$ is marginal disutility of labor. And also we can derive Euler equation as bellow.

$$U_C(s^t) = \beta \sum_{s^{t+1}} \frac{\pi(s^{t+1})}{\pi(s^t)} U_c(s^{t+1})[R(s^{t+1}) + 1 - \delta] \quad (22)$$

The symmetric equations are applied for foreign country households problems.

And the price of the riskless bond is determined by following equation.

$$\bar{Q}(s^t) = \beta \sum_{s^{t+1}} \frac{\pi(s^{t+1})}{\pi(s^t)} \frac{\lambda(s^{t+1})}{\lambda(s^t)} \frac{P_H(s^{t+1})}{P_H(s^t)} \frac{P(s^t)}{P(s^{t+1})} - \frac{\Phi'[D(s^t)]}{\beta} \tag{23}$$

The following condition equates the price of the riskless bond to the cost of adjusting bonds

$$\sum_{s^{t+1}} \frac{\pi(s^{t+1})}{\pi(s^t)} [\frac{\lambda^*(s^{t+1})}{\lambda^*(s^t)} \frac{P_H(s^{t+1})}{P_H(s^t)} \frac{P^*(s^t)}{P^*(s^{t+1})} - \frac{\lambda(s^{t+1})}{\lambda(s^t)} \frac{P_H(s^{t+1})}{P_H(s^t)} \frac{P(s^t)}{P(s^{t+1})}$$

$$= -\frac{\Phi'[D(s^t)]}{\beta} \tag{24}$$

5.5.2. Intermediate goods producers' maximization conditions

We can derive equilibrium conditions from (14) to (17).

$$R(s^t) = \alpha \frac{P_H(s^t)}{P(s^t)} A(s^t)^{1-\alpha} K(s^{t-1})^{\alpha-1} L(s^t)^{1-\alpha} \tag{25}$$

$$W(s^t) = (1-\alpha) \frac{P_H(s^t)}{P(s^t)} A(s^t)^{1-\alpha} K(s^{t-1})^{\alpha} L(s^t)^{-\alpha} \tag{26}$$

$$R^*(s^t) = \alpha\mu \frac{P_F^*(s^t)}{P^*(s^t)} A^*(s^t)^{1-\alpha} K^*(s^{t-1})^{\alpha-1} L^*(s^t)^{1-\alpha} \tag{27}$$

$$W^*(s^t) = (1-\alpha)\mu \frac{P_F^*(s^t)}{P^*(s^t)} A^*(s^t)^{1-\alpha} K^*(s^{t-1})^{\alpha} L^*(s^t)^{-\alpha} \tag{28}$$

5.5.3. Final goods producers' maximization conditions

We can derive the demand equations for intermediate goods using equations from (10), (11), (12) and (13).

$$Y_H(s^t) = \omega Y(s^t)\left(\frac{P_H(s^t)}{P(s^t)}\right)^{-\theta} \tag{29}$$

$$Y_F(s^t) = \mu^{\theta-1}(1-\omega)Y(s^t)\left(\frac{P_F(s^t)}{P(s^t)}\right)^{-\theta} \tag{30}$$

$$Y_H^*(s^t) = \mu^{-1}(1-\omega)Y^*(s^t)\left(\frac{P_H^*(s^t)}{P^*(s^t)}\right)^{-\theta} \tag{31}$$

$$Y_F^*(s^t) = \mu^{-\theta}\omega Y^*(s^t)\left(\frac{P_F^*(s^t)}{P^*(s^t)}\right)^{-\theta} \tag{32}$$

5.5.4 Market Clearing Conditions

Market clearing conditions in the final goods markets and the international bond market are described as bellow.

$$C(s^t) + X(s^t) = Y(s^t) \tag{33}$$

$$C^*(s^t) + X^*(s^t) = Y^*(s^t) \tag{34}$$

$$D(s^t) + D^*(s^t) = 0 \tag{35}$$

5.6 Defining and Deriving Real Exchange Rate

In this paper, real exchange rate is defined as bellow.

$$RER(s^t) = \frac{P^*(s^t)}{P(s^t)} \tag{36}$$

And RER can be expressed in other way when we use final goods production functions and demands of intermediate good

$$RER(s^t) = \left(\frac{\omega P_F(s^t)^{1-\theta} + (1-\omega)\mu^{\theta-1}P_H^{1-\theta}}{\omega P_H(s^t)^{1-\theta} + (1-\omega)\mu^{\theta-1}P_F^{1-\theta}}\right)^{\frac{1}{1-\theta}} \tag{37}$$

Then, the sources of RER fluctuation are primary bias in production, which is ω and the iceberg costs, which is μ. If ω is nearly 0.5, then the only source of RER variation when relative price of inputs is controlled is iceberg costs. The parameter μ is smaller than one and if we assume θ is bigger than one, then $\mu^{\theta-1}$ is smaller than one and this term gives asymmetric effects on home and foreign goods prices. In this paper, ω is controlled as almost 0.5 because the primary bias in production is assumed to be mainly caused by transportation costs. In this way we can measure transportation costs effects on RER fluctuation and inspect other features.

Also we can see that home bias is increasing in both countries when μ decreases, which means increasing transportation costs , or θ increases. These are critical factors in determining RER fluctuation.

And we can think about the relation with μ and ω. Both parameters are making home bias in this model. However the effects of μ on home bias depends on the value of θ and ω are not influenced by θ.

6. Results

6.1 Discussing the Home Bias in Trade Puzzle

By using equation (22), (23), (24) and (25), we can derive relative demand of intermediate goods as follows.

$$\frac{Y_H(s^t)}{Y_F(s^t)} = \frac{\omega}{1-\omega}\mu^{1-\theta}\left(\frac{P_F(s^t)}{P_H(s^t)}\right)^{\theta} \tag{38}$$

$$\frac{Y_F^*(s^t)}{Y_H^*(s^t)} = \frac{\omega}{1-\omega}\mu^{1-\theta}\left(\frac{P_H^*(s^t)}{P_F^*(s^t)}\right)^{\theta} \tag{39}$$

These equations stand for relative factor demand for final goods. The demand ratio is determined by the transportation costs and relative price of input factors. $\mu^{1-\theta}$ is larger than 1 on the condition that $\theta > 1$, and this means final goods producers input their home intermediate goods more than foreign goods. This home bias effect is independent to the relative price of input factors. This means that final producers put their home-made intermediate goods even if both intermediate goods prices are same. And this bias is getting severe as μ is decreasing or θ is increasing. By introducing transportation costs, we can get some sort of explanation for the home bias in trade puzzle.

