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MASTER THESIS

Exchange Rate Pass-Through Effect and Monetary Policy in Mongolia: Small Open Economy DSGE model

Author: **Bc. Oyu-Erdene Buyandelger**

Supervisor: **Ing. Aleš Maršál, M.A.**

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Declaration of Authorship

The author hereby declares that he compiled this thesis independently, using only the listed resources and literature, and the thesis has not been used to obtain a different or the same degree.

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Abstract

This thesis analyzes the incomplete exchange rate pass-through effect on Mongolian economy and its implication on monetary policy under foreign and domestic shocks. The analysis is carried out in a small open economy New Keynesian DSGE model proposed by Monacelli (2005), where incomplete exchange rate pass-through is introduced via nominal rigidities on import prices. In order to accomplish the goal, we firstly derive the solutions of the model, calibrate the parameters, and finally simulate the impulse responses. Moreover, SVAR estimation is achieved to estimate the pass-through. Four main results are obtained. **First,** the exchange rate pass-through into import price and inflation is 0.69% and 0.49% respectively in short run, implying incomplete pass-through in Mongolia. **Second,** the exchange rate acts as a shock absorber for domestic productivity and foreign demand shock, but as a shock amplifier for domestic demand shock. **Third,** in case of incomplete pass-through the central bank of Mongolia is required to adjust the nominal interest rate more under the productivity shock, but less for the domestic and foreign demand shock. **Finally**, deviations from the law of one price contributes considerably to the variability of the output gap under the low pass-through. Therefore, considering incomplete pass-through in the conduct of monetary policy is significant to improve the effectiveness of the monetary policy for the central Bank of Mongolia.

JEL Classification: F31, F41, E52, E12

Keywords: Incomplete exchange rate pass-through, monetary policy, small open economy DSGE model

Author's e-mail oyuerdene.buyand@yahoo.com

Supervisor's e-mail ales.marsal@seznam.cz

Abstrakt

Tato práce analyzuje neúplný zvýšený kurzový efekt na mongolskou ekonomiku a její implikace pro měnovou politiku v rámci zahraničních a domácích otřesu. Analýza se provádí v malé otevřené ekonomice podle modelu New Keynesian DSGE, navrženého Monacelli (2005) , kde neúplné kurz zvýšení je zaveden přes normalizace na dovozní ceny. Za účelem dosažení cíle, jsme se nejprve odvodili řešení modelu , kalibrovali parametry a nakonec simulovat impulsní odezvy . Navíc odhad SVAR je dosaženo odhadnutím promítání . Čtyři hlavní výsledky byly získané . Za prvé, kurz zvýšení na dovozní ceny a inflace je 0,69 % a 0,49 % , respektive v krátkodobém horizontu , z čehož vyplývá, neúplné promítání v Mongolsku . Za druhé, kurz se chová jako tlumič nárazů pro domácí produktivitu a zahraniční poptávku , ale jako tlumič zesilovač pro domácí poptávku . Za třeti , v případě neúplností je zapotřebí pro centrální banku Mongolska upravit nominální úrokové sazby více pod proudem produktivity, ale méně pro domácí a zahraniční poptávku. Konečně , odchylky od zákona jedné ceny významně přispívají k variabilitě mezery výstupu zvýšení nákladu přes cenu. Proto, vzhledem k neúplnému promítnutí v prováděné měnové politice je významné pro zlepšení její účinnosti pro centrální banku Mongolska .

Klasifikace	F31, F41, E52, E12
Klíčová slova	Neúplné kurz pass-through, měnová politika, malá otevřená ekonomika DSGE modelu

E-mail autora	oyuerdene.buyand@yahoo.com
E-mail vedoucího práce	ales.marsal@seznam.cz

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Acronyms

DSGE	Dynamic Stochastic General Equilibrium
CPI	Consumer Price Index
LOP	The law of one price
TOT	Terms of trade
SVAR	Structural Vector Auto Regressive
AR	Auto Regressive
IT	Inflation Targeting
OECD	Organization for Economic Co-operation and Development
CES	constant elasticity of substitution
l.o.p gap	The deviations from the law of one price
UIP	Uncovered Interest Parity
PPP	Purchasing Power of Parity
GDP	Gross Domestic Product
EIS	Elasticity of Intertemporal Substitution
IRFs	Impulse Response Functions
FDI	Foreign Direct Investment
AS	Aggregate Supply
AD	Aggregate Demand

Master Thesis Proposal

Author:	**Bc. Oyu-Erdene Buyandelger**	Supervisor:	Ing. Ales Marsal, M.A.
E-mail:	oyuerdene.buyand@yahoo.com	E-mail:	ales.marsal@seznam.cz
Phone:	+420 777 802 194	Phone:	777 071 297
Specialization:	Master of Economics and Finance	Defense Planned:	June 2014

Proposed Topic:

Exchange rate pass-through effect in Mongolia: Small Open Economy DSGE model

Topic Characteristics:

The goal of this thesis is to examine the exchange rate pass-through effect on the inflation and business cycle, thereby to identify an appropriate monetary policy for Mongolia. The analysis is pursued within the Small Open Economy New Keynesian DSGE model. In particular, I will utilize existing literature and apply the recently developed methodology to the case of Mongolia.

Mongolia represents about 0.01% of world GDP. Small impact on world economy places Mongolia into the class of small open economies (Dutu, 2012). Mongolian economy is very much dependent on other countries, especially on China absorbing 90% of Mongolian exports. The 80% of Mongolian exports are made of mineral commodities such as coal, gold and copper. Moreover, Mongolia import almost all goods from foreign countries, mainly from China and Russia. Therefore, exchange rate is highly volatile in Mongolia and its fluctuations make the economy more vulnerable.

The literature focused on Mongolia is scarce. In case of Mongolia there has been one study Gan-Ochir, (2011) represents one of the few studies. He focused on the role of the exchange rate in Mongolian economy using a theoretical framework of a stochastic open macro economy model based on the work of Bjornland (2004). This study shows the exchange rate acts as a shock absorber rather than a source of shocks in economy. The policy implication of his study is that flexible exchange rate is more appropriate for Mongolia.

Based on these findings, I argue that the exchange rate is source of shocks and the fixed exchange rate regime might be more appropriate for the Mongolian economy. Corsetti and Pesenti (2004) find that an inward-looking policy of domestic price stabilization is not optimal when firms' markups are exposed to currency fluctuations. The degree of pass-through and exchange rate exposure in domestic and foreign markets emerges as a key parameter in the design of optimal monetary rules, as well as in the welfare analysis of alternative monetary arrangements. Holub (2002) implies in his study that the fixed exchange rate policy might be more appropriate policy for emerging economies which are interrelated with its trading partners and central banks have low credibility.

I will develop small open economy DSGE model augmented by exchange rate pass-through effect and country specific ingredients. To goal is to capture pass-through effect to the inflation and its contribution to the business cycles, and to suggest the optimal exchange rate policy. The results of this thesis might contribute to the literature on this topic in Mongolia.

Hypotheses:

1. The exchange rate pass-through is incomplete for Mongolia
2. The exchange rate is a source of shock which can fluctuate the economy and contribute to the business cycles.
3. The exchange rate pass-through affect the performance of the monetary policy rule.

Methodology:

In order to test my hypothesis and accomplish the aim of the thesis, I will study as follows:

1) I will review literature on theoretical and empirical studies related to the exchange rate pass-through effect
2) I will amend the small open economy DSGE model introducing exchange rate pass-through effect based on papers which were previously published in Mongolia and other literatures such as papers by Jordi Gali and Tommaso Monacelli (2005), and Corsetti and Pesenti (2004) taking account to unique features in Mongolian economy.
3) I will solve the modified model, calibrate and simulate the model for specified form and alternative monetary regimes, and compare the results to the real data in Mongolia. As a result, I will suggest the optimal exchange rate policy.

I will use Mongolian data for main macroeconomic variables such as GDP, inflation, interest rate, exchange rate, real wages, imports, and M1 money supply in this thesis.
The small open economy DSGE model is based on New Keynesian framework. DSGE model is nowadays standard powerful and effective analytical tool for central banks.

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Author **Supervisor**

1 Introduction

In small open economy, the exchange rate pass-through has a considerable effect on inflation and output fluctuations. The exchange rate transmits the impact of any shock on the economy through its effect on import prices and relative prices. Under this circumstance, exchange rate channel plays a role as either shock absorber or amplifier in implementing the monetary policy, but how much it can absorb (or amplify) depends on the exchange rate pass-through. In particular, as classic theory based on AS-AD model, the exchange rate acts as a shock absorber when the domestic demand shock hits the economy. In this case, if the pass-through is incomplete, the demand shock has limited effect on inflation. In response to this shock, the monetary authority is required to increase the nominal interest rate at smaller amount. Therefore, the exchange rate pass-through is an important consideration with respect to the effectiveness of monetary policy. The goal of the thesis is to examine the effect of incomplete exchange rate pass-through on the economy and thereby its implications on the monetary policy in case of Mongolia.

Mongolian economy is very vulnerable to the exchange rate fluctuations originated from structural shocks. There are several reasons. Firstly, the exchange rate fluctuation works similar as cost-push shock in Mongolia. Imported goods are accounted about 80% of GDP. Hereof, the imported goods compose of 55% of total final consumption and the most of inputs in the domestic production are imported from abroad. Distribution business from abroad to the domestic market is dominated at the retail level. According to these features, when the foreign and domestic shock hit the economy, the exchange rate fluctuates more frequently at larger magnitude. For instance, during last five years the intensive rise of foreign direct investment caused dramatic increase of aggregate demand. Due to the large capital inflow in economy it seemed likely that the exchange rate (MNT/USD) will continue to appreciate. However even it depreciated dramatically by 20% in last year. Consequently, the import price index increased by 13% and currently it has high pressure on CPI inflation in Mongolian economy.

Secondly, foreign shocks such as commodity price shock in the world market, and Chinese demand shock increase the exchange rate fluctuations. Mongolian economy is very much dependent on main trade partner China. The 80% of Mongolian exports are made of mineral commodities such as coal, gold and copper. Moreover, the 90% of total export is supplied to the Chinese market. Therefore, Mongolian economy is very vulnerable to exchange rate fluctuations induced by other shocks.

On the other hand, the role of exchange rate in the monetary policy regime is still challenging issue for the central Bank of Mongolia (BoM). Under these circumstances, examining the impact of exchange rate on the economy and defining appropriate monetary policy reaction to the shocks are important issues to improve the effectiveness of the monetary policy.

The thesis focuses on the importance of the degree of pass-through. It is based on three hypotheses as follows: i) the exchange rate pass-through is incomplete in Mongolia; ii) the exchange rate is a source of shock that can fluctuate the economy and its impact depends on the degree of pass-through; iii) the monetary policy response depends on the degree of pass-through and thereby the monetary policy considering the exchange rate might have better achievement.

The analysis is pursued in a small open economy New Keynesian DSGE model, where incomplete exchange rate pass-through is introduced in the model via nominal rigidities on import prices. We follow the model proposed by Monacelli (2005). This assumption delivers the different result from the result of open economy model with complete exchange rate pass-through. Among the literature introducing incomplete pass-through in the analysis of monetary policy, the model proposed by Monacelli (2005) has two features. First, the equilibrium dynamics can be reduced easily to New Keynesian canonical representation of sticky price model. It allows to compare the difference between models with complete and incomplete pass-through clearly and easily. Second, this model can capture the crucial role of exchange rate expectation channel to inflation. Hence, we choose the model of Monacelli (2005).

To accomplish the goal, firstly we estimate the exchange rate pass-through using SVAR empirical methodology in order to confirm whether pass-through is incomplete in Mongolia. Secondly, we derive the solutions of the model. Thirdly, we calibrate the parameters based on literature and Mongolian data. Finally, we simulate the IRFs using Dynare Toolbox, Matlab software.

This study is the first attempt to examine the impact of incomplete exchange rate pass-through on economy and its implication on monetary policy under the framework of small open economy DSGE model with incomplete pass-through in case of Mongolia. The result of this thesis thus contributes to the literature in this field using small open economy DSGE model.

Main results obtained from this study are as follows: **i)** the exchange rate pass-through is incomplete in Mongolia; **ii)** the role of exchange rate depends on what type of shock hits the economy. The exchange rate works as a shock absorber of domestic productivity shock and foreign demand shock, but as an amplifier of domestic demand shock. Its absorbing (or amplifying) potential tends to increase under high pass-through; **iii)** the policy reaction in terms of nominal interest rate is required to be smaller to domestic demand shock and foreign demand shock but larger to the productivity shock under low pass-through; i**v)** the l.o.p gap may works as cost push and demand shocks. Stabilizing inflation is more costly in terms of output even though the inflation has the smallest volatility when the pass-through is sufficiently low; **v)** simple Taylor rule has better performance than flexible IT rule.

The thesis is structured as follows: Section 2 reviews the prior literature which consists of empirical and theoretical literature related with exchange rate pass-through and monetary policy. Section 3 provides the empirical estimation of exchange rate pass-through in Mongolia. Section 4 presents the small open economy DSGE model augmented by incomplete exchange rate pass-through. Section 5 describes the calibration of the model that is used in the simulation. In Section 6, the analysis of incomplete pass-through is achieved for different shocks. Section 7 discusses the performance of alternative monetary rule compared with simple Taylor rule for different degrees of pass-through. Conclusions are provided in Section 8.

.

2 Literature Review

In this section, we review the literature dealing with incomplete exchange change rate pass-through effect and monetary policy supporting the importance of introducing incomplete pass-through in the framework of small open economy New Keynesian DSGE model.

2.1. Theoretical concept in exchange rate pass-through and monetary policy

Brief theoretical concept in exchange rate pass-through

In small open economy, the exchange rate is an additional transmission channel for monetary policy. Small open economies are very vulnerable to exchange rate and external shocks. In general, investigating and understanding the effect of exchange rate on prices and economy are important to evaluate appropriate monetary policy.

Exchange rate fluctuations influence the economy through two channels. In direct channel, shift in exchange rate has direct effect on import prices through imported final consumption. Then it affects the consumer price (CPI) inflation through import prices. Whereas indirect channel, the exchange rate fluctuations transmit into domestic inflation via imported inputs and intermediate goods for domestically produced products. In addition, exchange rate shock typically influences the competitiveness of the home country by changing the relative price between domestic and foreign goods, and thereby affects aggregate demand. Thus, aggregate demand has an impact on inflation. Moreover, as reported in several papers, for example Monacelli (2005), the exchange rate expectation channel is a key ingredient for designing of monetary policy. However, the impact of exchange rate shock on economic activity depends on the degree of exchange rate pass-through. **The exchange rate pass-through is generally defined by the percentage change of imported goods' price, in local currency, in response to one percent unexpected shock to the nominal exchange rate between the trading partners exporting and importing countries** (Goldberg & Knetter, 1997).

There are numerous studies examining exchange rate-pass-through effect and its degree empirically and theoretically. Empirical studies showed that there is incomplete pass-through from exchange rate to import prices. Early papers, for example Marston (1990) estimated an average degree of exchange rate pass-through for industrialized countries of about 50%. In subsequent papers, Knetter (1989, 1993) and Gagnon and Knetter (1995) found that estimated pass-through is even lower.

Last decade, Campa and Goldberg (2002) analyzed empirically the exchange rate pass-through effect for 25 OECD countries between 1975 and 1999. They found there was no complete pass-through in 22 countries out of 25, in short-run. In contrast long-run pass-through was closer to 1% for most of the countries, but not equal to 1% for 9 countries. Moreover, Ghosh and Wolf (2001) observed there was a full pass-through in long-run, which can be theoretically explained by the fact that prices are sticky. Campa and Goldberg (2005) modified their previous result and claimed that there was a partial pass-through in 23 OECD countries covered in their study.

Coricelli et al. (2006) and Beirne et al. (2011) studied the exchange rate pass-through to consumer prices for central and eastern European member countries. They found that exchange rate pass-through is about 0.6% on average. Marzzi and Sheets (2007) attempted to explain continuous decline in the exchange rate pass-through to U.S import prices which decreased from 0.5% during 1970s and 1980s to around 0.2% over the years from 1997 to 2007. Parsons and Sato (2008) found that there is almost full pass-through in Japanese exports to East Asia. Etsuro Shioji et al. (2009) obtained that there is an incomplete exchange rate pass-through on import and export sides in Japanese economy. Recent studies also confirm there is incomplete pass-through in short- run and show degree of pass-through tends to decrease especially in industrialized countries. For instance, Frankel, Parsley, and Wei (2012) showed using narrowly defined new data set including 76 countries and observed incomplete pass-through in developing countries which explains the decline in pass-through coefficient in some developing countries as rising distribution costs.