6.2 Consumption real exchange rate anomaly

Chai, Kehoe and McGrattan(2001) find the main discrepancy between complete markets sticky price models and the data, which is that models predicts a high correlation between the real exchange rate and relative consumptions across countries. However statistical data show no relationship between two factors.[⑤] They refer to this discrepancy as the consumption real exchange rate anomaly.We can confirm that the model adopting iceberg costs solves this anomaly as follows.

[Table 3][⑥] : Selected cross-correlations between real exchange rate and relative consumption

	Corr(RS,C-C*)	Corr(DRS,D(C-C*))
Australia	-0.386	-0.196
Austria	-0.153	0.071
Canada	-0.474	-0.214
France	-0.254	-0.168
Germany	-0.288	0.032
Italy	-0.313	-0.272
Japan	0	0.26
Netherlands	-0.435	-0.258
New Zealand	0.515	0.55
Spain	-0.654	-0.377
Sweden	0.634	0.464
Switzerland	0.03	0.091
UK	-0.587	-0.529
Median	-0.288	-0.168

[Table 4] : Matrix of Correlation (Iceberg Costs 0%)

MATRIX OF CORRELATIONS (HP filter, lambda = 1600)

Variables	y	ys	c	cs	ph	phs	pf	pfs	l	ls	rer	a	x	xs	nx	cd	yd
Y	1	-0.7567	0.4973	0.1279	-0.4093	-0.4093	0.4093	0.4093	0.5752	-0.1967	0.4093	0.6123	0.9856	-0.844	-0.888	0.4255	0.9372
ys	-0.7567	1	0.1279	0.4973	0.4093	0.4093	-0.4093	-0.4093	-0.1967	0.5752	-0.4093	-0.0539	-0.844	0.9856	0.888	-0.4255	-0.9372
c	0.4973	0.1279	1	0.6233	-0.4232	-0.4232	0.4232	0.4232	0.8201	0.1359	0.4232	0.9628	0.3435	0.0171	-0.0668	0.434	0.197
cs	0.1279	0.4973	0.6233	1	0.4232	0.4232	-0.4232	-0.4232	0.1359	0.8201	-0.4232	0.4646	0.0171	0.3435	0.0668	-0.434	-0.197
ph	-0.4093	0.4093	-0.4232	0.4232	1	1	-1	-1	-0.8278	0.8278	-1	-0.5879	-0.3606	0.3606	0.1261	-0.9752	-0.4367
phs	-0.4093	0.4093	-0.4232	0.4232	1	1	-1	-1	-0.8278	0.8278	-1	-0.5879	-0.3606	0.3606	0.1261	-0.9752	-0.4367
pf	0.4093	-0.4093	0.4232	-0.4232	-1	-1	1	1	0.8278	-0.8278	1	0.5879	0.3606	-0.3606	-0.1261	0.9752	0.4367
pfs	0.4093	-0.4093	0.4232	-0.4232	-1	-1	1	1	0.8278	-0.8278	1	0.5879	0.3606	-0.3606	-0.1261	0.9752	0.4367

⑤See V. V Chari, Patrick J. Kehoe and Ellen R. McGrattan(2002)
⑥See Gianluca Benignoa, Christoph Thoenissen(2008)

l	0.5752	-0.1967	0.8201	0.1359	-0.8278	-0.8278	0.8278	0.8278	1	-0.3946	0.8278	0.9319	0.4629	-0.2393	-0.1598	0.7882	0.4118
ls	-0.1967	0.5752	0.1359	0.8201	0.8278	0.8278	-0.8278	-0.8278	-0.3946	1	-0.8278	-0.0561	-0.2393	0.4629	0.1598	-0.7882	-0.4118
rer	0.4093	-0.4093	0.4232	-0.4232	-1	-1	1	1	0.8278	-0.8278	1	0.5879	0.3606	-0.3606	-0.1261	$\boxed{0.9752}$	0.4367
a	0.6123	-0.0539	0.9628	0.4646	-0.5879	-0.5879	0.5879	0.5879	0.9319	-0.0561	0.5879	1	0.4752	-0.1489	-0.1829	0.5739	0.3554
x	0.9856	-0.844	0.3435	0.0171	-0.3606	-0.3606	0.3606	0.3606	0.4629	-0.2393	0.3606	0.4752	1	-0.9169	-0.9482	0.376	0.9761
xs	-0.844	0.9856	0.0171	0.3435	0.3606	0.3606	-0.3606	-0.3606	-0.2393	0.4629	-0.3606	-0.1489	-0.9169	1	0.9482	-0.376	-0.9761
nx	-0.888	0.888	-0.0668	0.0668	0.1261	0.1261	-0.1261	-0.1261	-0.1598	0.1598	-0.1261	-0.1829	-0.9482	0.9482	1	-0.1539	-0.9475
cd	0.4255	-0.4255	0.434	-0.434	-0.9752	-0.9752	0.9752	0.9752	0.7882	-0.7882	0.9752	0.5739	0.376	-0.376	-0.1539	1	0.454
yd	0.9372	-0.9372	0.197	-0.197	-0.4367	-0.4367	0.4367	0.4367	0.4118	-0.4118	0.4367	0.3554	0.9761	-0.9761	-0.9475	0.454	1

[Table 5] : Matrix of Correlation (Iceberg Costs 30%)

MATRIX OF CORRELATIONS (HP filter, lambda = 1600)