For theoretical studies, open economy models have simultaneously developed introducing both complete and incomplete exchange rate pass-through assumptions in the framework of monetary policy. Baseline studies, more recently so-called workhorse models such as Gali and Monacelli (1999, 2002, 2005), Clarida, Gali and Gertler (1999, 2001), Woodford (2003), and Obstfeld and Rogoff (2000) which have contributed to the literature on modelling the monetary policy in an open economy with the assumption of complete exchange rate pass-through. However, many other authors such as Smets and Wouters (2002), Adolfson (2001, 2007), Monacelli (2005), and Corsetti and Pesenti (2005) tested this phenomenon in open economies with incomplete exchange rate pass-through and found very interesting results[1].

Complete (perfect or full) exchange rate pass-through is defined by 1% change of prices of imported goods in local currency to 1% change of exchange rate. In the complete pass-through models, they assume that the LOP holds, implying that the identical products sell at the same common-currency price in different countries. The assumptions required for LOP to hold are profit maximization and costless transportation, distribution and resale (Goldberg & Knetter, 1997). This assumption means that in case of exchange rate changes, this change transmitted into the price of imported goods in local currency fully and immediately. However, the LOP fails as the results of extensive large empirical literature, even for goods narrowly defined into homogenous categories (Frankel 2004). Reasons for LOP not to hold can be classified into two categories: firstly, the transport costs, tariffs, and other trade barriers between the ports of exporting and importing countries; secondly, the costs of distribution and retail between the docks in importing country and the customer at the counter of the store. Therefore, recent findings evidence that the LOP does not hold and thereby there is incomplete exchange rate pass-through effect on import prices for both developed and developing countries.

Incomplete (imperfect or partial) exchange rate pass-through is defined by the percentage change of prices of imported goods in local currency to 1% change of exchange rate. In other words, the import price does not change in a one-to-one relation with the exchange rate. In the incomplete pass-through models, they assume that LOP does not hold, implying that the price of imported goods is not the same as the price of a foreign good in local currency. This assumption arises LOP gap from the difference between the cost of imported goods in local currency and the price of imported good set by importing firms in home country.

[1] See more detailed empirical literature from the section 2.2

Determinants of incomplete pass-through

Over the past two decades, theoretical and empirical literature has developed to explain the reasons why the exchange rate pass-through is incomplete which are in line with previous evidences. Dornbusch (1987) provided very reasonable argument that incomplete pass-through arises from monopoly firms that operate in imperfect competitive market and have the power to alter their mark-up (and not only prices) in response to exchange rate shock. Also, the finding of Hellerstein (2004) was in line with the result of Dornbusch (1987). He explained that incomplete pass-through is generated due to the double marginalization of the firms that operate in the distribution sector with imperfect competition. According to the double marginalization, distributors transmit exchange rate shock partially into their prices by absorbing some of the exchange rate fluctuations to preserve stable prices or expand their share in the market at the retail level. In regards to the double marginalization, Campa and Goldberg (2006, 2010) examined whether the distribution margin is sensitive to exchange rates. Using the data from 21 OECD countries, they explored that the distribution margins on final consumption are from 30 to 50% of purchaser prices (Campa & Goldberg, 2006). Expenditures on wholesale and retail sector costs, transportation and storage costs dominate in the distribution margins. Their result support that the changes of distribution margins are dependent on exchange rates. As they explained, if the exchange rate (in local currency) depreciates, imported goods become more expensive and in turn distribution margins decrease. All these results imply that the price of the imported goods is sticky for a certain period of time. Meaning is that even if exchange rate fluctuations change the marginal cost, importing price in domestic currency is not changed immediately and fully. Thus, nominal rigidities imply that exchange rate shock have smaller effect on import price and consumer price compared to the one in complete pass-through. It also implies that future exchange rate expectations are crucial to explain the effect of exchange rate shock on the output gap and inflation related to the monetary policy. Burstein, Neves, and Rebelo (2003) suggested an alternative reason that having incomplete pass-through can be partly explained by the existence of non tradables goods in consumption and distribution sectors generating a gap between border and retail prices.

Determinants of the degree of pass-through

Next issue related to the pass-through is to study the degree of exchange rate pass-through and its determinants. To study the elasticity of import prices and consumer prices to the exchange rate changes and the factors affecting it, two country model with wage stickness has been used. These models become workhorse models in the field. For example, Obstfeld and Rogoff (2000), Corsetti and Dedola (2005), and Campa and Goldberg (2006, 2010) used two country model assuming sticky wages, exogenous productivity and monopolistic competition set-up. As a result, this model provides the relationship between the elasticity of price of non-tradable goods, home tradable goods and imported goods to exchange rate changes, and determinants influencing their elasticities.

Moreover, elasticities of substitution among goods, wage and productivity conditions, imported input use in domestic production, and distribution margins play an important role in determining the elasticity of import price and consumer price in response to the exchange rate changes. Also, the share of tradable goods in the consumption basket, the share of imported goods in tradable goods influence on the elasticity of consumer price. It means briefly that openness index, share of import in the consumption, is the important to determine the degree of pass-through. The more an openness index increases, the sensitivity of import price and CPI inflation depending on exchange rate tend to increase. Campa and Goldberg (2006) showed the role of tradable goods in the economy influences the degree of exchange rate pass-through into CPI price. When the demand elasticities among goods are larger, the elasticity of import price and CPI price to exchange rate are smaller. As Corsetti and Dedola (2005) explained the role of productivity in the elasticity of price to exchange rate, if the productivity in home tradable goods production is higher compared to home non-tradable sector, then exchange rate pass-through will be larger. Campa and Goldberg (2006) showed that distribution margins have an effect to reduce the degree of pass-through into import prices when distributors can adjust their mark-ups as local currency depreciates, but it has an effect to increase the pass-through when non-tradable sector relies on imported inputs.

In addition, Campa and Goldberg (2006) also examined the role of imported inputs in the pass-through via tradable and non-tradable goods production. In their study, the share of imported inputs is accounted from 10 to 48% of the final price in tradable goods production, whereas from 3 to 22% in non-tradable goods production. They analyzed the sensitivities of various price indices and the CPI depending on the shares of import and imported inputs in tradable and non-tradable sectors. As their result, imported inputs influence on the prices of non-tradable goods and tradable goods in the final consumption baskets, in which result confirms that the exchange rate shock has an effect on domestic inflation via imported inputs. Also the impact of exchange rate fluctuation on the domestic inflation can be smaller when the domestic firms set the sticky price in the framework of monopolistic competition but it depends on how much non-tradable sector relies on the imported inputs.

Moreover, from the macroeconomic perspective, there are some studies examining the effects of macroeconomic variables. Campa and Goldberg (2005) showed that higher exchange rate volatility leads to higher pass-through and also composition of import bundles can change the degree of pass-through. Choudhri and Hakura (2006) using data for 71 countries found the strong evidence that there was a positive and significant relationship between the pass-through and average inflation rate across countries andtime duration. This result implies that higher inflation environment leads to higher degree of pass-through to the domestic inflation. Adolfson (2001) showed that the degree of shock persistence affects the degree of exchange rate pass-through. In other words, transitory shocks have smaller effect on expectations about future prices and exchange rates and thereby, it leads to lower pass-through. Junttilla and Korhonen (2012) presented that there is incomplete pass-through to aggregate import prices and positive correlation between pass-through and inflation of the importing country for nine OECD countries. Lin and Wu (2012) obtained that the pass-through is positively correlated with deflation. They explained this finding that firms experiencing deflation are willing to pass through directly their additional cost to price of the products as exchange rate depreciates.

Exchange rate pass-through and monetary policy

As mentioned in the beginning of this section, exchange rate shock is transmitted into the economy through two channels, via direct channel through changes in import price and indirect channel through changes in exports. In addition, exchange rate provides an additional channel for monetary policy transmission. As monetary authorities change the nominal interest rate, it affects the economy through two channels, via real interest rate and exchange rate. These two channels influence the aggregate demand and then affect inflation indirectly. However, exchange rate influences inflation through import price directly. Therefore, the effect of monetary policy transmitted through exchange rate channel depends on the degree of exchange rate pass-through (Adolfson, 2001).

In the DSGE model with sticky import price, incomplete pass-through is generated by nominal rigidities which are the parameters of price stickiness. Therefore, an increase of nominal rigidity leads to smaller exchange rate pass-through. This relationship does not depend on what kind of shock hits the economy (Adolfson, 2001). In that case, when the foreign shocks, such as foreign demand shock or price shock, hit the domestic economy via exchange rate changes; lower pass-through results in lower inflation, and hence smaller response of interest rate. It implies that the policy response will be the largest when the pass-through is complete because of greatest impact of exchange rate. In other words, as pass-through increases, the impact of foreign shocks on inflation is higher and thereby, the central bank is expected to make larger change in the interest rate. As opposed to the foreign shocks, when the pass-through is low and domestic demand or cost-push disturbance hits the economy, policy response to these shocks is large. Thus interest rate adjustment is required to be larger than one in high pass-through environment (Adolfson, 2001).

This is explained by the effect on working through the exchange rate channel of monetary policy transmission. If positive demand shock hits the domestic economy, it results in higher inflation. Hence, in response to the shock central bank increases the interest rate, so that contemporaneously exchange rate appreciates. The appreciation of the exchange rate has an impact to reduce directly the imported inflation and indirectly reduce the export related to the competitiveness through the exchange rate channel. Consequently, this appreciation on working through the increased interest rate causes to have lower CPI inflation. However, how much exchange rate channel has an effect on the inflation depends on the degree of pass-through. As exchange rate pass-through increases, the appreciation of exchange rate leads to lower imported inflation compared to the one of low pass-through. As an implication, when the pass-through is complete or high, the interest rate is required to adjust smaller. In case with high pass-through, the exchange rate acts as a shock absorber (Adolfson, 2001).

Another policy interest is that the degree of exchange rate pass-through affects the inflation-output variance trade-off. More pass-through decreases, the exchange rate channel becomes less important for monetary policy. The change in interest rate causes to change the exchange rate, but the change in exchange rate does not pass-through into the import price and further to the consumer price in the same scale. Thus, when the pass-through is low, any shocks with equal magnitudes have less impact on the variance in both inflation and output. It implies that in response to these shocks the policy-makers face a less trade-off between inflation and output variance. In that case, open economy with incomplete pass-through is characterized the same as closed economy settings to some extent. Consequently, for a given output variability the inflation variance is smaller when the pass-through is lower (Adolfson, 2001).

2.2. Monetary policy with incomplete pass-through

Over the past couple of decades, numerous papers such as Clarida, Gali and Gertler (1999, 2001), Gali and Monacelli (1999, 2002, 2005), Smets and Wouters (2002), Woodford (2003), and Monacelli (2005) have analyzed the monetary policy using general equilibrium models of closed and open economies in complete and incomplete exchange pass-through environments.

As a result of several studies, stabilizing the domestic price is the optimal monetary policy to maximize welfare in a closed economy. In open economies with complete exchange rate pass-through, the authors find similar results as same as in closed economies that the optimal monetary policy should focus on the domestic price stability. Interestingly, the implication of this result in open economies is that the exchange rate volatility does not have any direct impact on welfare whereas only the price volatility affects welfare.

However, many authors such as Monacelli (2005), Adolfson (2001, 2007), Devereux and Engel (2002), Corsetti and Pesenti (2005), and Sutherland (2005) examine this issue in open economies with incomplete exchange rate pass-through. They find very interesting results that the exchange rate volatility and the degree of pass-through are key parameters in the design of optimal monetary policy. As their implications, inward-looking monetary policy cannot be the optimal monetary rule.

Gali and Monacelli (1999) lay out small open economy New Keynesian DSGE model with complete exchange rate pass-through introducing Calvo type staggered price setting. Authors use this framework for analyzing the properties and macroeconomics implications of three alternative monetary policy regimes such as an optimal monetary policy, Taylor rule and an exchange rate peg for small open economy. They show that an exchange rate peg may stabilize better than the Taylor rule. In follow up paper, Gali and Monacelli (2005) show that a key difference among these regimes depends on the relative amount of exchange rate volatility that they entail. Furthermore, they show that domestic inflation targeting can be the optimal policy regime. One of their important findings shows that welfare results of basic New Keynesian model in a closed economy which is in line with the results of open economy. It implies that there is no trade-off between the output gap stabilization and domestic price stability, and the exchange rate is not necessary to be considered. It means that domestic price stabilization policy can be considered as the optimal monetary policy.

Since the first version of the paper of Gali and Monacelli (2005), there have been significant contributions to the literature on monetary policy regimes in open economies, including McCallum and Nelson (2000), Clarida, Gal´ı and Gertler (2001, 2002), Schmitt-Groh´e and Uribe (2001), Kollmann (2002), Parrado and Velasco (2002) and Benigno and Benigno (2003).

Clarida et al. (2001) developed a new open economy macro model of optimal monetary policy in small open economy. They showed how their analysis changes in case of small open economy in comparison to the analysis in closed economy (Clarida et al.,1999). In their study, the optimal monetary policy can be achieved by Taylor rule in small open economy. This result was similar to their result of closed economy model. Openness affects the parameters of the model in terms of quantitative implications, but the general form of the optimal interest rate rule does not change from closed economy case. Moreover, they show that domestic inflation should be target of the central bank and floating exchange rate is allowed when there is complete exchange rate pass-through.

Above mentioned results have been robust with respect to certain extensions of the model. For example, Benigno and Benigno (2001, 2003), Obstfeld and Rogoff (2002), and Benigno (2001) conclude that pursuing domestic price stability keeps on characterizing the optimal monetary policy when assumptions as international financial market and international cooperation are changed. Their results are consistent with the previous result of Gali & Monacelli (2005) and others.

In these models, they assume that exchange rate pass-through is complete, implying the LOP holds continually. However, the empirical literature, i.e. Rogoff (1996) and

Goldberg and Knetter (1997), suggested that the exchange rate pass-through is incomplete. Firstly, the LOP failed sufficiently for tradable goods. Secondly, exchange rate pass-through on wholesale import price is more rapid than on retail consumer prices. On the other hand, there is vast empirical evidence that changes in nominal exchange rates affect import prices only gradually (Smets & Wouters, 2002).

Another counterpart examining exchange rate pass-through effect on the optimal conduct of monetary policy studies introducing incomplete exchange rate pass-through in small open economy. There have been many papers such as Adolfson (2001), Smets and Wouters (2002), Monacelli (2005), and Sutherland (2005) examining monetary policy in the existence of imperfect exchange rate pass-through.

In early 21 century, some other studies conducted to examine the monetary policy in open economy with producer currency pricing or local currency pricing concepts using the Obstfeld and Rogoff (1995) model and concepts of international macroeconomics. For instance, Devereux and Engel (2002) investigated the implications of local currency pricing by extending Obstfeld and Rogoff (1995) framework. They found the optimal monetary policy is completely in line with fixed exchange rates. Holub (2002) studied importing low inflation via pegged exchange rates using Obstfeld (1996a) model and traditional optimum currency area theory. His result implied that the fixed exchange rate policy might be more appropriate policy for emerging economies which are interrelated with its trading partners and central banks have low credibility.

While Monacelli (1999), and Adolfson (2001) papers analyzed the performance of simple monetary policy rules in the existence of imperfect exchange rate pass-through. However, Smets and Wouters (2002) criticized that they did not take into account the costs of imperfect pass-through and hence ignore the particular role for exchange rate stabilisation that it implies. In particular, Adolfson (2001) investigated the impact of imperfect exchange rate pass-through on the central bank’s reaction, and its implications when the foreign and domestic shocks hit the economy. The result of his study showed that lower pass-through can cause higher exchange rate volatility, but this result can vary depending on entering exchange rate into the function.

The results of Bacchetta and van Wincoop (2000), Devereux and Engel (2003) and Corsetti and Pesenti (2001b) studies are that exchange rate volatility can affect on welfare if there is an incomplete exchange rate pass-through with local currency pricing. As their implications, exchange rate volatility should be considered significantly in the design of optimal monetary policy when incomplete pass-through exists.

Smets and Wouters (2002) investigated the implications of incomplete exchange rate pass-through and sticky prices of the imported goods for optimal monetary policy. They developed open economy dynamic general equilibrium model with sticky domestic and import prices. Their model differed from the benchmark model of Gali and Monacelli (1999) as introducing monopoly firms in the imported goods sector with sticky prices and Blanchard-Yaari-type overlapping generations. VAR technique has been used for their study to estimate the degree of domestic and import price stickiness. As a result, they showed that the central bank should aim to minimize a weighted average of domestic and import price inflation in order to have the minimum resource costs of staggered price setting.

Their results were very similar to Corsetti and Pesenti (2000) study where they found the producers increase their price in the market in response to the variability of profits due to the exchange rate volatility. Also, low degree of pass-through was critical limit for the ability of monetary policy to affect economy via flexible price allocation. Therefore, as their next study based on the model with predetermined domestic and foreign prices of Corsetti and Pesenti (2001a), in which they showed that minimizing the expected value of CPI weighted average of mark-ups[2] is the optimal monetary policy. However, other authors criticized these papers where they only concentrated on the optimal monetary policy under discretion and hence they ignored the important role of exchange rate under commitment by transmitting through expectational channel to inflation.