Variables	y	ys	c	cs	ph	phs	pf	pfs	l	ls	rer	a	x	xs	nx	cd	Yd
y	1	0.0868	0.9471	0.3573	0.3411	0.3411	-0.3411	-0.3411	0.9623	-0.1548	-0.3411	0.9939	0.9816	-0.0785	-0.5751	0.645	0.6757
ys	0.0868	1	0.3573	0.9471	-0.3411	-0.3411	0.3411	0.3412	-0.1548	0.9623	0.3411	0.1861	-0.0785	0.9816	0.4331	-0.645	-0.6757
c	0.9471	0.3573	1	0.582	0.1043	0.1043	-0.1043	-0.1042	0.8247	0.1279	-0.1043	0.9625	0.8684	0.2058	-0.3222	0.4572	0.4364
cs	0.3573	0.9471	0.582	1	-0.1043	-0.1043	0.1043	0.1043	0.1279	0.8247	0.1043	0.4467	0.2058	0.8684	0.1517	-0.4572	-0.4364
ph	0.3411	-0.3411	0.1043	-0.1043	1	1	-1	-1	0.4934	-0.4934	-1	0.3199	0.4651	-0.4651	-0.9454	0.228	0.5049
phs	0.3411	-0.3411	0.1043	-0.1043	1	1	-1	-1	0.4934	-0.4934	-1	0.3199	0.4651	-0.4651	-0.9454	0.228	0.5049
pf	-0.3411	0.3411	-0.1043	0.1043	-1	-1	1	1	-0.4934	0.4934	1	-0.3199	-0.4651	0.4651	0.9454	-0.228	-0.5049
pfs	-0.3411	0.3412	-0.1042	0.1043	-1	-1	1	1	-0.4934	0.4934	1	-0.3199	-0.4651	0.4651	0.9454	-0.228	-0.5049
l	0.9623	-0.1548	0.8247	0.1279	0.4934	0.4934	-0.4934	-0.4934	1	-0.3832	-0.4934	0.9381	0.9962	-0.3154	-0.7275	0.7621	0.8266
ls	-0.1548	0.9623	0.1279	0.8247	-0.4934	-0.4934	0.4934	0.4934	-0.3832	1	0.4934	-0.0541	-0.3154	0.9962	0.622	-0.7621	-0.8266
rer	-0.3411	0.3411	-0.1043	0.1043	-1	-1	1	1	-0.4934	0.4934	1	-0.3199	-0.4651	0.4651	0.9454	$\boxed{-0.228}$	-0.5049
a	0.9939	0.1861	0.9625	0.4467	0.3199	0.3199	-0.3199	-0.3199	0.9381	-0.0541	-0.3199	1	0.9631	0.0217	-0.5369	0.5642	0.5978
x	0.9816	-0.0785	0.8684	0.2058	0.4651	0.4651	-0.4651	-0.4651	0.9962	-0.3154	-0.4651	0.9631	1	-0.2439	-0.697	0.7246	0.7844
xs	-0.0785	0.9816	0.2058	0.8684	-0.4651	-0.4651	0.4651	0.4651	-0.3154	0.9962	0.4651	0.0217	-0.2439	1	0.5789	-0.7246	-0.7844
nx	-0.5751	0.4331	-0.3222	0.1517	-0.9454	-0.9454	0.9454	0.9454	-0.7275	0.622	0.9454	-0.5369	-0.697	0.5789	1	-0.5183	-0.746
cd	0.645	-0.645	0.4572	-0.4572	0.228	0.228	-0.228	-0.228	0.7621	-0.7621	-0.228	0.5642	0.7246	-0.7246	-0.5183	1	0.9546
yd	0.6757	-0.6757	0.4364	-0.4364	0.5049	0.5049	-0.5049	-0.5049	0.8266	-0.8266	-0.5049	0.5978	0.7844	-0.7844	-0.746	0.9546	1

6.3 Discussing The Feldstein-Horioka puzzle

The Feldstein-Horioka puzzle is one of the most famous puzzle in international finance. It has been discussed widely but it is still a puzzle. This puzzle was documented by Martin Feldstein and Charles Horioka in their 1980 paper. Theoretically investors are able to easily invest anywhere beyond border. Therefore the return per unit of investment across the countries is supposed to be similar. Under this assumption, there would be no clear pattern between savings and investment in a country. However according to the data, long-period averages of national saving rates are highly correlated with similar averages of national saving rates. This discrepancy is referred as the Feldstein-Horioka puzzle.

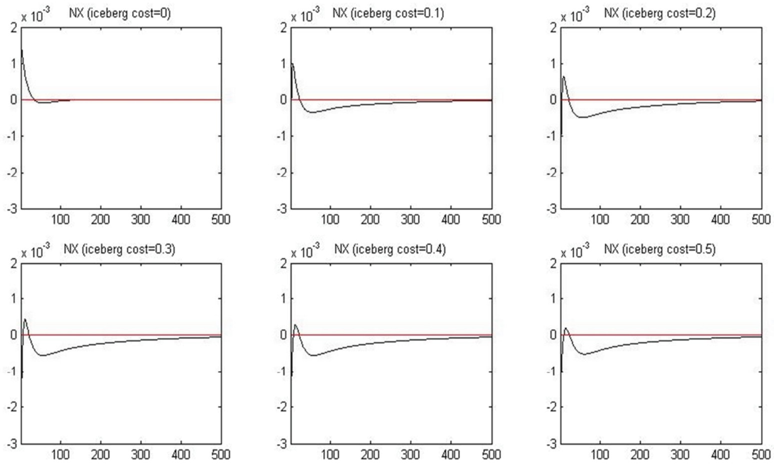
There has been a lot of trials to solve this issue, but nothing fully explains this problem. One of the explanations is adopting transaction costs. This is already discussed by Obsfeld and Roogoff in 2001. In their paper, they explain that transport costs can temper current-account imbalances. This means that there is some kind of restriction on investing and iceberg costs might be this restriction. In this paper, we check the trade balance after introducing iceberg costs and see how it changes.

By introducing trade costs, we can get some points to explain this issue. When the positive TFP shock occurs in home country, the foreign country producer has an incentive to import intermediate goods made in home country because this product is cheaper. However if the trade cost exists, then this price goes down less than before and foreign country producer loses incentive to increase home products portion. Therefore trade costs lower the volume of trade and it tempers current-account imbalance. And this effect makes national saving and investments converge.

[Table 6] : Standard deviation of Current-Account ($\theta = 5, \omega = 0.51$)

Iceberg Cost(%)	0	0.1	0.2	0.3	0.4	0.5
S.d. (NX)	0.0204	0.0131	0.0091	0.0066	0.0049	0.0037

[Figure 1] : current account movements



6.4 The international consumption correlations puzzle is still a puzzle

If we assume Arrow-Debreu complete-markets framework, country specific output risks should be pooled, so domestic per capita consumption should not heavily be influenced by country specific income shock. This means consumption correlations between countries are supposed to be high. However, in a real world, consumption correlations are much lower than we expects. This is consumption correlation puzzle, and This has spawned some subpuzzles such as Backus puzzle. Backus, Kehoe, and Kydland(1992) showed the fact that international output growth rates are more highly correlated than consumption growth rate rates. Table 5 shows data of consumption correlations and output correlations between US and other countries.

[Table 7] : International Comovements in OECD Economics[7]

	Correlation with Same U.S. Variable					
Country	y	c	x	g	n	z
Australia	0.51	-0.19	0.16	0.23	-0.18	0.52
Austria	0.38	0.23	0.46	0.29	0.47	0.17
Canada	0.76	0.49	-0.01	-0.01	0.53	0.75
France	0.41	0.39	0.22	0.22	0.26	0.39
Germany	0.69	0.49	0.55	0.55	0.52	0.65
Italy	0.41	0.02	0.31	0.31	-0.01	0.35
Japan	0.6	0.44	0.56	0.56	0.32	0.58
Switzerland	0.42	0.4	0.38	0.38	0.36	0.43
United Kingdom	0.55	0.42	0.4	0.4	0.69	0.35
Europe	0.66	0.51	0.53	0.53	0.33	0.56

[Table 8](Corr(Y,Y*), Corr(C,C*))

	$\theta = 0.85$	$\theta = 1.01$	$\theta = 1.5$	$\theta = 3$	$\theta = 5$	$\theta = 10$
IC=0	0.922, 0.995	0.978, 0.999	0.258, 0.964	-0.499, 0.823	-0.667, 0.720	-0.756, 0.623
IC=0.1	0.883, 0.995	0.976, 0.999	0.195, 0.957	-0.433, 0.777	-0.526, 0.654	-0.505, 0.561
IC=0.2	0.766, 0.994	0.970, 0.999	0.113, 0.940	-0.328, 0.698	-0.310, 0.587	-0.110, 0.565
IC=0.3	0.593, 0.993	0.963, 0.999	0.053, 0.920	-0.248, 0.644	-0.139, 0.574	0.086, 0.582

After simulating iceberg cost model, we can get the results above. In table 6 none of result resolves the Backus-Smith puzzle. All results still show that correlation between outputs is lower than correlation between

[7] See Backus Kehoe Kydland(1993)

consumptions. If elasticity of substitution is high, then firms are sensitive to price. When positive shock appears in home country, then home price goes down, and all firms including foreign firms are likely to use home intermediate good more, and intermediate production decreases. Therefore foreign output has negative correlation with home output when elasticity of substitution is high.

However, the transport cost mitigates this process so it can increase the value of correlation between outputs. We can check this feature in table 6. And also the cost weakens the relationship between two country consumptions.

6.5 RER Volatility and Persistency

The real exchange rate is the relative price of foreign final good, so difference in both country's final goods prices makes RER volatility. In basic IRBC model, the basic mechanism that makes RER volatility works as follows. When a positive TFP shock occurs in the home economy, the amount of home intermediate goods production increases and also output, consumption, investment increase as follows. As home intermediate goods production increases relatively the price of this product is going down and the price of foreign country intermediate good is going up. And the components of final goods in each country are asymmetric due to home bias, so the price effects on each country's final good price are also asymmetric. In production of final goods home intermediate goods are used much more than foreign intermediate goods, and in case of foreign final goods, the portion is opposite. Therefore s positive TFP shock makes home final goods more cheaper and foreign final goods less cheaper. This process makes RER volatility basically.

In this paper, transportation costs and high elasticity of substitution are considered and this factor makes RER more volatile by several effects. The first effect is about home bias in factor demand. This effect is already discussed in section 7.1.

The second effect is elasticity of substitution effect. Recall the relative demand equation in intermediate good.

$$\frac{Y_H(s^t)}{Y_F(s^t)} = \frac{\omega}{1-\omega}\mu^{1-\theta}\left(\frac{P_F(s^t)}{P_H(s^t)}\right)^{\theta} \tag{38}$$

$$\frac{Y_F^*(s^t)}{Y_H^*(s^t)} = \frac{\omega}{1-\omega}\mu^{1-\theta}\left(\frac{P_H^*(s^t)}{P_F^*(s^t)}\right)^{\theta} \tag{39}$$

The relative demand is determined by $\left(\frac{P_H^*(s^t)}{P_F^*(s^t)}\right)^{\theta}$ as well as $\mu^{1-\theta}$. The latter one is fixed bias with respect to the relative price, but the former factor is a function of the relative price and this is amplified by θ. Now let's think about final good price.

$$P(s^t)^{1-\theta} = \omega P_H(s^t)^{\theta-1} + (1-\omega)\mu^{\theta-1}P_F(s^t)^{1-\theta} \tag{40}$$

$$P(s^t) = P_H(s^t)\left(\frac{Y_H(s^t)}{Y(s^t)}\right) + P_F(s^t)\left(\frac{Y_F(s^t)}{Y(s^t)}\right) \tag{50}$$

We can derive the latter equation from the formal one. The second equation stands for the components of final products price, and the final good price is the combination of weighted intermediate prices. Now we can analyze the fluctuation of RER. If home intermediate good price is decreasing due to productivity shock, this makes the final products price decrease directly. And also final producer put more weight on home intermediate good. This second effects is getting severe on the high elasticity of substitution. By this mechanism, home final good is getting cheaper.

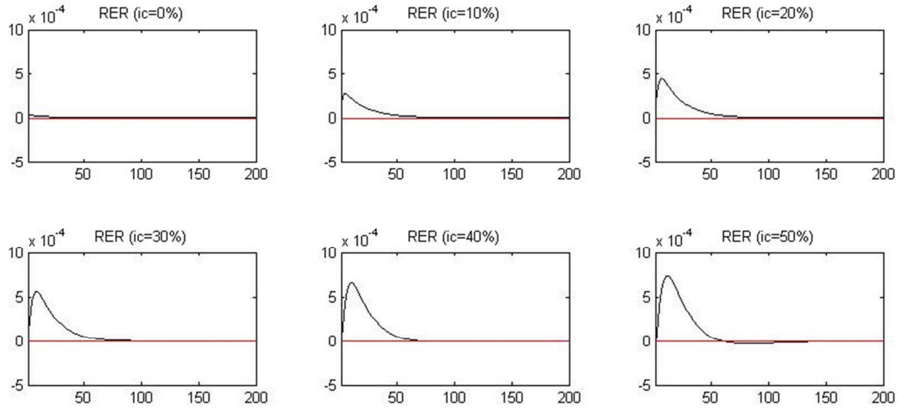
In case of foreign final good, these effects are shattered due to transport cost. With this cost, home intermediate good is not decreasing as much as home country case, therefore weight is not changing enough. Therefore this gap in two way effects makes difference in prices and RER volatility severe. Below table shows RER volatility with respect to the iceberg cost and the elasticity of substitution.