Monacelli (2005) introduced incomplete exchange rate pass-through on import prices in New Keynesian dynamic model. He argued that introducing incomplete pass-through produces important implications for the design of monetary policy. He found that the result of the model with incomplete pass-through is fundamentally different from the one of a closed economy model unlike Clarida, Gali, and Gretler (2001)[3]. Moreover, his important finding was that the optimal commitment policy compared to

[2] Mark-ups are charged in the domestic market by domestic and foreign producers

[3] Clarida et al. (2001) showed that the result of a small open economy in New Keynesian model with complete pass-through is essentially the same as the one of closed form.

discretion, reduces the l.o.p gap and has more stable nominal and real exchange rates (Monacelli, 2005).

Deveurex and Engel (2002), Corsetti and Pesenti (2005), and Sutherland (2005) are also pioneer researchers studying the impact of incomplete pass-through on the optimal design of monetary policy in terms of welfare analysis.

Particularly, Corsetti and Pesenti (2005) aimed to build a baseline general equilibrium model of optimal monetary policy among interdependent economies with nominal rigidities, imperfect competition in production, forward-looking price setting and incomplete pass-through. As a result, they found that monetary policy stabilizing domestic price is not optimal when currency fluctuations decrease the firm markups. The degree of pass-through and exchange rate exposure in domestic and foreign markets emerge as key parameter in the design of optimal monetary rules as well as in the welfare analysis of alternative monetary arrangements (Corsetti & Pesenti, 2005). They explained their findings that inward-looking monetary policy can increase the volatility of the exchange rate and thereby, firms that probably lose their revenue due to such volatility can increase the price of their products in the domestic market to avoid the possible losses. Ultimately, the increase of imported goods price will decrease the domestic customer real wealth. Therefore, they concluded that monetary policy aiming at internal price stabilization can be inefficient. To assess alternative monetary policy in an open economy context, they considered some extensions and their outcomes of the baseline model assessing the case for international monetary cooperation and reconsidering the 'rules-vs-discretion' for an open economy. Their model framework differs from one of the above models for price setting in which prices are assumed one period predetermined. Hence this model cannot be used for analyzing the dynamic gains from the commitment.

Sutherland (2005) analyzed the welfare effects of exchange rate volatility by taking account the relationships between exchange rate volatility, imperfect pass-through and welfare. This paper compiled based on Corsetti and Pesenti (2001b, 2005) and Devereux and Engel (1998, 2003) studies. The result showed that if the exchange rate pass-through is complete, then the weight on the exchange rate volatility is zero. This implies that optimal monetary policy at the home country targets to stabilize the price of domestic goods. In contrast, when the pass-through is incomplete, the optimal policy should consider the variation of exchange rate. The optimal policy for home economy may include stabilizing or destabilizing the exchange rate depending on such factors: the magnitude of pass-through, size and openness of home economy, the elasticity of labor supply, monetary policy in the foreign country and the source of exogenous disturbances. Incomplete pass-through, labor supply is elastic and foreign monetary policy is being used to stabilize foreign producer prices, then home welfare is decreasing in exchange rate volatility. In these circumstances, allowing some volatility in home producer prices is optimal for home monetary authority in order to achieve more stable nominal exchange rate. This leads to analyze the trade-off explicitly between price and exchange rate stabilization. Corsetti and Pesenti (2005) and Devereux and Engel (2003) assumed that if all prices are pre-fixed, it is not possible explicitly to analyze the trade-off. Besides these differences in model structure, this paper also differs from other papers by focusing on specific analysis for the optimal policy of a single country. They focused more on Nash equilibria or coordinated policy for two large economies.

Sutherland (2006) investigated the ‘expenditure switching effect’ for the role of exchange rate in monetary policy in small open economy. In his study, he showed that if the elasticity of substitution between home and foreign goods is not equal to unity, the variances of producer prices and terms of trade (TOT) can influence welfare. Producer-price targeting can be compared to alternative regimes such as consumer-price targeting and fixed exchange rate. The result of his study showed that the fixed exchange rate has higher welfare than the other regimes only if the elasticity of substitution between home and foreign goods is very high. In other words, terms-of-trade volatility (and thus exchange-rate volatility) can be an important factor in welfare maximizing monetary policy even there is complete pass-through.

Flamini (2007) investigated the effects of imperfect exchange rate pass-through together with delayed pass-through on constraining inflation targeting using a full-blown micro founded model. His work was distinguished from previous papers introducing delayed pass-through. The result demonstrated the imperfect pass-through tends to decrease the TOT volatility. Furthermore, incomplete pass-through restrains monetary policy more when monetary policy targets CPI inflation. Decreasing pass-through tends to raise the variability of economic activity and to worsen the trade-off between CPI inflation and output. However in case of targeting domestic inflation, the author obtained opposite results that imperfect pass-through did not constrain the monetary policy and worsen the trade-off between CPI inflation and output. For that reason Flamini (2007) concluded that the imperfect pass-through targets domestic inflation better than CPI inflation. This finding was not consistent with the results of previously studied papers.

Above mentioned results in examining the optimal monetary policy in case of open economy with incomplete exchange rate pass-through are quite robust in recent related papers. For instance, De Paoli (2009) investigated the optimal monetary policy in small open economy with monopolistic competition and nominal rigidities. In this model, utility-based loss of function is determined by a quadratic function of domestic inflation, output gap and real exchange rate. The result indicated that the substitution of domestic goods with foreign goods in low real exchange rate volatility is more optimal for monetary policy authority than targeting of domestic inflation regime.

Divino (2009) analyzed the role of exchange rate pass-through on designing the optimal monetary policy for small open economy. The model created on general equilibrium model with price stickiness. As a result, the real exchange rate affects the real marginal cost of firm, aggregate supply and demand. Also, the openness of economy has a direct impact on welfare, and the monetary authority confronts trade-off between inflation and output stabilization. Hence, the optimal policy is different from closed economy. Additionally, the author suggested that targeting domestic inflation with controlled floating real exchange rate is the optimal monetary policy.

2.3. Mongolian studies on exchange rate pass-through

There are not many studies focused on exchange rate pass-through in Mongolia. Gan-Ochir (2009)[4] analyzed the exchange rate pass-through to domestic consumer prices in Mongolian case using data on monthly basis from January, 1998 to January, 2008 and recursive VAR estimation methodology. He obtained that the exchange rate pass-through to consumer prices is about 10 percent in 5 month after the shock. However it increases up to about 55 percent after 4 months. Also, he found that the exchange rate causes CPI inflation with about 7-8 percent fluctuation. Thus he draw conclusion higher exchange rate pass-through to inflation. Moreover, the persistence and volatility of the

[4] http://www.mongolbank.mn/documents/tovhimol/20130419_Exchange_rate_pass.pdf

exchange rate are low in Mongolia. Previously, Davaajargal (2005) and Khulan (2005)[5] published papers in which the lagged exchange rate had an effect on consumer price between 3rd month and 6th month after exchange rate shock hit the economy.

Recently, Gan-Ochir (2011)[6] focused on the role of the exchange rate in Mongolian economy using theoretical framework of a stochastic open macro economy model based on Bjornland (2004) which is estimated using SVAR. This model is simply extended the Keynesian stochastic open macro economy model developed by Blanchard and Quah (1989) which showed the exchange rate acts as a shock absorber rather than a source of shocks in economy. The implication policy of his study was that flexible exchange rate is more appropriate for Mongolia.

Avralt-Od and Davaadalai (2010)[7] examined an asymmetric impact of exchange rate on inflation using SVAR estimation methodology. They proved that there is an asymmetric impact of exchange rate on inflation. The elasticity of inflation to exchange rate depreciation is higher than the elasticity of inflation to exchange rate appreciation. In other words, the increase of the consumer price due to the exchange rate depreciation is higher than the decrease of the consumer price due to the exchange rate appreciation.

More recently, Batsukh et al. (2014)[8] investigated an optimal monetary policy in the framework of small open economy DSGE model extended by natural resource sector. They analyzed four different inflation targeting (IT) rules. As a result, they found the responses of inflation and output variability to domestic demand and monetary policy shocks were smaller, but their responses to foreign debt were higher. The supply shock was the most costly shock in terms of inflation volatility, interest rate and foreign debt when policy rules were IT with exchange rate band and exchange rate based IT rules. Thus, they suggested that the volatility of exchange rate should be considered to some extent in designing of monetary policy.

[5] http://www.mongolbank.mn/documents/tovhimol/group3/02.pdf
[6] http://www.mongolbank.mn/documents/tovhimol/20130422_Role_exchange.pdf
[7] http://www.mongolbank.mn/documents/tovhimol/group5/07.pdf
[8] http://eri.mn/Discussion-Paper/04_Monetary

3 Empirical estimation of exchange rate pass-through in Mongolia

We achieve the empirical estimation of exchange rate pass-through in order to confirm whether the pass-through on import prices is incomplete in Mongolia. Even though there is a few literature for example Gan-Ochir (2009) that estimated exchange rate pass-through in the past, the estimation performed here is different for model, and data range. The estimation technique is based on Campa and Goldberg (2006). We perform the structural estimation of a VAR system for three endogenous variables: exchange rate, import prices, and consumer price index (CPI)[9].

As a result of estimation, the exchange rate pass-through into import price and CPI are 0.69% and 0.49% for short run (in one quarter) in Mongolia (see **Table 5** in Appendix II). The exchange rate pass-through into import price (0.69%) means that import price in tugrik[10] increases 0.69% in response to 1% depreciation of exchange rate (MNT/USD) in one quarter. Hence, **the pass-through into import price is incomplete** because the increase of import price is less than 1%. The exchange rate pass-through into CPI also is incomplete.

As in Campa and Goldberg (2006), average pass-through elasticity of import price to exchange rate is 0.64% and exchange rate pass-through into consumer prices is 0.17 over the long run for 23 OECD countries. As Menon (1996) that is empirical basis of incomplete exchange rate pass-through in small open economies, he reported that exchange rate pass-through estimations are empirically in the range of 20%-80%.

[9] The structural form of VAR for Δy is given by $B\Delta y_t = b(L)\Delta y_t + u_t$; where B is a regular matrix, $b(L)$ is a polynomial in the lag operator L, u is a white noise process, the vector of structural shocks. Data for Mongolia is covered from 2000Q1 to 2011Q4. We use nominal exchange rate of USD against tugrik (Mongolian currency, MNT), import price index, and CPI. We impose the Cholesky restriction following ordering: exchange rate, import prices, and consumer prices index. The lag in VAR system is chosen as four.

[10] Mongolian currency (MNT is code, ₮ is sign)

4 Small Open Economy DSGE model

The one follows Monacelli (2005) and introduces incomplete exchange rate pass-through on import prices in New Keynesian dynamic model. This assumption makes the result different compared with one of open economy model with complete pass-through.

Our theoretical framework is based on a dynamic New Keynesian general equilibrium, small-scale model. The model has two asymmetric countries, a small open economy and a large approximately closed one. The model incorporates four economic agents: domestic household, domestic firm, importing firm, and central bank. Goods markets characterize monopolistic competition, and domestic and importing firms set their prices in a staggered fashion of Calvo (1983). Introducing incomplete pass-through on import prices and allowing import prices as nominal rigidity are the main innovation of the model. This model developed to analyze the impact of incomplete pass-through on the design of monetary policy.

4.1. Domestic households

The domestic open economy is populated by infinitely-lived households. The representative households seek to maximize the following intertemporal sum of utility:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\varphi}}{1+\varphi} \right] \tag{1}$$

where $\beta \in (0,1)$ is the subjective discount factor of the future stream of utilities. N_t denotes hours of labor, and C_t is a composite consumption index. The parameter σ is the constant relative risk aversion parameter. The parameter φ is elasticity of labor supply in CES utility function.

The representative household faces the following sequence of intertemporal budget constraints of the form:

$$\int_0^1 \left[P_{H,t}(i) C_{H,t}(i) + P_{F,t}(i) C_{F,t}(i) \right] di + E_t\{Q_{t,t+1} D_{t+1}\} \leq D_t + W_t N_t + T_t \tag{2}$$

where $P_{H,t}(i)$ and $P_{F,t}(i)$ denote the prices of domestic and foreign good (i) respectively. $Q_{t,t+1}$ is one period ahead stochastic discount factor for nominal payoffs at time t relevant to the domestic household. D_{t+1} can be understand as the nominal payoff in period $t+1$ of the portfolio held at the end of period (t) and it includes shares in firms. In other words, D_{t+1} is a single financial asset that pays a risk free rate of return (one year risk free bond). In the model, the households are assumed to own the firms, thus profits serve as a resource for households. W_t is the nominal wage, and T_t is lump-sum transfers or taxes. All variables are expressed in units of domestic currency.

4.1.1. Preferences

Composite consumption index is defined by a Dixit-Stiglitz aggregator of home and foreign consumption.

$$C_t \equiv \left[(1-\gamma)^{\frac{1}{\eta}} C_{H,t}^{\frac{\eta-1}{\eta}} + \gamma^{\frac{1}{\eta}} C_{F,t}^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}} \tag{3}$$

where $C_{H,t}$ is an index of consumption of domestic goods. $C_{F,t}$ is an index of consumption of foreign goods (imported goods). Parameter $\eta > 0$ measures the elasticity of substitution between domestic and foreign goods. Parameter $\gamma \in [0,1]$ corresponds to the share of domestic consumption allocated to imported goods. Thus it represents a natural index of openness.

The consumptions of domestic and foreign goods are given by the constant elasticity of substitution (CES) aggregators as follows:

$$C_{H,t} \equiv \left(\int_0^1 C_{H,t}(i)^{\frac{\varepsilon-1}{\varepsilon}} di\right)^{\frac{\varepsilon}{\varepsilon-1}} \; ; \qquad C_{F,t} \equiv \left(\int_0^1 \left(C_{F,t}(i)\right)^{\frac{\varepsilon-1}{\varepsilon}} di\right)^{\frac{\varepsilon}{\varepsilon-1}}$$

Where parameter $\varepsilon > 1$ denotes the elasticity of substitution among goods within each category.

The overall price index P_t is represented by the price index of home goods and of foreign goods denominated in home currency.

$$P_t \equiv \left[(1-\gamma)P_{H,t}^{1-\eta} + \gamma P_{F,t}^{1-\eta}\right]^{\frac{1}{1-\eta}} \tag{4}$$

The price indexes for domestic and imported goods are given by:

$$P_{H,t} = \left(\int_0^1 P_{H,t}(i)^{1-\varepsilon} di\right)^{\frac{1}{1-\varepsilon}}; \;\; P_{F,t} = \left(\int_0^1 P_{F,t}(i)^{1-\varepsilon} di\right)^{\frac{1}{1-\varepsilon}} \quad \text{for all } i \in (0,1)$$

In order to define the demands for domestic and foreign goods within each category of goods, the households have to solve the cost minimization problem. The problem is solved by minimizing the expenditure of each category of goods subject to the constraint of the CES aggregators consumption of each category of goods and using the definition of the price indexes for domestic and imported goods. For example, the problem is defined as follows for domestic goods:

$$min \rightarrow \int_0^1 P_{H,t}(i) C_{H,t}(i) di$$

$$s.t.\; C_{H,t} \equiv \left(\int_0^1 C_{H,t}(i)^{\frac{\varepsilon-1}{\varepsilon}} di\right)^{\frac{\varepsilon}{\varepsilon-1}}$$

As a result of optimization, the optimal allocation of the cost minimization yields the demand functions for domestic and foreign i-th goods[11]:

$$C_{H,t}(i) = \left[\frac{P_{H,t}(i)}{P_{H,t}}\right]^{-\varepsilon} C_{H,t}; \qquad C_{F,t}(i) = \left[\frac{P_{F,t}(i)}{P_{F,t}}\right]^{-\varepsilon} C_{F,t} \tag{5}$$

Combining the optimality conditions in equation (5) with the definitions of price indexes for domestic $P_{H,t}$ and foreign goods $P_{F,t}$ yields:

$$\int_0^1 \left[P_{H,t}(i) C_{H,t}(i) + P_{F,t}(i) C_{F,t}(i)\right] di = P_{H,t} C_{H,t} + P_{F,t} C_{F,t} \tag{6}$$

Minimizing the total consumtption cost subject to the constraint of composite consumption index, the optimal allocation of expenditures between domestic and foreign goods yields demand functions for domestic and foreign goods[12]:

$$C_{H,t} = (1-\gamma)\left[\frac{P_{H,t}}{P_t}\right]^{-\eta} C_t; \quad C_{F,t} = \gamma\left[\frac{P_{F,t}}{P_t}\right]^{-\eta} C_t \tag{7}$$

Using the above optimal conditions, intertemporal budget constraints (equation (2)) can be rewritten as:

$$P_t C_t + E_t\{Q_{t,t+1} D_{t+1}\} \leq D_t + W_t N_t + T_t \tag{8}$$

Finally, in order to define the optimal condition for labor supply and consumptions, the households have to solve the utility maximization problem. The problem is solved by maximizing the utility (equation (1)) subject to the intertemporal budget constraint

[11] Detailed derivation of the intra basket problem is deferred to Appendix 1.1, equations (A1)
[12] Detailed derivation is provided in Appendix 1.2, equations (A2) and (A3).