[Table 9] : RER Volatility (standard deviation)

	$\theta = 0.85$	$\theta = 1.01$	$\theta = 1.1$	$\theta = 1.2$	$\theta = 1.5$	$\theta = 2$	$\theta = 3$	$\theta = 5$	$\theta = 10$	$\theta = 20$
ic=0	**0.0003**	**0.0002**	**0.0002**	**0.0002**	**0.0002**	**0.0001**	**0.0001**	**0.0001**	**0.0000**	**0.0000**
ic=0.1	**0.0002**	**0.0002**	**0.0003**	**0.0003**	**0.0004**	**0.0005**	**0.0006**	**0.0006**	**0.0006**	**0.0008**
ic=0.3	**0.0000**	**0.0002**	**0.0004**	**0.0005**	**0.0008**	**0.0011**	**0.0011**	**0.0011**	**0.0014**	**0.0018**
ic=0.5	**0.0002**	**0.0003**	**0.0005**	**0.0007**	**0.0012**	**0.0016**	**0.0015**	**0.0013**	**0.0018**	**0.0026**

We can also confirm that persistency is increasing as iceberg cost is getting higher in the graph of RER depicted bellow. These results are yielded by using impulse-response function.

[Figure 2] : RER Impulse Response results in θ=5



7. Conclusion

This paper documents the results that the transportation costs can increase the volatility and persistency of real exchange rate, but cannot fully explains the volatility of RER in data. Instead there are several implications.

First, this paper introduces iceberg costs in IRBC model and estimates the effects of this cost on the international finance puzzles in one model. Obstfeld and Rogoff(2001) show that transportation costs can be common cause for these puzzles, but this paper evaluates how much the cost improve the features in one model. The model simulates that the cost can be cause for the puzzles such as the home bias in trade puzzle, the Feldstein-Horioka puzzle, the international consumption correlation puzzle and the purchasing power parity puzzle.

Secondly, this paper shows the relationship between iceberg costs and elasticity of substitution in the RER fluctuation. If the iceberg costs not exists in model, the RER volatility and persistency is decreasing as the elasticity of substitution increases. However, high elasticity of substitution can amplify the RER fluctuation when the iceberg costs are modeled.

For future research, it would be interesting to introduce iceberg costs into the trade-nontrade model or the model with permanent shock.

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9. Appendix

1. Dynare Code

```
close all

Var yh yhs yf yfs ph phs pf pfs y ys c cs l ls x xs k ks w ws rk rks
margut marguts rer q d nx a as gy gys gc gcs cd yd ;

varexoe_ae_as;

parameters b gamma alpha beta delta omega epsilon theta sigma sigmas
rhoa rhoas ccorr psi phi ic;

gamma   = 0.34;
alpha   = 0.36;
epsilon  = 2;
beta     = 0.99;
delta    = 0.025;
omega    = 0.51;
theta    = 5;
psi      = 0;
phi      = 0.01;
ic = 0.5;

rhoa    = 0.97;
rhoas    = 0.025;

sigma   = 0.0073/(1-alpha);
sigmas  = 0.0073/(1-alpha);
ccorr    = 0.29;

model;
  (1-gamma)/gamma*exp(c)/(1-exp(l)) = exp(w);
  (1-gamma)/gamma*exp(cs)/(1-exp(ls)) = exp(ws);
gamma/exp(c)*(exp(c)^gamma*(1-exp(l))^(1-gamma))^(1-epsilon) =
exp(margut);
  gamma/exp(cs)*(exp(cs)^gamma*(1-exp(ls))^(1-gamma))^(1-epsilon) =
exp(marguts);
exp(k) = (1-delta)*exp(k(-1))+exp(x); exp(ks) =(1-delta)*exp(ks(-
1))+exp(xs); exp(margut) =
beta*(exp(margut(1))*exp(rk(1))+exp(margut(1))*(1-delta)); exp(marguts)
=  beta*(exp(marguts(1))*exp(rks(1))+exp(marguts(1))*(1-delta));

exp(margut(+1))/exp(margut)*(exp(ph(+1))/exp(ph)) =
exp(marguts(+1))/exp(marguts)*exp(phs(+1))/exp(phs) + phi*d/beta;
exp(q)+phi*d=beta*(exp(margut(+1))/exp(margut))*(exp(ph(+1))/exp(ph));

alpha*exp(w)*exp(l) = (1-alpha)*exp(k(-1))*exp(rk);
alpha*exp(ws)*exp(ls) = (1-alpha)*exp(ks(-1))*exp(rks);

exp(w) = exp(ph)*(1-alpha)*exp(k(-1))^alpha*exp(a)^(1-alpha)*exp(l)^(-
alpha);

exp(ph)=exp(phs)*exp(rer)*exp(-ic);

exp(ws) = exp(pfs)*exp(-ic)*(1-alpha)*exp(ks(-1))^alpha*exp(as)^(1-
alpha)*exp(ls)^(-alpha);

exp(-ic)*exp(pfs)=exp(pf)/exp(rer);

exp(yh) = omega*exp(ph)^(-theta)*exp(y);
exp(yf) = (1-omega)*exp(pf)^(-theta)*exp(y)*(exp(-ic))^(theta-1);
exp(yhs) = (1-omega)*exp(phs)^(-theta)*exp(ys)*(exp(-ic))^(-1);
exp(yfs) = omega*exp(pfs)^(-theta)*exp(ys)*(exp(-ic))^(-theta);
```