(equation (2)). As a result, the optimality conditions for the household's problem are determined as follows[13]:

$$\frac{W_t}{P_t} = C_t^{\sigma} N_t^{\varphi} \tag{9}$$

Equation (9) is a standard intratemporal optimal condition representing the labor supply of the household, and

$$1 = \beta R_t E_t \left\{ \left[\frac{C_{t+1}}{C_t}\right]^{-\sigma} \left[\frac{P_{t+1}}{P_t}\right]^{-1} \right\} \tag{10}$$

where $R_t = \frac{1}{E_t\{Q_{t,t+1}\}}$ is the gross return a riskless one-period discount bond paying off one unit of domestic currency in $t + 1$. Equation (10) is intertemporal optimal condition that represents the Euler equation.

We assume the existence of complete markets for state-contigent money claims in units of domestic currency. Under this assumption, optimal conditions equatin (9) and (10) can be written in a convenient log-linearized form as:

$$w_t - p_t = \sigma c_t + \varphi n_t \tag{11}$$

$$c_t = E_t\{c_{t+1}\} - \frac{1}{\sigma}[i_t - E_t\{\pi_{t+1}\}] \tag{12}$$

Where lower case letters indicates logs of the respective variables while capital letters indicate level. w_t is the nominal wage, n_t is labor hours, i_t is the log nominal interest rate, and π_t is the CPI inflation rate.

In the rest of the world, a representative household has to solve the same problem as the domestic household. Thus, the optimal decision is the same as the one determined above. Gali and Monacelli (2002) assume that a small open economy is negligible relative to the rest of the world. Thus, this assumption allows to treat the latter as if it was a closed economy. It means that there are only two asymmetric countries in the world. One is small relative to the other. This model set-up admits to model explicitly the role of financial markets and risk sharing and to cope with a typical problem of unit-root in consumption that describes traditional small open economy models with incomplete markets.

[13] Detailed derivation of the household life time utility maximization is deferred to Appendix 1.3, equations (A4) and (A5).

4.1.2. Pass-through, the Real Exchange Rate, and Deviations from PPP

In order to define the relationships between incomplete pass-through and deviations from the LOP, and between the real exchange rate and deviations from the LOP, the expressions of CPI price index and TOT are used in the derivations.

Thus, first the CPI expression is needed to log-linearize around the steady state. Log-linearized CPI price index is given by[14]:

$$p_t = (1-\gamma)p_{H,t} + \gamma p_{F,t} \tag{13}$$

Using equation (14), the one can obtain the expression between domestic inflation and CPI-inflation:

$$\begin{aligned} \pi_t = p_t - p_{t-1} &= (1-\gamma)\pi_{H,t} + \gamma\pi_{F,t} \\ &= p_{H,t} - p_{H,t-1} + \gamma(s_t - s_{t-1}) \\ &= \pi_{H,t} + \gamma\Delta s_t \end{aligned} \tag{14}$$

Where $s_t \equiv p_{F,t} - p_{H,t}$ denotes (log) TOT, i.e., the *domestic currency relative price of imports*. TOT equation holds independently of the degree of pass-through. $\gamma\Delta s_t$ makes the gap between CPI inflation and domestic inflation. It implies that the gap between two inflations depends on the index of openness γ and the percent change in the TOT.

The production in the small open economy is a negligible fraction of the world's consumption basket. Thus, the rest of the world characterizes as a closed economy in the model. It implies that domestic inflation is equal to the CPI inflation in the rest of the world, i.e, $p_t^* = p_{F,t}^*$, and $\pi_t^* = \pi_{F,t}^*$ for all t. The variables representing the rest of the world are denoted with an asterisk.

Based on empirical evidence, pass-through is assumed to be incomplete in the model. Thus under the assumption of incomplete pass-through, the LOP does not hold. This means that the price of any imported goods in the market of small open economy is not equal to the price of the identical good in the world market in terms of domestic currency. In other words, the economy is indentified by deviation of the world price from the domestic currency price of imports as follows:

$$P_{F,t} \neq \mathcal{E}_t P_t^*$$

[14] Detailed derivation is shown in Appendix 1.4, equation (A6).

where $\mathcal{E}_t$ is the nominal exchange rate, $P_t^*$is the price of foreign country in the terms of its own currency. From the above expression the l.o.p gap is defined as follows in log-linearized form:

$$\psi_{F,t} = (e_t + p_t^*) - p_{F,t} \tag{15}$$

where $\psi_{F,t}$ measures *the law-of-one-price gap* (l.o.p gap). In order to show the effect of l.o.p gap, in what follows it is useful to define the relationship between the real exchange rate and l.o.p gap. Real exchange rate is given by:

$$Q_t = \frac{\mathcal{E}_t P_t^*}{P_t}$$

Log-linearized form is

$$q_t = e_t + p_t^* - p_t$$

Combining the expressions of TOT and l.o.p gap, the real exchange rate in log-linearized form can be rewritten:

$$\begin{aligned} q_t &= e_t + p_t^* - p_t \\ &= s_t + p_{H,t} + \psi_{F,t} - p_t \\ &= s_t - \gamma s_t + \psi_{F,t} = \psi_{F,t} + (1-\gamma) s_t \end{aligned} \tag{16}$$

Equation (16) includes two sources of deviation from aggregate PPP in this framework. The first one, $(1-\gamma)s_t$, is related with heterogeneity of consumption baskets between the small economy and the rest of the world as long as $\gamma < 1$. As parameter γ approaches one,$\gamma \rightarrow 1$, two aggregate consumption baskets will be the same and relative price variations will not be in equilibrium. The l.o.p gap is the second source of deviation from PPP. When the pass-through is incomplete, the l.o.p gap contributes to the variability of the real exchange rate. We can see that the role of the term $\psi_{F,t}$ from the determination of the dynamics of imports inflation.

4.2. Domestic Producers

Monopolistic competitive firms are a continuum, indexed by $i \in [0,1]$ in the domestic goods market. The firms are owned by consumers. Domestic each firm produces a differentiated good. All goods are tradable. They operate a constant return to scale technology (linear technology) represented by the following production function:

$$Y_t(i) = Z_t N_t(i) \tag{17}$$

Where $z_t = logZ_t -$ (log) labor productivity. Domestic productivity is assumed to follow a simple stochastic autoregressive process:

$$z_t = \rho z_{t-1} + \varepsilon_{z,t} \tag{18}$$

where $0 \leq \rho \leq 1$ is persistence parameter and $\varepsilon_{z,t} - i.i.d$ shock. Log-linearized production function is written as $y_t(i) = z_t + n_t(i)$. In order to obtain aggregate output, I combine the definition of aggregate output, $Y_t \equiv \left[\int_0^1 Y_t(i)^{\frac{\varepsilon-1}{\varepsilon}} di\right]^{\frac{\varepsilon}{\varepsilon-1}}$, with the above production function and then log-linearize the function:

$$y_t = z_t + n_t \tag{19}$$

In the rest of the world, firms are assumed to have an identical technology with (log) productivity following an exogenous process $z_t^* = \rho z_{t-1}^* + \varepsilon_{z^*,t}^*$, where $\varepsilon_{z^*,t}^*$ is white noise, possibly correlated with $\varepsilon_{z,t}$. Thus, aggregate output function is identical to equation (19).

In order to choose the efficient labor input, the firms have to minimize their total cost. Cost minimization brings the following efficiency condition in log-linearized form:

$$mc_t^r = \left(w_t - p_{H,t}\right) - z_t \tag{20}$$

where mc_t^r denotes the (log) real marginal cost. It is common across firms.

In the model, domestic firms are assumed to reset their prices in a staggered fashion, as in Calvo-Yun rule. Each firm sets new prices with probability $1 - \theta_H^k$ in any given period and the price set at time t will still hold at time $t + k$. Hence, a measure of $1 - \theta_H$ of producers reset their prices, while a fraction θ_H keep their prices unchanged. A firm reoptimizing in period t need to set the optimal new price, $P_{H,t}^{new}$ that maximizes the current market value of the profits generated while that price remains effective. Firm i's production is constrained by the sum of dometic and foreign demand. The export price of the domestic good, $P_H^*(i)$, is assumed to be flexible and determined by the LOP. The optimal price setting problem is defined as follows:

$$\underbrace{max}_{P_{H,t}^{new}} \rightarrow \sum_{k=0}^{\infty} \theta^k E_t\left\{Q_{t,t+k}\left[Y_{t+k|t}(i)\left(P_{H,t}^{new} - MC_{t+k}^n\right)\right]\right\}$$

$$s.t{:}\ Y_{t+k}(i) = C_{H,t+k}(i) + C_{H,t+k}^*(i)$$

After taking the first-order condition and log-linearization, the log-linear equation for the optimal newly set domestic prices are given by[15]:

$$p_{H,t}^{new} = (1 - \theta_H \beta) \sum_{k=0}^{\infty} (\theta_H \beta)^k E_t\left\{p_{H,t+k} + mc_{t+k}^r\right\} \tag{21}$$

[15] Detailed log-linearization is provided in Appendix 1.5, equation (A8).

where $p_{H,t}^{new}$ is the (log) of newly set prices. This pricing decision in the model is a forward-looking one. Firms in the rest of the world faces the identical price setting problem and hence, the pricing technology is identical to that of domestic firms.

The domestic aggregate price index evolves according to:

$$P_{H,t} = \left[\theta_H P_{H,t}^{1-\varepsilon} + (1-\theta_H)\left(P_{H,t}^{new}\right)^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}} \tag{22}$$

By log-linearizing equation (22) and combining with equation (21), a typical forward-looking Phillips curve is determined by[16]:

$$\pi_{H,t} = \beta E_t\{\pi_{H,t+1}\} + \lambda mc_t^r \tag{23}$$

where $\lambda_H \equiv \frac{(1-\theta_H)(1-\theta_H\beta)}{\theta_H}$, $\widehat{mc_t^r} = mc_t^r + \mu$ denotes the the (log) real marginal cost deviations from its steady state $(-\mu)$. In our model, μ is assumed to be zero and thereby $\widehat{mc_t^r} = mc_t^r$. Expected domestic inflation rate, $E_t\{\pi_{H,t+1}\}$, affects the today's domestic inflation. It implies that the expectation about the inflation in the future contributes more to today's inflation rather than past inflation (Clarida et al. (1999)). In case of Mongolia, Dutu (2012) showed that Mongolian people make quite forward-looking decision because they don't care much on past inflation due to the high inflation environment. The real marginal cost deviations caused by cost push shocks such as movements in nominal wage.

4.3. Incomplete pass-through and Imports Pricing

Now the dynamic of import pricing is discussed in this section. This is the central modelling novelty of the paper by Monacelli (2005). Many empirical works' results suggest that a setup featuring incomplete pass-through should allow the l.o.p gap to be, and large, gradual, as well as persistent.

To account for these facts, this section is developed in the model. We assume that the domestic market is populated by local retailers who import differentiated goods for which the LOP holds "at the dock". However, the importers set the domestic currency price of imported goods by solving an optimal markup problem. This generates the l.o.p gap in the short run, while pass-through gets complete only asymptotically in the long-run. This implies that the LOP holds in the long-run. This feature is more consistent

[16] Detailed log-linearization is provided in Appendix 1.6, equation (A13)

with the findings of the empirical works and distinguishes our modelling of incomplete pass-through from the one of other papers such as Corsetti and Pesenti (2005).

Consider a local retailer who import good j at a cost $\mathcal{E}_t P^*_{F,t}(j)$. This cost is the price paid in the world market. $\mathcal{E}_t$ is the level of the nominal exchange rate. The retailers face a downward sloping demand for imported goods like the local producers. The retailers of imported goods are assumed to reset their prices in a staggered fashion like domestic firms. Each retailer firm sets new prices with probability $1-\theta_F^k$ in any given period and the price set at time t will still hold at time $t+k$. Hence, a measure of $1-\theta_F$ of retailers reset their prices, while a fraction θ_F keep their prices unchanged. A retailer firm, who wants to change their price in period t, need to choose new price, $P^{new}_{F,t}(j)$ expressed in domestic currency to maximizes the current market value of the profit. Retailer firm j's imported goods are constrained by the demand of imported goods j in the domestic market. The optimal price setting problem is defined as follows:

$$\underbrace{max}_{P^{new}_{F,t}(j)} \rightarrow \quad E_t\left\{\sum_{k=0}^{\infty} \beta^k \Lambda_{t,t+k}\theta_F^k \left(P^{new}_{F,t}(j) - \mathcal{E}_{t+k}P^*_{F,t+k}(j)\right) C_{F,t+k}(j)\right\}$$

$$s.t: C_{F,t+k}(j) = \left(\frac{P^{new}_{F,t}(j)}{P_{F,t+k}}\right)^{-\varepsilon} \cdot C_{F,t+k}$$

where $P^*_{F,t}(j)$ denotes the foregin-currency price of the imported good, θ_F^k is the probability that the price $P^{new}_{F,t}(j)$ set for good j at time t still holds k periods ahead, and $\beta^k\Lambda_{t,t+k}$ is a relevant stochastic discount factor. The degree of domestic price stickness θ_H is allowed to be different from the degree of the import price stickness θ_F.

As a result of the FOC, the newly set import price is given by:

$$P^{new}_{F,t}(j) = \frac{\varepsilon}{\varepsilon-1} \cdot \frac{E_t\left\{\sum_{k=0}^{\infty} \beta^k \Lambda_{t,t+k}\theta_F^k \left(\mathcal{E}_{t+k}P^*_{F,t+k}(j)C_{F,t+k}(j)\right)\right\}}{E_t\left\{\sum_{k=0}^{\infty} \beta^k \Lambda_{t,t+k}\theta_F^k C_{F,t+k}(j)\right\}} \tag{24}$$

After taking logarithms of equation (24) and using a first order Taylor approximation around steady state, the log-linearized form of equation (24) yields[17]:

$$p^{new}_{F,t}(j) = (1-\theta_F\beta)E_t\left\{\sum_{k=0}^{\infty} (\theta_F\beta)^k \left(\psi_{F,t+k} + p_{F,t+k}\right)\right\} \tag{25}$$

In order to obtain the dynamic of import pricing, imported goods' price index is useful.

[17] Detailed log-linearization is provided in Appendix 1.7, equation (A15)

$$P_{F,t} \equiv \left[\theta_F P_{F,t-1}^{1-\varepsilon} + (1-\theta_F)\left(P_{F,t}^{new}\right)^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}} \qquad (26)$$

By log-linearizing equation (26) and combining with equation (25), an aggregate supply curve for imports goods is defined as follows[18]:

$$\pi_{F,t} = \beta E_t\{\pi_{F,t+1}\} + \lambda_F \psi_{F,t} \qquad (27)$$

where $\lambda_F = \frac{(1-\theta_F)(1-\theta_F\beta)}{\theta_F}$. Domestic currency inflation of import goods (eq. 27) is often referred to as New Keynesian forward-looking Phillips curve. The percentage change of import price depends on the expectation about future import price changes and the l.o.p gap (the gap between the foreign producer's equilibrium price and the import price charged in the domestic market in domestic currency). In other words, as the world price of imports exceeds the local currency price of the same good, imported inflation increases. Therefore, a nominal depreciation increases the difference between the price paid by the importers in the world market and the local currency price charged in the domestic market. Consequently, this difference leads to increase the importer's marginal cost and thereby rises the imported inflation. However, how much nominal depreciation pass-through into imported inflation depends on the parameter θ_F. This parameter related to nominal rigidity controls the degree of pass-through (i.e. the ratio of costs of changing the price to costs of staying away from the equilibrium price). The increase of θ_F implying a greater nominal rigidity leads to decrease exchange rate pass-through. Therefore, as it is explained in the literature (Dornbusch (1987) and Hellerstein (2004)), the price stickness can be one of reasons that exchange rate pass-through is incomplete and thereby the LOP does not hold. Thus, when the value of θ_F is high, the impact of nominal depreciation exchange rate tends to be smaller on the imported inflation. In case of $\theta_F = 0$, equation (25) reduces to a simple LOP equation $p_{F,t} = e_t + p_t^*$.

Equation (27) can be rewritten as integrating forward:

$$\pi_{F,t} = E_t\left\{\sum_{k=0}^{\infty} \beta^k \lambda_F \psi_{F,t+k}\right\} \qquad (28)$$

which shows that imports price inflation is a function of the present discounted value of current and expected future deviations from the LOP (i.e. purely forward looking

[18] Detailed derivation is provided in Appendix 1.8, equation (A20)

variable). In other words, current dynamic of import price inflation depends on the current and expected future l.o.p gap.

4.3.1. Risk Sharing and Uncovered Interest Parity

Risk sharing: It is assumed that agents in both economies have access to a complete set of internationally traded securities. Under the assumption of complete securities markets, household's intertemporal condition (equation 10) must hold for the representative household in foreign economy, $Q_{t,t+1} = \beta \left(\frac{C_{t+1}^*}{C_t^*}\right)^{-\sigma} \left(\frac{P_t^*}{P_{t+1}^*}\right)\left(\frac{\varepsilon_t}{\varepsilon_{t+1}}\right)$. Because the financial markets at domestic and international level are complete with perfect capital mobility, the expected nominal return in foreign country is equal to the expected domestic-currency return from foreign bonds.

Therefore, combining Euler equation (10) for domestic and foreign economy and using definition of real exchange rate (eq.16), the relationship between home and foreign country's consumptions can be obtained in log-linearized form:

$$c_t = c_t^* + \frac{1}{\sigma} q_t \tag{29}$$

Plugging the expression of q_t, it can be rewritten as[19]:

$$c_t = c_t^* + \frac{1}{\sigma}\left[(1-\gamma)s_t + \psi_{F,t}\right] \tag{30}$$

where σ is the intertemporal elasticity of substitution in consumption? It has implications for consumption risk sharing. In equilibrium, changes at the ratio of marginal utilities of consumption must indicate changes in real exchange rate. Deviations from the LOP affect the changes of relative consumption baskets via affecting changes of real exchange rate.

Uncovered Interest Parity: Under complete international asset markets, it is also possible to derive a standard log-linear version of uncovered interest parity (UIP) condition. Under the assumption of complete international financial markets, households can invest both in domestic and foreign bonds (D_t and D_t^*). Therefore, by solving again the households' maximization problem including foreign bonds, the equilibrium price of a riskless bond denominated in foreign currency is able to determined by $R_t^{*-1} = E_t\left\{Q_{t,t+1} \cdot \frac{\varepsilon_{t+1}}{\varepsilon_t}\right\}$. Earlier on in Euler equation (10), we defined

[19] Detailed derivation is provided in Appendix 1.9, equation (A23).

the price of domestic bond as $R_t^{-1} = E_t\{Q_{t,t+1}\}$. Thus, under the assumption, these two prices should be equal, $E_t\{Q_{t,t+1}[R_t - R_t^*(\mathcal{E}_{t+1}/\mathcal{E}_t)]\} = 0$, to obtain a version of UIP condition (Gali and Monacelli, 2005). After log-linearizing this equivalence, a standard log-linear version of the UIP condition is given by[20]:

$$i_t - i_t^* = E_t\{\Delta e_{i,t+1}\} \tag{31}$$

The equation (31) shows that difference between domestic nominal interest rate and foreign (rest of the world) nominal interest rate is equal to the expected rate of depreciation for domestic currency.

4.3.2. Decomposition of the Real Marginal Cost

In order to obtain relationship between domestic real marginal cost and open economy factors in equilibrium, we rearrange the equation (20) of domestic real marginal cost using international risk sharing equation (30) and market clearing condition, $c_t^* = y_t^*$, in the rest of the world. Thus, the domestic real marginal cost (or inverse of the domestic mark-up) can be stated as:

$$\begin{aligned} mc_t^r &= (w_t - p_{H,t}) - z_t \\ &= (w_t - p_t) + \gamma s_t - z_t \\ &= \sigma c_t + \varphi y_t + \gamma s_t - (1+\varphi) z_t \\ &= \varphi y_t - (1+\varphi) z_t + \sigma y_t^* + s_t + \psi_{F,t} \end{aligned} \tag{32}$$

Equation (32) shows that domestic real marginal cost is increased in domestic output. Initially, the increase of output leads to increase of labor demand (employment) via production function, and thereby the increase of labor demand causes the real wage to increase via real wage. Consequently, the real marginal cost increases. Domestic technology has a negative effect on the domestic real marginal cost through its direct effect on labor productivity. Moreover, from the equation, we can see that open economy factors also affect the real marginal cost. World output,y_t^*, has a positive effect on the real marginal cost through its effect on labor supply via risk sharing. The TOT, s_t, has a positive effect on real marginal cost. It means that an improvement on TOT (increase of domestic currency relative price of imports) increases the real marginal cost through its effect on export and as such aggregate demand.

[20] Detailed derivation is provided in Appendix 1.10, equation (A26)

4.4. Goods Market Equilibrium

To describe the equilibrium in the domestic goods market, first market clearing conditions is required to be defined:

$$Y_t(i) = C_{H,t}(i) + C^*_{H,t}(i) \tag{33}$$

Where $Y_t(i)$ and $C_{H,t}(i)$ denotes the supply and domestic demand for the domestically produced good i, respectively. $C^*_{H,t}(i)$ is world demand for the domestic good i produced in home country. In other words, the production of domestic good i is determined by the sum of domestic and foreign demand for good i produced in domestic market.

Therefore, first plugging equations (5) and (7) into equation (33), then doing aggregation using definition of aggregate output, $Y_t = \left[\int_0^1 Y_t(i)^{\frac{\varepsilon-1}{\varepsilon}} di\right]^{\frac{\varepsilon}{\varepsilon-1}}$, and finally after rearranging the supply equation using definitions of TOT, $S_t = \frac{P_{F,t}}{P_{H,t}} = \frac{\mathcal{E}_t P^*_t}{P_{H,t}}$, and real exchange rate, $Q_t = \frac{\mathcal{E}_t P^*_t}{P_t}$, aggregate supply equation is rewritten as:

$$Y_t = \vartheta Y^*_t S^\eta_t \left\{(1-\gamma)Q_t^{\frac{1}{\sigma}-\eta} + \gamma\right\} \tag{34}$$

And it can be written as in log-linearized form:

$$y_t - y^*_t = \frac{1}{\sigma}\left[\omega_s s_t + \omega_\psi \psi_{F,t}\right] \tag{35}$$

Equation (35) shows proportional relation between domestic and foreign output which is affected by the presence of incomplete pass-through in the domestic goods market equilibrium. In the equation, $\omega_s \equiv 1 + \gamma(2-\gamma)(\sigma\eta - 1) > 0$ is elasticity of relative output to TOT and $\omega_\psi \equiv 1 + \gamma(\sigma\eta - 1) > 0$ is the elasticity of relative output to the l.o.p gap, with $\omega_s \geq \omega_\psi$.

The expression (30) makes clear that in equilibrium, any movement in relative output requires an adjustment in relative prices, summarized by equation in previous paragraph. For instance, consider the case of a rise in domestic output. In this case, equilibrium requires a real depreciation. It can be achieved in two ways: either a fall in the domestic currency price of domestic goods (relative to foreign goods, i.e., a rise in s_t) or a nominal depreciation bringing a deviation from the LOP for imports (i.e., a rise in $\psi_{F,t}$).

4.5. Policy Target in the Rest of the World

In the present model, small open economy is assumed to be negligible in the world economy. Thus, the rest of the world indicates as a closed economy which implies $p_t^* = p_{F,t}^*$ and $\pi_t^* = \pi_{F,t}^*$ for all t. The equilibrium real marginal cost is defined same as in closed economy (i.e., obtained for $\gamma = 0$):

$$mc_t^* = (\sigma + \varphi)y_t^* - (1 + \varphi)z_t^* \quad (36)$$

which is simply the closed economy version of equation (32). Hence, by imposing $mc_t^* = 0$ (which implies $\pi_t^* = 0$), the natural (flexible-price) level of output in the world economy easily is given by:

$$\overline{y_t^*} = \frac{(1 + \varphi)}{(\sigma + \varphi)} \cdot z_t^* \quad (37)$$

As in canonical sticky-price model with Calvo price staggering, the output gap will be completely stabilized under fully flexible prices, i.e,

$$\widetilde{y_t^*} = y_t^* - \bar{y}_t{}^* = 0 \quad (38)$$

Throughout the rest of the paper, it is assumed that the monetary policy objective is to replicate the flexible price allocation by simultaneously stabilizing inflation and output gap. It is well known that such policy is the optimal in case of closed economy in the framework of New Keynesian DSGE model with staggered price setting and it is also in line with the first best outcome of Goodfriend and King (1997), and Woodford (2002) studies. However, in order to examine the impact of foreign domestic shock on Mongolian economy, in section 6.2.3 we assume that central bank in the rest of the world follows simple Taylor rule.

4.6. Flexible Domestic Prices

In this section, we describe the equilibrium dynamics in the small open economy under the assumption that *domestic producer prices* are flexible. This is useful to derive two results. First one is that nominal exchange rate volatility is related to the degree of pass-through. Second one is that the l.o.p gap must respond positively to a (relative) productivity shock for sufficiently low degree of pass-through.

In case of flexible domestic prices the domestic pricing equation (20) yields a constant markup. Therefore we assume that domestic prices remain fixed at their optimal level, as firms would have no incentive to deviate from such state of affairs. By imposing a constant markup,($mc_t = 0$), in equation (32) and substituting equation (35), the domestic flexible price level of output is expressed by:

$$\bar{y_t} = \bar{y_t}^n - \left(\frac{\omega_s - \omega_\psi}{\sigma + \varphi\omega_s}\right)\bar{\psi}_{F,t} \tag{39}$$

Where $\bar{y_t}^n = \left(\frac{w_s(1+\varphi)}{\sigma+\varphi w_s}\right) z_t + \left(\frac{\sigma(1-w_s)}{\sigma+\varphi w_s}\right) y_t^*$ denotes the natural level of output, i.e., the one that would obtain in case of both flexible domestic prices and complete pass-through. Below we show how to obtain a reduced form expression for $\bar{\psi}_{F,t}$. As note, two measure of output gap exactly coincide in the special case $\omega_s = \omega_\psi$.

The l.o.p gap can be written

$$\bar{\psi}_{F,t} = \bar{e_t} - \bar{p}_{F,t} \tag{40}$$

and TOT

$$\bar{s_t} = \bar{e_t} - \bar{\psi}_{F,t} \tag{41}$$

Defining $\bar{s_t}$ from equation (35) and combining it with equation (41), we can get an expression for nominal exchange rate:

$$\bar{e_t} = \frac{\sigma}{w_s}(\bar{y_t} - y_t^*) + \left(1 - \frac{w_\psi}{w_s}\right)\bar{\psi}_{F,t} \tag{42}$$

Which can be rearranged, using equation (39), to obtain

$$\bar{e_t} = \bar{e_t}^n + \left(\frac{\sigma\left(w_s - w_\psi\right)}{\sigma + \varphi w_s}\right)\bar{\psi}_{F,t} \tag{43}$$

where $\bar{e_t}^n = \left(\frac{\sigma(1+\varphi)}{\sigma+\varphi w_s}\right)(z_t - z_t^*)$ denotes the natural nominal exchange rate. Hence, as long as $\omega_s \neq \omega_\psi$, the l.o.p gap contributes to the volatility of the nominal exchange rate beyond the one implied by its natural level. Thus, the model seems to be in line with the view which is a lower degree of pass-through is related with higher exchange rate volatility (Betss and Devereux, 2000). Intuitively, as the pass-through is lower, the larger nominal exchange rate variation will be required to achieve a given adjustment in real relative prices along the transition to the equilibrium.

Next, it is useful to derive relationship between l.o.p gap and relative productivity. Initially, combining equations (40) and (43), and then substituting the arranged equation into equation (27) and solving difference equation for expression $\overline{p_{F,t}}$, the dynamic of l.o.p gap can be obtained[21]:

[21] Detailed derivation is provided in Appendix 1.11, equation (A31).

$$\overline{\psi_{F,t}} = \Gamma(z_t - z_t^*) - \left(\frac{\mu_1(\sigma + \varphi w_s)}{\sigma + \varphi w_\psi}\right)\overline{p_{F,t-1}} \tag{44}$$

where $\mu_1 < 0$ and $\Gamma \equiv \left(\frac{\sigma(1+\varphi)}{\sigma+\varphi w_\psi}\right) - \left(\frac{\sigma+\varphi w_s}{\sigma+\varphi w_\psi}\right)\Omega = \left(\frac{\sigma(1+\varphi)}{\sigma+\varphi w_\psi}\right)\left[1 - \frac{(\sigma+\varphi w_s)\beta\mu_1\lambda_F}{\left((\sigma+\varphi w_\psi)(1-\rho\beta\mu_1)\right)}\right]$.

One can easily show that $\Gamma > 0$ for sufficient low degree of pass-through, which in turn implies that l.o.p gap *must rise* in response to relative increase in domestic productivity (Monacelli, 2005). This result depends on importers feeding nominal exchange rate movements gradually on domestic currency import prices. Also this result will be useful to analyze the inflation dynamics in response to productivity shock.

4.7. Supply Block

In this section, we illustrate how to introduce incomplete pass-through affects the supply side relationships of the model. First, we need to define the output gap which is the percentage deviation of current output from natural level of output, i.e.,

$$\widetilde{y_t} \equiv y_t - \overline{y_t}^n \tag{45}$$

Notice again in this equation, the natural level of output is the one that would obtain under both flexible prices and complete pass-through. Therefore, using the definition of output gap, the equation (35) can be easily expressed in terms of gaps:

$$\widetilde{y_t} = \frac{w_s}{\sigma}\widetilde{s_t} + \frac{w_\psi}{\sigma}\psi_{F,t} \tag{46}$$

Equation (46) implies that the output gap is proportional to both the (domestic) TOT gap and the l.o.p gap.

The equilibrium real marginal cost (32) can be written after combining with equation (46), as:

$$mc_t^r = \left(\varphi + \frac{\sigma}{w_s}\right)\widetilde{y_t} + \left(1 - \frac{w_\psi}{w_s}\right)\psi_{F,t} \tag{47}$$

Equation (47) implies that the existence of incomplete pass-through breaks down the proportionality relationship between real marginal cost and output gap which typically characterizes the canonical sticky-price model with imperfect competitive markets. With incomplete pass-through, the real marginal cost is proportional to both of output gap and l.o.p gap. The potential contrasting equilibrium behavior of these two determinants of the real marginal cost in response to productivity shocks will be key to understand the policy trade-off faced by the monetary authority. The analysis below will be further studied on this point.

To obtain the relationship between domestic inflation dynamic and deviations from the LOP, we substitute the equation (46) into equation (23). As a result, the **aggregate supply curve** based on domestic inflation is given by:

$$\boldsymbol{\pi_{H,t} = \beta E_t\{\pi_{H,t+1}\} + k_y \tilde{y}_t + k_\psi \psi_{F,t}} \tag{48}$$

Where $k_y \equiv \lambda_H \left(\varphi + \frac{\sigma}{\omega_s}\right)$ and $k_\psi \equiv \lambda_H \left(1 - \frac{\omega_\psi}{\omega_s}\right)$. This is New Keynesian Phillips curve for domestic inflation. The output gap in the equation indicates the aggregate demand determinants affecting the domestic inflation. Thus, it is aggregate demand channel to inflation. The last term $\psi_{F,t}$ can represent the aggregate supply factors influencing the domestic inflation. Interestingly, it allows to interpreting the l.o.p gap as *endogenous supply shocks*. The result of equation (44) determines that the term $\psi_{F,t}$ will increase in response to an increase of domestic productivity when the pass-through is sufficiently low. Therefore, equation (48) implies that for any given output gap level, an increase of the l.o.p gap induced by endogenously positive productivity shock can lead to the increase of domestic inflation. This result opposes in a practice that is common in models of the New Keynesian Phillips curve of “appending” (inefficient) cost-push terms to the right hand side of equation (48) as a proxy for supply shocks.

By solving equation (48) forward it produces:

$$\pi_{H,t} = E_t \left\{ \sum_{k=0}^{\infty} \beta^k \left(k_y \tilde{y}_{t+k} + k_\psi \psi_{F,t+k} \right) \right\} \tag{49}$$

which implies that domestic inflation is purely forward-looking and it depends on current and expected future value of the output gap and the l.o.p gap.

4.7.1. CPI-based Aggregate Supply

In this section, we show how the deviations from LOP is linked to the CPI inflation dynamic.

By substituting equations (27) and (48) of domestic and import price inflation dynamic into the equation (14) of CPI inflation, one can obtain the expression for a CPI based **aggregate supply curve**:

$$\boldsymbol{\pi_t = \beta E_t\{\pi_{t+1}\} + k_y^c \tilde{y}_t + k_\psi^c \psi_{F,t}} \tag{50}$$

Where $k_y^c \equiv (1-\gamma)k_y$ and $k_\psi^c \equiv (1-\gamma)k_\psi + \gamma\lambda_F$. CPI inflation characterizes forward-looking Phillips curve representation likewise domestic inflation. The equation (50) shows that for a given output gap, an increase of the l.o.p gap causes CPI inflation to increase. Therefore, to stabilize the inflation fully, the output gap is required to fall. Moreover, one different thing from domestic inflation is that the coefficient k_{ψ}^{c} is still positive, $k_{\psi}^{c} = \gamma\lambda_F > 0$ in case of $\sigma = \eta = 1$. It implies that the l.o.p gap continues to affect CPI inflation even in special case of $\sigma = \eta = 1$[22]. This feature will be important below to make additionally an existing trade-off between the stabilization of the output gap and of the CPI inflation.