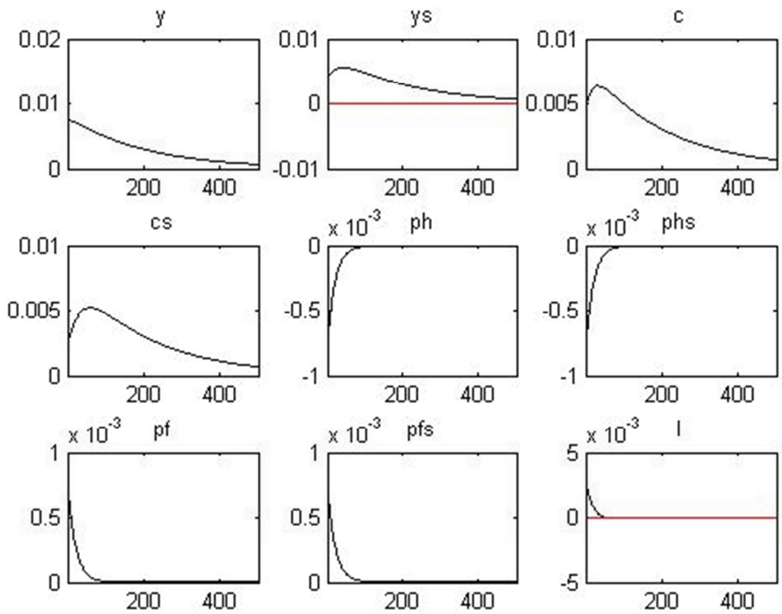
```
exp(y) = exp(c) + exp(x);
exp(ys) = exp(cs) + exp(xs);
exp(yh) + exp(yhs) = exp(k(-1))^(alpha)*(exp(a)*exp(l))^(1-alpha);
exp(yf) + exp(yfs) = exp(ks(-1))^(alpha)*(exp(as)*exp(ls))^(1-alpha);

  exp(y)^((theta-1)/theta)=omega^(1/theta)*exp(yh)^((theta-1)/theta)+(1-
omega)^(1/theta)*(exp(-ic))^((theta-1)/theta)*(exp(yf))^((theta-
1)/theta);  //production function final good home
  exp(ys)^((theta-1)/theta)=omega^(1/theta)*exp(yfs)^((theta-
1)/theta)+(1-omega)^(1/theta)*(exp(-ic))^((theta-
1)/theta)*(exp(yhs))^((theta-1)/theta);

exp(q)*d = exp(ph)*exp(yhs)-exp(pf)*exp(yf)+ d(-1)/exp(a(-1))- phi/2*d^2;
nx = (exp(ph)*exp(yhs)-exp(pfs)*exp(yf));

a = rhoa*a(-1)+ rhoas*as(-1) + e_a;
as = rhoas*a(-1)+ rhoa*as(-1) + e_as;

exp(gy)=exp(y)-exp(y(-1));
exp(gys)=exp(ys)-exp(ys(-1));

exp(gc)=exp(c)-exp(c(-1));
exp(gcs)=exp(cs)-exp(cs(-1));

exp(cd)= exp(c)-exp(cs);
exp(yd)= exp(y)-exp(ys);

end;

 [xss,kss,css,lss,rss]=steadystate(beta,delta,alpha,gamma)

initval;
c = log(css);
cs = log(css);
l = log(lss);
ls = log(lss);
x = log(xss);
xs = log(xss);
k = log(kss);
ks = log(kss);
margut = log(gamma/css);
marguts = log(gamma/css);

rk =  log(rss);
rks =  log(rss);

y = log(xss + css);
ys = log(xss + css);
yh = log(omega)+(y);
yf = log(1-omega)+(ys);
yhs = log(1-omega)+(ys);
yfs = log(omega)+(y);
nx=0;
a=0;
as=0;
end;

shocks;
vare_a=sigma^2;
vare_as=sigmas^2;
vare_a,e_as = ccorr*sigma*sigmas;
end;

steady;

stoch_simul(dr_algo=0, irf=500, order = 1,hp_filter=1600) y ys c
csphphspfpfs l lsrer a x xsnx cd yd ;
```

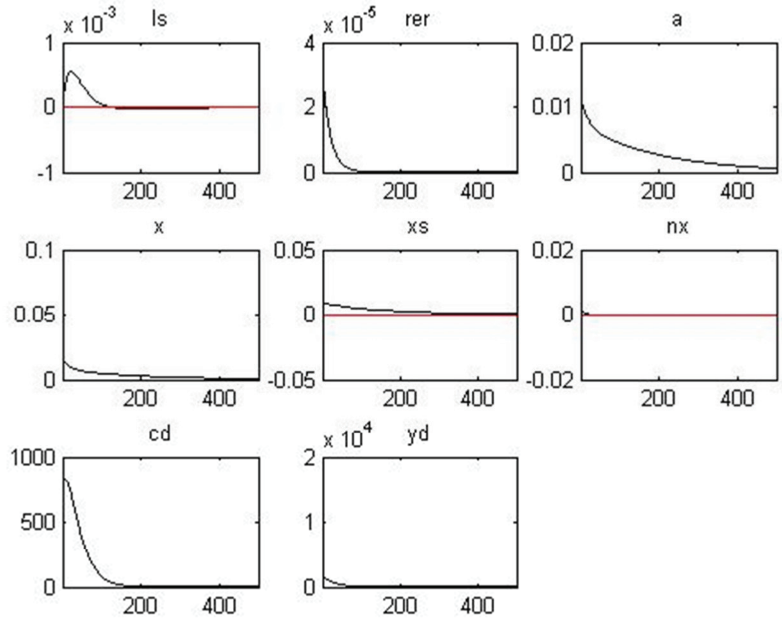
2. Matlab Results

2.1. $\theta = 5, \omega = 0.51,\ ic = 0$

VARIABLE	MEAN	STD. DEV.	VARIANCE
y	**0.1291**	**0.0224**	**0.0005**
ys	**0.1291**	**0.0224**	**0.0005**
c	**-0.1671**	**0.0062**	**0**
cs	**-0.1671**	**0.0062**	**0**
ph	**0**	**0.0016**	**0**
phs	**0**	**0.0017**	**0**
pf	**0**	**0.0017**	**0**
pfs	**0**	**0.0016**	**0**
l	**-1.1803**	**0.004**	**0**
ls	**-1.1803**	**0.004**	**0**
rer	**0**	**0.0001**	**0**
a	**0**	**0.0148**	**0.0002**
x	**-1.2319**	**0.0793**	**0.0063**
xs	**-1.2319**	**0.0793**	**0.0063**
nx	**0**	**0.0204**	**0.0004**
cd	**-13**	**1722.112**	**2965669**
yd	**-13**	**20598.63**	**4.24E+08**

Variables	y	ys	c	cs	ph	phs	pf	pfs	l	ls	rer	a	x	xs	nx	cd	yd
y	1	-0.6674	0.5357	0.217	-0.4276	-0.4276	0.4276	0.4276	0.6287	-0.1354	0.4276	0.6533	0.9817	-0.7846	-0.8641	0.4265	0.9131
ys	-0.6674	1	0.217	0.5357	0.4276	0.4276	-0.4276	-0.4276	-0.1354	0.6287	-0.4276	-0.0005	-0.7846	0.9817	0.8641	-0.4265	-0.9131
c	0.5357	0.217	1	0.7208	-0.3645	-0.3645	0.3645	0.3645	0.8269	0.2701	0.3645	0.9498	0.3653	0.0768	-0.0618	0.3736	0.1745
cs	0.217	0.5357	0.7208	1	0.3645	0.3645	-0.3645	-0.3645	0.2701	0.8269	-0.3645	0.5199	0.0768	0.3653	0.0618	-0.3736	-0.1745
ph	-0.4276	0.4276	-0.3645	0.3645	1	1	-1	-1	-0.7828	0.7828	-1	-0.591	-0.3893	0.3893	0.1578	-0.9756	-0.4683
phs	-0.4276	0.4276	-0.3645	0.3645	1	1	-1	-1	-0.7828	0.7828	-1	-0.591	-0.3893	0.3893	0.1578	-0.9756	-0.4683
pf	0.4276	-0.4276	0.3645	-0.3645	-1	-1	1	1	0.7828	-0.7828	1	0.591	0.3893	-0.3893	-0.1578	0.9756	0.4683
pfs	0.4276	-0.4276	0.3645	-0.3645	-1	-1	1	1	0.7828	-0.7828	1	0.591	0.3893	-0.3893	-0.1578	0.9756	0.4683
l	0.6287	-0.1354	0.8269	0.2701	-0.7828	-0.7828	0.7828	0.7828	1	-0.248	0.7828	0.957	0.5068	-0.2101	-0.1814	0.7451	0.4184
ls	-0.1354	0.6287	0.2701	0.8269	0.7828	0.7828	-0.7828	-0.7828	-0.248	1	-0.7828	0.0191	-0.2101	0.5068	0.1814	-0.7451	-0.4184
rer	0.4276	-0.4276	0.3645	-0.3645	-1	-1	1	1	0.7828	-0.7828	1	0.591	0.3893	-0.3893	-0.1578	0.9756	0.4683
a	0.6533	-0.0005	0.9498	0.5199	-0.591	-0.591	0.591	0.591	0.957	0.0191	0.591	1	0.5063	-0.1176	-0.1841	0.5753	0.358
x	0.9817	-0.7846	0.3653	0.0768	-0.3893	-0.3893	0.3893	0.3893	0.5068	-0.2101	0.3893	0.5063	1	-0.8822	-0.9387	0.3861	0.9673
xs	-0.7846	0.9817	0.0768	0.3653	0.3893	0.3893	-0.3893	-0.3893	-0.2101	0.5068	-0.3893	-0.1176	-0.8822	1	0.9387	-0.3861	-0.9673
nx	-0.8641	0.8641	-0.0618	0.0618	0.1578	0.1578	-0.1578	-0.1578	-0.1814	0.1814	-0.1578	-0.1841	-0.9387	0.9387	1	-0.1654	-0.9464
cd	0.4265	-0.4265	0.3736	-0.3736	-0.9756	-0.9756	0.9756	0.9756	0.7451	-0.7451	0.9756	0.5753	0.3861	-0.3861	-0.1654	1	0.4671
yd	0.9131	-0.9131	0.1745	-0.1745	-0.4683	-0.4683	0.4683	0.4683	0.4184	-0.4184	0.4683	0.358	0.9673	-0.9673	-0.9464	0.4671	1

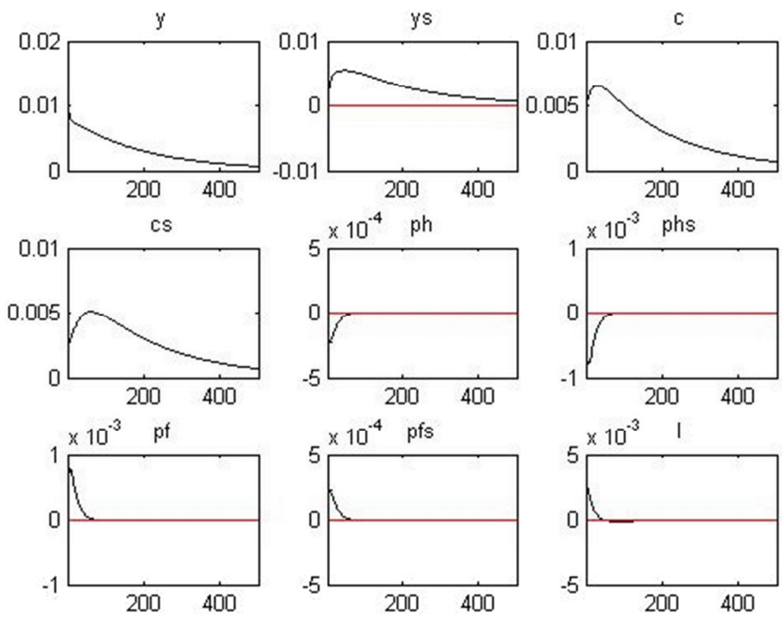

y
ys
c
cs
x 10^-3 ph
x 10^-3 phs
x 10^-3 pf
x 10^-3 pfs
x 10^-3 l
200
400


x 10^-3 ls
x 10^-5 rer
a
x
xs
nx
cd
x 10^4 yd
200
400

2.2. $\theta = 5, \omega = 0.51,\ ic = 0.3$

VARIABLE	MEAN	STD. DEV.	VARIANCE
y	-0.0346	0.0156	0.0002
ys	-0.0346	0.0156	0.0002
c	-0.3309	0.0064	0
cs	-0.3309	0.0064	0
ph	-0.1048	0.0004	0
phs	0.1952	0.0015	0
pf	-0.1048	0.0015	0
pfs	0.1952	0.0004	0
l	-1.1803	0.0044	0
ls	-1.1803	0.0044	0
rer	0	0.0011	0
a	0	0.0148	0.0002
x	-1.3956	0.0464	0.0022
xs	-1.3956	0.0464	0.0022
nx	-0.0758	0.0066	0
cd	-13	1850.033	3422623
yd	-12.9999	10767.27	1.16E+08