4.8. The Demand Block

In this section, we describe how the aggregate demand depends on the l.o.p gap. First, using the equation (30), the market clearing condition can be rewritten as:

$$y_t = \left(\frac{w_s}{1-\gamma}\right) c_t + \left(1 - \frac{w_s}{1-\gamma}\right) c_t^* - \left(\frac{\gamma\eta}{(1-\gamma)}\right) \psi_{F,t} \qquad (51)$$

Then, substituting equation (51) into Euler equation (12) and using the output gap definition and equation (14) of CPI inflation, we can obtain the following **aggregate demand** equation:

$$\boldsymbol{\tilde{y}_t = E_t\{\widetilde{y_{t+1}}\} - \frac{w_s}{\sigma}\left(i_t - E_t\{\pi_{H,t+1}\} - \bar{r}_t^{\,n}\right) + \Gamma_y E_t\{\Delta\psi_{F,t+1}\}} \qquad (52)$$

where $\Gamma_y = \frac{\gamma(1-\gamma)(\sigma\eta-1)}{\sigma}$ and $\bar{r}_t^{n} \equiv \sigma\left(\frac{\varphi(\omega_s-1)}{\sigma+\varphi\omega_s}\right) E_t\{\Delta y_{t+1}^*\} - \left(\frac{\sigma(1-\rho)(1+\varphi)}{\sigma+\varphi\omega_s}\right) z_t$ is the natural real interest rate. This is so-called the dynamic New Keynesian IS equation. Equation (52) shows that in case of $\sigma\eta > 1$, implying $\Gamma_y > 0$, the expected future changes in the l.o.p gap influences negatively the expected changes in the output gap. In case of Mongolia, we set these parameters value to $\sigma = 6$ and $\eta = 2$. Therefore, expected changes in the l.o.p gap may have positive effect on the expected changes in the output gap because $\sigma\eta > 1$ in case of Mongolia. This means that if exchange rate is expected to depreciate in the future, the depreciation through its effect on the l.o.p gap may lead to decrease the output gap in the future.

[22] For CPI inflation: in case of $\sigma = \eta = 1 \rightarrow k_{\psi}^{c} = \gamma\lambda_F > 0$ → Deviations from the LOP continue to affect CPI inflation (unlike producer inflation); For Domestic inflation: if $\sigma = \eta = 1 \rightarrow k_{\psi}^{c} = 0$

4.9. Breaking the Canonical representation

The equilibrium dynamics in recent open economy New Keynesian optimizing model are able to be determined in terms of the output gap and inflation which are similar to the closed and open economy model. This representation of the equilibrium dynamics is so-called the canonical New Keynesian model. Clarida et al. (1999) showed that, in case of a closed economy, the equilibrium dynamics in small-scale model of New Keynesian model can be represented as canonical model for inflation and output gap. Then Clarida et al. (2001) argued whether or not this canonical representation holds in case of the open economy. As they found, the canonical representation of open economy model is isophormic to its closed economy model.

However, these models were developed under the assumption of complete exchange rate pass-through. Therefore, Monacelli (2005) argued that the existence of the incomplete pass-through in the model may change the canonical representation of New Keynesian model. As the equilibrium dynamics of aggregate supply equation (48) and aggregate demand equation (52), Monacelli (2005) showed clearly that the introduction of incomplete pass-through breaks the isomorphism of canonical sticky-price model between the closed and open economies. Likewise introducing incomplete pass-through in the model, the l.o.p gap is independently included in both equations of aggregate supply and demand.

To understand the effect of incomplete pass-through working through the l.o.p gap, let examine the monetary policy channels to inflation in the present model. If the monetary authority changes the nominal interest rate, it firstly changes the output gap through real rate via equation (52) and then has an effect on inflation via both equations (48) and (50). **This is a typical aggregate demand channel** which is common to both closed and open economies. In open economy, changes in TOT and in the trade balance associated with the expenditure switching effect increases the effect of this aggregate demand channel. Thus, when the pass-through is complete, the interest rate changes in case of open economy impact only on the magnitude of the changes in output gap. It is clear that from the equation (46) under $\psi_{F,t} = 0$ (i.e., complete pass-through), the TOT affect proportionally to the output gap and in turn its effect on demand through output gap alters the slope of the aggregate demand equation (50). **However, when the pass-through is incomplete, implying $\psi_{F,t} \neq 0$ in equation (46), the l.o.p gap becomes**

the independent channel of aggregate demand to inflation via equation (52). This is one feature of the present model breaking the identical canonical representation between closed and economy models.

Moreover, aggregate supply effects are another channel to inflation. The changes in exchange rate affect the aggregate supply. Firstly, the nominal exchange rate has a direct effect on CPI inflation. However, this effect would be smaller when the pass-through is incomplete. Secondly, the changes in nominal exchange rate influence the TOT, the wage and the real marginal cost via equation (32). Thus, from the equation (48) it is clear that **the l.o.p gap will be an independent supply side channel to inflation** (both producer and CPI). This is second factor changes the canonical representation.

4.10. Monetary Policy in Mongolia

As in Batsukh et al. (2014), we assume that the BoM follows inflation targeting (IT) rule because BoM has adopted an IT regime since 2007. The Mongol bank (central bank of Mongolia) has a flexible exchange rate regime, but sometimes intervenes in foreign exchange market to stabilize the exchange rate due to high pressure on inflation. On the other hand, literature, for example Adolfson (2007), suggests that the policy makers might enhance the social welfare by incorporating the exchange rate into the simple policy rule. For that reason, we assume that Mongol bank implements flexible IT rule including the change in real exchange rate based on Batsukh et al. (2014).

$$i_t = \rho + b_\pi \pi_t + b_y \tilde{y}_t + b_q (q_t - q_{t-1}) \tag{53}$$

where i_t is the nominal interest rate. ρ denotes the steady state value of nominal interest rate. The parameters b_π, b_y, b_q are the policy maker's reaction coefficients. π_t is CPI inflation measure the central bank bases the instrument rule on. $\tilde{y}_t$ is the output gap, q_t is real exchange rate. In the steady state, π_t and q_t are assumed to be zero. This rule implies that BoM adjusts the nominal interest rate in response to changes in CPI inflation, the output gap, and real exchange rate. As including the real exchange rate, the central bank reacts quickly on the change in the real exchange rate and thereby possibly offset the exchange rate effects.

Nevertheless, for simplicity and interpreting the transmission of exchange rate channel to Mongolian economy, we use the simple Taylor rule proposed by Taylor (1993) in the benchmark model.

$$i_t = \rho + b_\pi \pi_t + b_y \tilde{y}_t \tag{54}$$

When the persistence parameter of the lagged nominal interest rate is equal to zero, the interest rate rule becomes the simple Taylor rule. This rule implies that the Mongol bank reacts on only the change in inflation and output gap. However, responding to the CPI inflation indicates the indirect exchange rate response.

We compare the performance of flexible IT rule with the one of simple Taylor rule under the incomplete pass-through for variability of inflation, the output gap, and the nominal exchange rate in the section 7.3.

4.11. Exogenous shocks

In order to analyze the impact of additional two shocks on Mongolian economy besides the domestic productivity shock, we introduce domestic demand and foreign demand exogenous shock into the model additionally.

Domestic Demand Shock

The exogenous domestic demand shock to output is added to dynamic IS equation (52).

$$\widetilde{y_t} = E_t\{\widetilde{y_{t+1}}\} - \frac{w_s}{\sigma}\left(i_t - E_t\{\pi_{H,t+1}\} - \overline{r_t}^n\right) + \Gamma_y E_t\{\Delta\psi_{F,t+1}\} + \varepsilon_{y,t} \tag{55}$$

The shock is assumed to follow AR(1) process as follows:

$$\varepsilon_{y,t} = \rho_y \varepsilon_{y,t-1} + \nu_{y,t}$$

where ρ_y is the persistence parameter of the shock. Disturbance $\nu_{y,t}$ is zero mean and i.i.d shock with variance σ_y^2.

Foreign Demand Shock

The foreign dynamic IS equation (as closed economy) with exogenous shock is defined:

$$\widetilde{y_t^*} = E_t\{\widetilde{y_{t+1}^*}\} - \frac{1}{\sigma}\left(i_t^* - E_t\{\pi_{H,t+1}\} - \overline{r_t^*}^n\right) + \varepsilon_{y^*,t} \tag{56}$$

The shock is assumed to follow AR(1) process as follows:

$$\varepsilon_{y^*,t} = \rho_{y^*} \varepsilon_{y^*,t-1} + \nu_{y^*,t}$$

where ρ_{y^*} is the persistence parameter of the foreign shock. Disturbance $\nu_{y^*,t}$ is zero mean and i.i.d shock with variance $\sigma_{y^*}^2$.

5 Calibration

In this section, we determine the values of the parameters in the present model. The parameters are chosen based on combination of calibration and calculated parameters using real data. We calibrate most of parameters based on Dutu (2012) and Batsukh et al. (2014). The summary of chosen parameters is shown in Table 1.

Table 1. Calibration of parameters

№	Definition	Parameters	Mongolia	Source
	Households' parameters			
1	Constant Relative Risk Aversion (CRRA)[23]	$\boldsymbol{\sigma}$	6	Havranek et al. (2013)
2	Discount factor	$\boldsymbol{\beta}$	0.99	Dutu (2012)
3	An openness index	$\boldsymbol{\gamma}$	0.55	Dutu (2012)
4	The inverse of elasticity of labor supply in CES utility function	$\boldsymbol{\varphi}$	3	Monacelli (2005)
5	The elasticity of substitution between domestic and foreign goods	$\boldsymbol{\eta}$	2	Dutu (2012)
6	Discount subject factor	$\boldsymbol{\rho}$	$-\log(\beta)$	
	Firm's parameters			
7	Calvo pricing for domestic producers	$\boldsymbol{\theta_H}$	0.84	Dutu (2012)
8	Calvo pricing for importing firms (degree of pass-through)	$\boldsymbol{\theta_F}$	0.65	Dutu (2012)
	Exogenous shocks parameters			
	Domestic productivity shock			
9	The persistence of labor productivity shock in home country	$\boldsymbol{\rho_z}$	0.88	ARIMA(1,0) estimation
10	The standard deviation of labor productivity shock in home country	$\boldsymbol{\sigma_z}$	0.0153	ARIMA(1,0) estimation
	Domestic demand shock			
11	The persistence of domestic demand shock in domestic country	$\boldsymbol{\rho_y}$	0.8	assumption
12	The standard deviation of domestic demand shock in domesctic country	$\boldsymbol{\sigma_y}$	0.078	assumption
	Foreign demand shock			
13	The persistence of foreign demand shock in foreign country	$\boldsymbol{\rho_{y^*}}$	0.8	assumption
14	The standard deviation of foreign shock in foreign country	$\boldsymbol{\sigma_{y^*}}$	0.078	asssumption
	Simple Taylor Rule (Domestic economy)			
15	Adjustment coefficient of CPI inflation	$\boldsymbol{b_\pi}$	2.4	Batsukh et al. (2014)

[23] This parameter (CRRA) is defined by inverse of constant elasticity of intertemporal substitution (EIS). $\sigma = 1/\theta$ and $\theta = -\frac{u'(c)}{cu"(c)}$ where utility fuction is $U\big(c(t)\big) = \frac{c(t)^{1-\sigma}}{1-\sigma}$

16	Adjustment coefficient of the output	b_y	1.6	Batsukh et al. (2014)
	Flexible IT (Domestic economy)			
17	Adjustment coefficient of CPI inflation	b_π	1.8	Batsukh et al. (2014)
18	Adjustment coefficient of the output gap	b_y	0.8	Batsukh et al. (2014)
19	Adjustment coefficient of real exchange rate change (in case of flexible IT rule)	b_q	0.75	Batsukh et al. (2014)
	Simple Taylor Rule (Foreign economy)			
20	Adjustment coefficient of CPI inflation	b_π^*	2	assumption
21	Adjustment coefficient of the output gap	b_y^*	0.8	assumption

Technology

The parameter of main interest for this thesis is θ_F which governs the degree of exchange rate pass-through in the present model with incomplete pass-through. This parameter is chosen as four different values to cover different rates of exchange rate pass-through in below analysis (next section). In case of Mongolia, this parameter is set to 0.65 based on the Bayesian estimation of Dutu (2012). The parameter θ_F is probability that price set at time t will hold a price at time $(t + k)$ for importing firms. As this parameter takes a higher value, the price becomes more rigid. Adolfson et al. (2007) estimated θ_F as 0.52 but θ_H as 0.89 for Europe. This shows that Mongolian domestic producers have more flexible price and may change the price frequently according to the relatively high inflation environment. However, the import price is more rigid in Mongolia compared with Europe.

In order to choose an openness index, γ, one can follow Dutu (2012) which is World bank working paper and set the value $\gamma = 0.55$. This parameter measures the share of imported goods in the consumption basket. In case of Mongolia, most of consumption is provided by imported goods due to the fact that the industrial sector is not well developed.

Preferences

Calibrating the constant relative risk aversion parameter, one follows Havranek et al., (2013) study and set the value $\sigma = 6$. It means that the elasticity of intertemporal substitution (EIS) is equal to 0.16. Havranek et al., (2013) found that mean EIS is 0.5. However, the value of EIS is larger for households of the countries with higher income per capita. For households in developing countries, EIS tends to be close to 0 because they are restricted by subsistence requirement. The lowest values belong to the intervals ($E < 0.1$ and $0.1 < EIS < 0.3$) as their classification. Therefore, we set the EIS as

0.16. This lower elasticity shows that the households in Mongolia are not willing to give up larger amount of current consumption to consume more in the future. In Mongolia, poverty rate was 30% of the population by the end of 2012 and the share of saving in household total income is on average very small.

In most of the literature, the discount factor, β, is fixed at 0.99. This indicates that households have high degree of patience with respect to their future consumption and it implies real interest rate of 4% in steady state[24].

Elasticity of labor supply in CES utility function, φ, is chosen to be 3, meaning that 1% increase of real wage leads to 3% increase of labor supply. It is set higher than 1 chosen by Dutu (2012) who calibrated it based on Adolfson et al., (2007). In case of Mongolia, households can be willingly to supply more their labor as the wage increases because income effect may be more than substitution effect due to the lower wage in developing country.

Elasticity of substitution between domestic and foreign goods, η, is set to 2. This shows how much the domestic households substitute domestic goods with imported goods. Therefore, the chosen value of parameter means the demand of import good increases by 2% when the price of domestic good increases by 1%. We follow Dutu (2012) study who explained that it is much lower than in Europe due to the developments of transport and supply. For example, Maršal (2011) determined this parameter as 5 in Czech Republic where the prices of imported goods are cheaper and thus the substitutability of domestic good can be higher in Europe due to the well-developed transport and supply network and arrangement cost is reasonably low.

Monetary Policy

For the parameters, $\boldsymbol{r_\pi, r_y, r_q}$, of monetary policy, we follow Batsukh et al., (2014) study. They calibrated these parameters based on Roger et al., (2009) study. Dutu (2012) concluded that Mongolian central bank behaves is similar to European central bank. In terms of values for parameters of Taylor rule, it appears that Mongolian central bank focuses more on stabilizing the inflation rather than output gap and the real exchange rate. Notice that Batsukh et al., (2014) set policy parameters higher than in Dutu (2012).

[24] Because in steady state, real interest rate is defined by $r = -\log(\beta) = \rho$

Shocks

The persistence of domestic productivity shock is set to 0.88 which is obtained by estimation of ARIMA (1,0,0) for labor productivity data from 2000Q1 to 2013Q4. The standard deviation of productivity shock is set to 0.0153 which is defined by computing standard deviation of residual from ARIMA (1,0,0) estimation. The parameters of other shocks are chosen based on assumption.

6 Analysis of incomplete pass-through

In this part, impulse response analyses to domestic and foreign shocks are carried out in order to investigate the effects of incomplete exchange rate pass-through on the economy and the central bank's reaction. First in case of Mongolia, the impact of the productivity shock is analyzed under the framework of the present model enriched with the incomplete pass-through. Second, we present sensitivity analysis and study how different degrees of pass-through influence the impact of foreign and domestic disturbances on the economy.