Variables	y	ys	c	cs	ph	phs	pf	pfs	l	ls	rer	a	x	xs	nx	cd	yd
y	1	-0.3105	0.8316	0.2093	-0.1873	-0.1873	0.1873	0.1873	0.9708	-0.3357	0.1873	0.9342	0.9749	-0.49	-0.7433	0.6852	0.8095
ys	-0.3105	1	0.2093	0.8316	0.1873	0.1873	-0.1873	-0.1873	-0.3357	0.9708	-0.1873	0.0057	-0.49	0.9749	0.6205	-0.6852	-0.8095
c	0.8316	0.2093	1	0.5876	-0.3173	-0.3173	0.3173	0.3173	0.8276	0.1147	0.3173	0.9656	0.6871	0.0384	-0.2924	0.4541	0.3844
cs	0.2093	0.8316	0.5876	1	0.3173	0.3173	-0.3173	-0.3173	0.1147	0.8276	-0.3173	0.4461	0.0384	0.6871	0.107	-0.4541	-0.3844
ph	-0.1873	0.1873	-0.3173	0.3173	1	1	-1	-1	-0.3922	0.3922	-1	-0.2976	-0.1179	0.1179	-0.3194	-0.6987	-0.2314
phs	-0.1873	0.1873	-0.3173	0.3173	1	1	-1	-1	-0.3922	0.3922	-1	-0.2976	-0.1179	0.1179	-0.3194	-0.6987	-0.2314
pf	0.1873	-0.1873	0.3173	-0.3173	-1	-1	1	1	0.3922	-0.3922	1	0.2976	0.1179	-0.1179	0.3194	0.6987	0.2314
pfs	0.1873	-0.1873	0.3173	-0.3173	-1	-1	1	1	0.3922	-0.3922	1	0.2976	0.1179	-0.1179	0.3194	0.6987	0.2314
l	0.9708	-0.3357	0.8276	0.1147	-0.3922	-0.3922	0.3922	0.3922	1	-0.3986	0.3922	0.9357	0.9383	-0.4851	-0.6247	0.7849	0.807
ls	-0.3357	0.9708	0.1147	0.8276	0.3922	0.3922	-0.3922	-0.3922	-0.3986	1	-0.3922	-0.0628	-0.4851	0.9383	0.5116	-0.7849	-0.807
rer	0.1873	-0.1873	0.3173	-0.3173	-1	-1	1	1	0.3922	-0.3922	1	0.2976	0.1179	-0.1179	0.3194	0.6987	0.2314
a	0.9342	0.0057	0.9656	0.4461	-0.2976	-0.2976	0.2976	0.2976	0.9357	-0.0628	0.2976	1	0.8352	-0.1713	-0.4772	0.572	0.5736
x	0.9749	-0.49	0.6871	0.0384	-0.1179	-0.1179	0.1179	0.1179	0.9383	-0.4851	0.1179	0.8352	1	-0.6563	-0.8551	0.7144	0.9049
xs	-0.49	0.9749	0.0384	0.6871	0.1179	0.1179	-0.1179	-0.1179	-0.4851	0.9383	-0.1179	-0.1713	-0.6563	1	0.7688	-0.7144	-0.9049
nx	-0.7433	0.6205	-0.2924	0.107	-0.3194	-0.3194	0.3194	0.3194	-0.6247	0.5116	0.3194	-0.4772	-0.8551	0.7688	1	-0.4398	-0.8424
cd	0.6852	-0.6852	0.4541	-0.4541	-0.6987	-0.6987	0.6987	0.6987	0.7849	-0.7849	0.6987	0.572	0.7144	-0.7144	-0.4398	1	0.8465
yd	0.8095	-0.8095	0.3844	-0.3844	-0.2314	-0.2314	0.2314	0.2314	0.807	-0.807	0.2314	0.5736	0.9049	-0.9049	-0.8424	0.8465	1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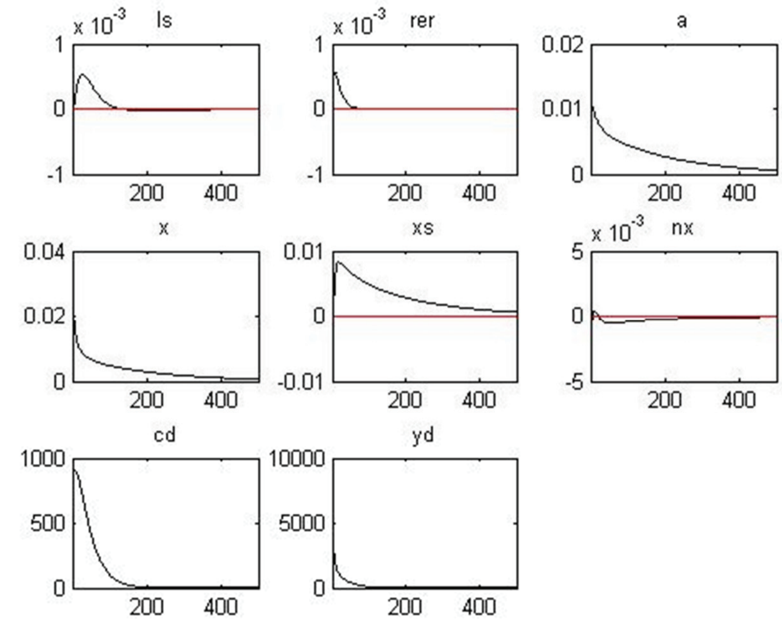
ys
c
cs
x 10^-4 ph
x 10^-3 phs
x 10^-3 pf
x 10^-4 pfs
x 10^-3 l
200
400


x 10^-3 ls
x 10^-3 rer
a
x
xs
x 10^-3 nx
cd
yd
200
400

국문 초록

거래비용 도입에 따른 실질환율 변동성 연구

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실질환율 변동성 퍼즐은 국제금융 분야에서 논의되고 있는 난제 중 하나이다. 기존의 IRBC 모형의 경우 이 문제에 대하여 충분한 설명을 하지 못하고 있다. 본 논문은 일반적인 IRBC 모형에서 국가간 무역시 발생하는 거래비용을 도입하여 실질환율의 변동성 및 지속성을 설명한다. 높은 거래비용 및 수입재화와 국내재화 간의 높은 대체탄력성을 가정한다면 모델을 통하여 이러한 실질환율 변동성 문제를 어느 정도 설명할 수 있으며 다른 국제금융분야의 퍼즐들에 대해서도 설명력을 갖는 것으로 나타났다.

주요어 : 실질환율, 변동성, 지속성, 거래비용, 대체탄력성, 퍼즐

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