6.1. Impulse Response Analysis

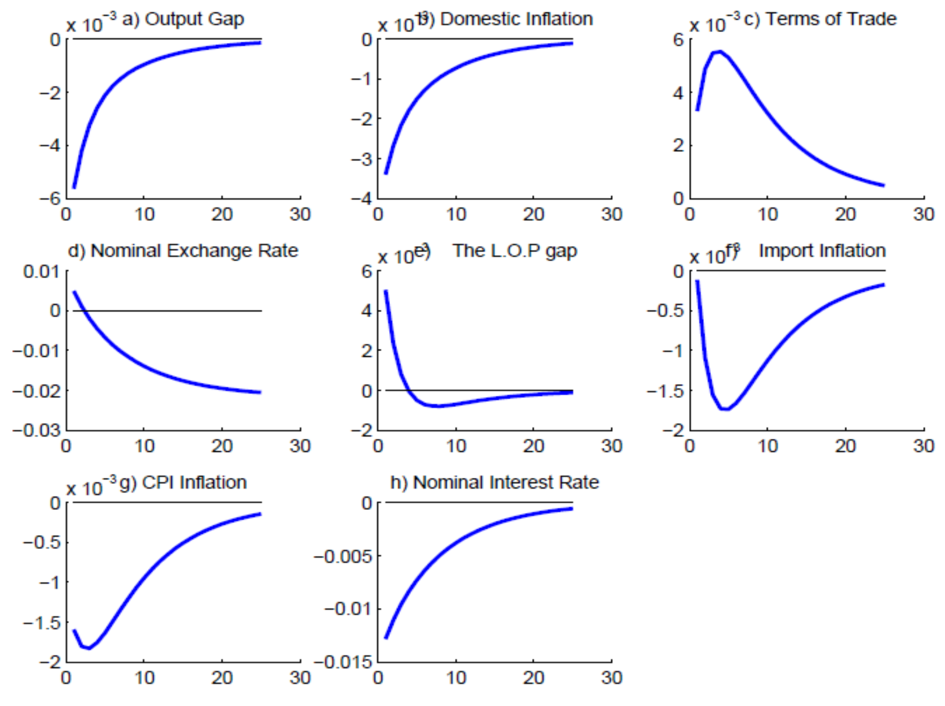
The transmission mechanism and the effect of domestic productivity positive shock are studied in Mongolia under incomplete pass-through. To investigate it one uses the impulse responses (IRFs) simulated by the benchmark model, in which BoM and the central bank of foreign country follow both simple Taylor rule.

Assuming that the labor productivity increases in Mongolia due to the innovation in education system. Figure 1 illustrates the impulse response of main macroeconomic variables to this shock under incomplete pass-through.

Initially, well-educated workers are able to produce more products at given time (resources) and thereby to expand the potential output. This leads to lower the output gap and to decrease the real marginal cost (see Figure 1a). The domestic inflation thus declines due to the fall of real marginal cost. Consequently, the domestic goods will be more competitive compared with foreign goods. Therefore, the improving TOT in Mongolia induces the demand of export to increase and makes the nominal exchange rate to depreciate (see Figure 1, c and d).

Furthermore, even though the exchange rate depreciation directly leads to rise the import price under the complete pass-through, in this case imported inflation drops

Figure 1. **IRFs to domestic productivity shock in Mongolia**



Source: Author's calculation

slightly (see the Figure 1f). This decline of import price is explained by sticky price in importing firms and the temporary exchange rate fluctuation. In order to expand their shares in the market, importing firms in Mongolia might not change their prices immediately. The reason is that the size of market is small and households' income is relatively low. Thus CPI inflation declines significantly due to the reductions of both domestic inflation and importing inflation (see Figure 1g).

At the same time, the BoM decreases the nominal interest rate to stabilize the output gap and CPI inflation under the simple Taylor. This policy reaction also induces the exchange rate depreciation. Under the standard (i.e, complete pass-through) exchange rate channel of monetary policy, exchange rate depreciation supports the monetary authority to achieve their goal by increasing the inflation via direct and indirect channel of exchange rate. However under the incomplete pass-through, **direct effect of exchange rate depreciation is smaller on increasing CPI inflation.** Thus the exchange rate depreciation generates the positive the the l.o.p gap. Simultaneously, the exchange rate depreciation influences to increase the inflation through improving the TOT. **However, its indirect effect is also smaller because of incomplete pass-through**. In other words, the positive l.o.p gap weakens the TOT and thereby it contributes less to increase CPI inflation. **Thus, when the pass-through is incomplete,**

the exchange rate channel becomes less important to increase the inflation (equation (14), Section 4.1). However, the exchange rate channel works as a shock absorber in case of domestic productivity shock.

As introducing incomplete exchange rate pass-through, the l.o.p gap works **as an additional independent channel to inflation through aggregate demand** (via equation (52), Section 4.8) and **aggregate supply** (via equations (32), (48), and (50), Section 4.8).

The drop of nominal interest rate leads to the expectation of persistent nominal exchange rate appreciation under the UIP condition and in turn causes the expected future l.o.p gap to decline (see Figure 1e). The expectation of nominal appreciation implies that the price of imported goods will be cheaper in the future, so that the households tend to decrease imported consumption in the present days, in contrast to increase consumption in the future (via risk sharing and Euler equation). **Consequently, the expected exchange rate appreciation contributes to decrease inflation further through the reduction of aggregate demand, but to increase the expected future aggregate demand** (equation (52), and (48)). The outcome of this l.o.p gap channel of aggregate demand side is opposed to the desirable outcome of monetary policy while the monetary authority aims to raise the inflation. **Thus the monetary authority meets the trade-off between the stabilization of the output gap and of the l.o.p gap (**see Figure 1a, e**)**.

For domestic firms using imported inputs in their production, their real marginal costs grow as exchange rate depreciates. **In this case, the positive l.o.p gap indicating a growth of marginal cost causes both domestic and CPI inflation to increase** (equation (32)). In Mongolia, this effect can be large because the domestic industry is not well developed and the most of domestic production inputs is imported from abroad. Though, the reduction of domestic inflation can be explained that the effect of productivity shock on domestic inflation is larger than the one of the l.o.p gap even though the positive l.o.p gap produces higher inflation (via equation (32)). **Therefore, the l.o.p channel of aggregate supply side strengthens the effectiveness of monetary policy reaction to productivity shock.**

In the long run, positive productivity shock results in an increase of domestic output level and of the price level. All variables approach their steady state except nominal exchange rate. Even though the shock eventually disappears, it makes the exchange rate to appreciate permanently (see Figure 1d). The reason is that the LOP of imported goods holds in the long run. The nominal exchange rate is adjusted to compensate the wedge between the import price (in domestic currency) and the foreign price (in foreign currency). Ultimately, the import price rises and the foreign price does not change under the assumption that Mongolia has a negligible impact on the rest of the world. As a consequence, the exchange rate remains appreciated permanently and new steady-state level of the exchange rate does not cause any further inflationary impulses.

In summary, as introducing incomplete pass-through in the model, the effect of monetary policy transmitted through exchange rate channel is expected to be smaller on inflation and output gap. In addition, two additional independent channels of the l.o.p gap arise related to the aggregate demand and supply effects. As the pass-through is incomplete, the policy makers face the trade-off between output gap and the l.o.p gap stabilization.

6.2. Comparison analysis of different degrees of pass-through

In this section, one analyzes how the impulse responses to such shocks as positive productivity shock, domestic demand shock, and foreign demand shock change depending on the degrees of exchange rate pass-through.

The results of previous section suggest that the **low pass-through may decrease** volatility of imported inflation, CPI inflation, TOT and domestic inflation compared to high pass-through. In contrast, it may cause the variability of output gap to **increase.** Therefore, we are interested in examining whether there is relationship between degree of pass-through and the volatilities of macro variables in Mongolian economy.

To investigate this relationship, IRFs are compared to different degrees of pass-through[25]. Four different degrees of pass-through are chosen based on Adolfson (2007):

[25] **Notice for terms:**
Pass-through decreases means higher degree of pass-through (θ_F take higher value). If we discuss about **degree of pass-through**, it is the **parameter value of $\boldsymbol{\theta}$.** So the term **"pass-through"** is different from degree of pass-through. If we discuss about **pass-through**, it is about **the magnitude of exchange rate pass-through effect** to imported inflation and other variables.

almost zero pass-through ($1-\theta_F = 0.01$[26]), case of Mongolia ($1-\theta_F = 0.35$), higher pass-through ($1-\theta_F = 0.55$), and almost full pass-through ($1-\theta_F = 0.99$[27]). **The decrease in degree of pass-through ($\boldsymbol{\theta_F}$) implies that the import price becomes more flexible and the magnitude of pass-through gets higher. Hence, the impact of any shocks may have higher effect on the economy.**

6.2.1. Productivity shock

As the nominal rigidity increases (smaller $(1-\theta_F)$), the exchange rate pass-through into import price decreases. From Figure 2d and f, we can observe that imported inflation does not change under almost zero pass-through ($1-\theta_F = 0.01$ as red line) when the exchange rate depreciates. In contrast, the imported inflation increases and fluctuates at the max level under almost full pass-through. **Thus, it confirms that as the pass-through gets lower, the price of imported goods tends to increase slightly in comparison to higher pass-through.**

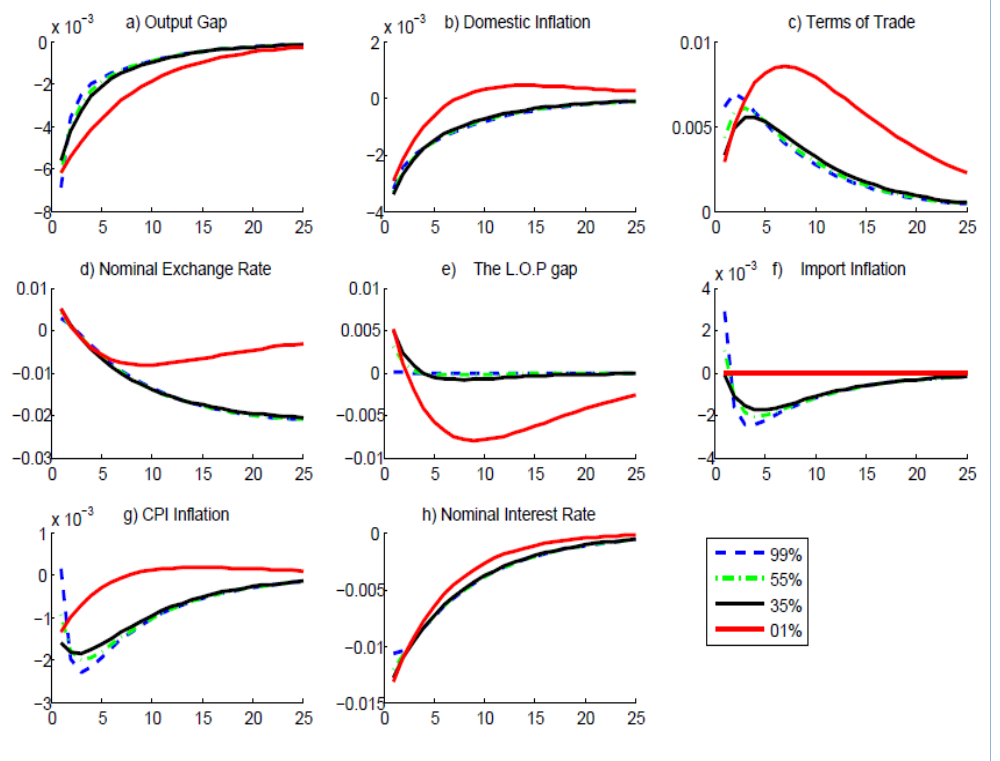
For the CPI inflation and TOT, this relationship also holds. Even though TOT with the almost zero pass-through initially increases at the lowest level, after a few periods it dramatically increases larger than the one with almost full pass-through. The reason is that the exchange rate depreciation affects TOT strongly because the import price does not change under almost zero pass-through. More importantly, under the almost full pass-through CPI inflation is positive while under the lower pass-through (e.g.$\theta = 0.65$) it is negative. **Thus, we can conclude that the exchange rate channel under the almost full pass-through contributes considerably to CPI inflation whether it would be positive or negative.** In other words**, under the low pass-through exchange rate channel is less important** for monetary policy implementation even though it acts as a shock absorber.

Another important point should be noticed that **the l.o.p channel of aggregate supply side has more positive effect on domestic inflation as the pass-through declines.** As seen in Figure 2b (red line), the higher l.o.p gap (lower pass-through) causes more

[26] **For convention to easily understand:** the value (1-θ_F) is used in the figure. So henceforth, in the figure, 0.01 means lower pass-through, 0.99 means higher pass-through. But the value does not indicate the exact value of pass-through.

[27] In this case, the model with incomplete pass-through will transform approximately to the model with complete pass-through. The parameter θ_F represents the degree of pass-through. $\theta_F = 0$ means that exchange rate pass-through is complete, optimal price of import (equation (25), Section 3.3) reduces to a LOP.

Figure 2. **Comparison of IRFs to domestic productivity shock under different pass-through**



Source: The author's calculation

increase of the real marginal cost and in turn it contributes to increase the domestic price level more (red line is higher than other lines).

Another important point should be noticed that **the l.o.p channel of aggregate supply side has more positive effect on domestic inflation as the pass-through declines.** As seen in Figure 2b (red line), the higher l.o.p gap (lower pass-through) causes more increase of the real marginal cost and in turn it contributes to increase the domestic price level more (red line is higher than other lines).

Thus, under the low pass-through, the l.o.p channel of aggregate supply side is more important for monetary authority because it works in line with the objective of monetary policy. It may work as a shock absorber. **In other words, as the pass-through declines, it can lead to less volatile of the inflation.**

For the l.o.p channel of aggregate demand side, the l.o.p gap (the expected appreciation of exchange rate) is expected to decrease more according to the changes of UIP condition under the almost zero pass-through.

As a result, the decrease of current aggregate demand leads to more decrease of the output gap. We can clearly see this in red line (Figure 2a) which is lower than other lines. In other words, **as the pass-through decreases, the l.o.p channel through expected exchange rate has more negative effect on the output gap and in turn the inflation further decreases.** This result contradicts with the objective of monetary policy to stabilize the output gap and inflation. **Under the low pass-through, the l.o.p gap acts as an amplifier of the shock effect**. However, the l.o.p channel of aggregate supply may have stronger impact than the l.o.p gap channel of aggregate demand side because the inflation is more stable under the low pass-through. Above results for domestic productivity shock are summarized in Table 2.

Table 2. The impact of productivity shock (summarized results)

Cases	**Pass-through**	**Degree of pass-through**	**The Exchange rate channel**	**The l.o.p gap demand channel**	**The l.o.p gap supply channel**	$Var(\pi_t)$	$Var(\tilde{y})$
			The impact of channels				
Lowest pass-through	1%	99%	lowest impact	largest impact	largest impact	lower	higher
Mongolia	35%	65%	larger than 1%	lower than 1%	lower than 1%	(+) ↓	(+) ↑
Higher pass-through	55%	45%	larger than 35%	lower than 35%	lower than 35%		
Highest pass-through	99%	1%	largest	lowest	lowest	higher	lower
			absorber	amplifier	absorber		

Source: Author's conclusion

To summarize Figure 2, we may conclude that **the lower pass-through leads to decrease the impact of productivity shock on the domestic inflation, import inflation, CPI inflation and TOT.** However, **the output gap tends to fluctuate at highest level under the lowest pass-through** due to the larger the l.o.p gap. Therefore, under the lowest pass-through, **the policy makers tend to face more inflation and output gap variability trade-off.**

6.2.2. Domestic Demand Shock

According to the productivity shock results, the following questions arise: Does the lower pass-through lead to lower impact of any shocks such as foreign and domestic shocks? How does the inflation and output gap variability depend on these shocks?

In the literature, Adolfson (2001) found that using unconditional variance calculation low pass-through implies less variability of inflation, output and other variables. In case of Mongolia, unconditional variances also show that the unconditional variances of both inflation and output gap decreases as the pass-through declines (see Table 3).

Table 3. Unconditional variances

Pass-through	θ_F	$Var\ (\pi_t)$	$Var(\tilde{y})$
0.01	0.99	1.11%	0.62%
0.35	0.65	5.63%	4.27%
0.55	0.45	6.61%	5.25%
0.99	0.01	7.49%	6.18%

Source: Author's calculation

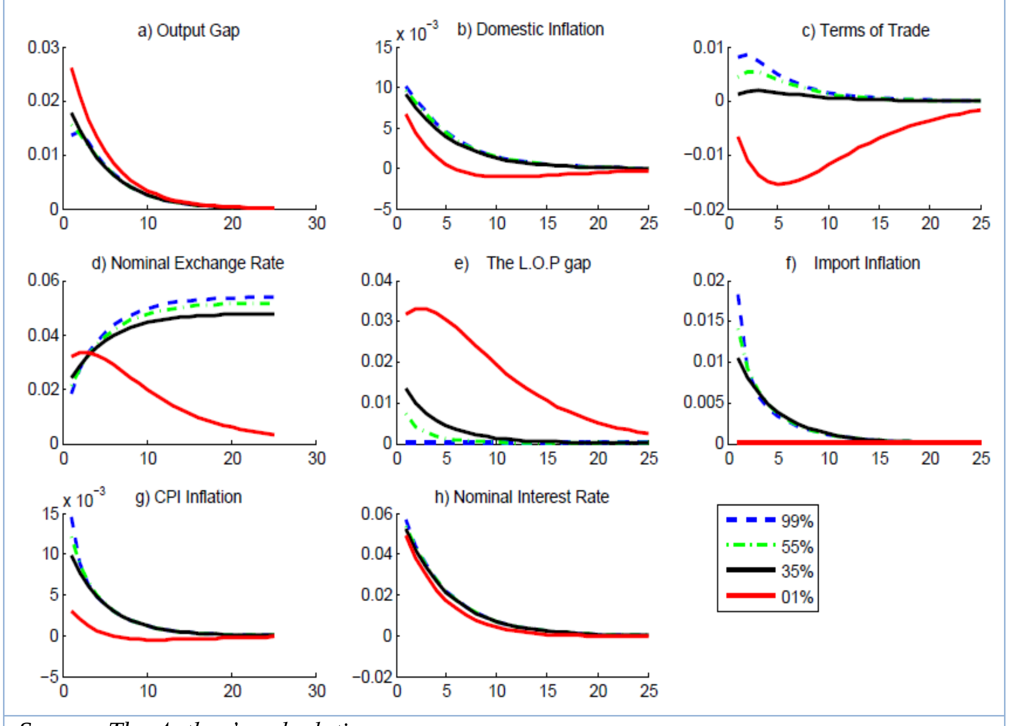
However, this result may change depending on the type of shocks. In case of productivity shock, the variability of inflation decreases while the variability of output increases as the pass-through decreases. Thus one analyzes the impacts of foreign demand shock and domestic demand shock on Mongolian economy.

Last five years, the FDI is being intensely increased in mining sector of Mongolia. The rise of FDI caused dramatic the increase of aggregate demand and fast GDP growth. According to the large capital inflow in economy, analysts were expected the exchange rate (MNT/USD) to appreciate but during this period exchange rate did not appreciate and even it depreciated by considerable amount in last years. This exchange rate appreciation currently has high pressure on CPI inflation in Mongolian economy. Therefore, it is important to analyze the impact of aggregate demand shock on Mongolian economy.

From Figure 3, as the domestic demand grows suddenly, it directly drives to increase the domestic inflation and the CPI inflation. In response to the demand shock, the central bank escalates the nominal interest rate making the exchange rate appreciation.

However, exchange rate channel works in another way as expected by monetary authority. In the fact, the nominal exchange rate depreciates (see Figure 3d). In Mongolia, the rise of aggregate demand tends to encourage the imports because there

Figure 3. **Comparison of IRFs to domestic demand shock under different pass-through**



Source: The Author's calculation

is no enough potential for the industrial sector to provide immediately increasing demand by domestic production. Thus, there can be two reasons why the exchange rate depreciates. First one is that imported consumption grows due to the higher price of domestic good. It can lead to increase the import price and to depreciate the exchange rate. Second reason is that the demand of imported inputs in production may increase dramatically due to the growth of the output.

Thus, it can also have an effect on exchange rate to depreciate. In the future, the exchange rate is expected to depreciate further because the BoM increases the nominal interest rate. In the case of demand shock, **the exchange rate channel acts as an amplifier of demand shock** because the exchange rate depreciation induces further increase of import price and CPI inflation. However**, the lower pass-through causes the effect of exchange rate channel on inflation to reduce** (see Figure 3c, f, and g). The l.o.p gap channel of aggregate supply side produces higher domestic inflation. Therefore, **this channel serves as an amplifier** when the BoM plans to reduce the inflation. The l.o.p gap of aggregate demand channel also magnifies the impact of the productivity shock. Therefore, the expected depreciation of exchange rate leads to increase the current output gap and to decrease the expected future output gap as the pass-through lowers. In this case, higher pass-through tends to have less variability of

Table 4. The impact of domestic demand shock (summarized results)

Cases	**Pass-through**	**Degree of pass-through**	**The Exchange rate channel**	**The l.o.p gap demand channel**	**The l.o.p gap supply channel**	$Var\ (\pi_t)$	$Var(\tilde{y})$
			The impact of channels				
Lowest pass-through	1%	99%	lowest impact	largest impact	largest impact	lower	higher
Mongolia	35%	65%	larger than 1%	lower than 1%	lower than 1%		
Higher pass-through	55%	45%	larger than 35%	lower than 35%	lower than 35%	(+) ↓	(+) ↑
Highest pass-through	99%	1%	largest	lowest	lowest	higher	lower
			amplifier	amplifier	amplifier		

Source: Author's calculation

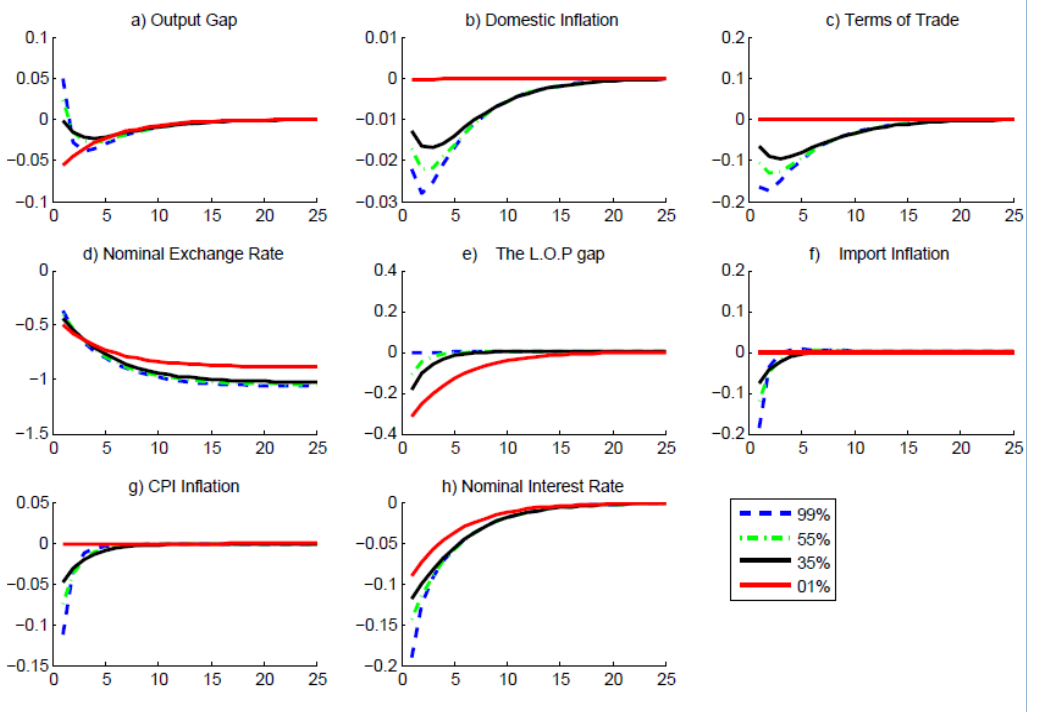
output gap but more variability of inflation. Summarized results are presented in Table 4. However, as the pass-through decreases, the impact of the demand shock on domestic inflation, imported inflation, and CPI inflation tends to decline.

While the low pass-through causes the output gap to increase. **These relations between pass-through and the impact of shocks are the identical for domestic productivity and demand shocks.** Moreover, the nominal exchange rate deviates from the trend in the long run except the case of the lowest pass-through.

6.2.3. Foreign Demand Shock

China can characterize as a rest of the world assumed in the model for Mongolia. Undoubtedly, China is the largest country in the world as size of the population and economic progress. It is also neighbour and main trade partner country of Mongolia. The shocks originated in Chinese economy definitely affect the Mongolian economy to some extent as Mongolian economy is mainly dependent on Chinese economy in terms of an export and import. Recently, Chinese government approved the upcoming five year plan which is focused on encouraging the domestic demand. Therefore, it is important to analyze how demand expansion occurred in China affects Mongolian economy. The positive demand shock drives to increase the output and to decrease the price of the goods in China. These effects transmit to Mongolian economy through two channels: demand of export and the TOT. The output expansion in China starts to rising

Figure 4. **Comparison of IRFs to foreign demand shock under different pass-through**



Source: The author's calculation

the demand of commodity exports of Mongolia, which in turn expands the output level in Mongolia via the aggregate demand (see Figure 4a).

Consequently, the output growth may create the domestic inflation. Simultaneously, foreign positive demand shock makes Mongolian economy less competitive in the world market via TOT. As the price level declines in China, Mongolian households and producers prefer to buy cheaper goods from China. It thus causes the demand of domestically produced goods to decrease and the demand of imported goods (and inputs) to increase. Ultimately, domestic and CPI price fall and the nominal exchange rate appreciates. The BoM responds by decreasing the nominal interest rate to the foreign shock, which induces the exchange rate depreciation. However, consequently the exchange rate appreciates because the magnitude of appreciation is larger than one of depreciation induced by monetary authority. When the foreign demand shock hits the economy, **the decreasing pass-through leads to less the volatilities of variables**. Thus, **exchange rate channel absorbs some of effects of the foreign shock**. In case of the lowest pass-through, the volatility of output gap also tends to increase. Moreover, one interesting fact is that the foreign demand shock may more likely affect the Mongolian economy likewise the productivity shock.

As a result of section 6.2, generally **the volatilities of macroeconomic variables tends to decline as the pass-through decreases.** However, the variability of output gap tends to increase for all shocks when the pass-through is low. Moreover, **the impact of domestic demand shock tends to be amplified by the exchange rate channel and its amplification effect is larger under the high pass-through.** In contrast to this result, exchange rate works as a shock absorber of domestic productivity shock and foreign demand shock and its absorbing potential tends to increase under the high pass-through. **As the presence of incomplete pass-through, the l.o.p gap channels arises in association with aggregate demand and supply side effects.** From the comparison analysis, these channels may have considerable effects on domestic inflation and output gap. **The l.o.p gap aggregate channel seems to have more effect on output gap to fluctuate** while the exchange rate channel is mainly stronger than the l.o.p gap supply side channel. Thus it implies that the expectation of exchange rate and the l.o.p gap have considerable effect on inflation and output gap trade-off.

7 Monetary Policy with incomplete pass-through

7.1. Policy reactions to shocks

We analyze how policy reactions depend on the degree of pass-through to aforementioned shocks under the simple Taylor rule.

Under the domestic productivity shock, the output gap, both domestic and CPI inflation decrease. To counter this shock the interest rate is reduced, implying a concurrent depreciation of exchange rate (Figure 2). Aftermath, it induces higher inflation of imported goods as the pass-through becomes larger. Therefore, this offsets the productivity disturbance more, which **needs less adjustment of interest rate under almost complete pass-through.** In this case, the exchange rate channel with larger pass-through acts more as a shock absorber. Therefore, the policy reaction (in terms of change in nominal interest rate) on productivity shock is decreased as the pass-through increases (see **Table 5**, (a) column).

Table 5. Contemporaneous reaction of monetary policy to shocks

the change in nominal interest rate (%)

Pass-through	θ_F	Productivity shock $\varepsilon_{z,t}$ *(a)*	Domestic Demand shock $v_{y,t}$ *(b)*	Foreign demand shock $v^*_{y,t}$ *(c)*
0.01	0.99	-1.31	4.95	-9.00
0.35	0.65	-1.28	5.24	-11.80
0.55	0.45	-1.21	5.41	-14.27
0.99	0.01	-1.07	5.69	-18.93
The role of exchange rate channel for MP		**absorber**	**amplifier**	**absorber**

In contrast to the productivity shock, the response of the nominal interest rate on the domestic demand and foreign demand shock is increasing in the pass-through (as an absolute value). For the domestic demand disturbance, higher pass-through contributes to having a higher inflation because the exchange rate channel amplifies the impact of the domestic demand shock on the economy. In order to stabilize the inflation, **the central bank thus needs to increase the nominal interest rate more when the pass-through is high** (see **Table 5**, (b) column)**.** This higher interest rate adjustment probably lead to increase the cost of stabilizing the inflation in terms of the output gap volatility. As previously discussed, the foreign demand shock has a greater impact on Mongolian economy as the pass-through increases. In other words, low exchange rate pass-through limits more the magnitude of the shock transmitted through changes in exchange rate. Thus, the central bank **responds by larger amount of changes in nominal interest rate to the foreign demand disturbance** as the pass-through gets higher (see Table 6, (c) column).

Taken together, all results imply that the monetary policy reactions to shocks depend on considerably **what shock** hits the economy, in turn **how the role of exchange rate** changes in case of different shocks, and eventually **whether the pass-through** is complete or incomplete (high or low).

The BoM **may needs to adjust more the nominal interest rate under the productivity shock** in case of incomplete pass-through. Whereas BoM **is required less adjustment of the interest rate for the domestic and foreign demand shock.** This implication is supported by the finding of Dutu (2012) who concluded BoM does not respond sufficiently as inflation levels require. He explained it may relate to unanticipated increase in the interest rate which has quite persistent and adverse effects on the economy.

7.2. Policy trade-off

In this section, we analyze the how the policy trade-off depends on the degree of pass-through for different shocks. Literature evidences that the policy makers are compelled to trade-off output variability for reducing the inflation variability in the open economy. Moreover, the trade-off between inflation and output gap variability varies depending on type of shocks.

As the pass-through increases, the volatility of both inflation and output gap tends to increase for all shocks (see Table 6 and Figure 5). Among these three shocks, the foreign demand shock creates the largest volatility in both inflation and output gap regardless of the degree of pass-through in Mongolian economy.

Though, the output gap variability is larger in case of the lowest pass-through for all shocks. As the pass-through decreases, the volatility of the output gap tends to increase for domestic demand shock (see Table 6).

Table 6. The volatility of inflation, output gap, and nominal exchange rate

the standard deviation (%)

Pass-through	θ_F	Productivity shock			Domestic demand shock			Foreign demand shock		
		inflation	output gap	exchange rate	inflation	output gap	exchange rate	inflation	output gap	exchange rate
0.01	0.99	0.04	0.17	0.31	0.09	0.72	1.09	0.01	1.52	10.68
0.35	0.65	0.06	0.14	0.73	0.27	0.49	0.66	1.15	0.77	16.45
0.55	0.45	0.06	0.14	0.74	0.31	0.46	0.83	1.64	1.12	17.52
0.99	0.01	0.07	0.15	0.74	0.34	0.45	0.93	2.29	1.70	18.34

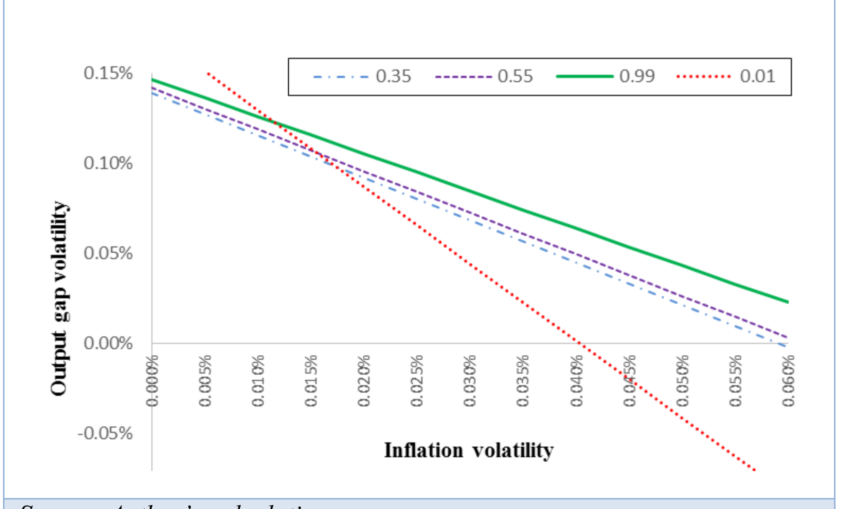
Source: Author's calculation

Though, the output gap variability is larger in case of the lowest pass-through for all shocks. As the pass-through decreases, the volatility of the output gap tends to increase for domestic demand shock (see Table 6). This is line with the result of Flamini (2007). **Possible reason is that the l.o.p gap may works like cost push and demand shocks, which in turn induces to increase the real marginal cost and the expected inflation under the sufficiently low pass-through.** In other words, as the pass-through decreases, larger l.o.p gap contributes to increasing inflation. However, this effect weakens the effectiveness of monetary policy action for maintaining inflation. Therefore, the central bank needs to increase the nominal interest rate further to neutralize the effect of l.o.p gap channel. This action may causes to have higher volatility of the output gap. Therefore, **even though having the low pass-through is more desirable, stabilizing inflation is more costly in terms of lost output when the pass-through is sufficiently low.** Eventually, policymakers face a new task to stabilize the l.o.p gap because they cannot simultaneously stabilize the output gap and the l.o.p gap. Monacelli (2005), Corsetti and Pesenti (2005), and Devereux and Engel (2002) concluded that in order to affect future inflation expectations, the central bank must execute optimally the l.o.p gap against the output gap. Therefore, manipulating the expectation of future exchange rate behavior and indirectly of the l.o.p is important.

Furthermore, another point is that as pass-through decreases, the volatility of nominal exchange rate generally tends to decline for all three shocks (see Table 7). However, the low pass-through leads to having the highest volatility of the nominal exchange rate for domestic demand shock. This exchange rate behavior is not consistent with Adolfson (2001) who showed the lower pass-through causes higher exchange rate volatility.

Figure 5. **Inflation-Output gap variability trade-off for domestic productivity shock**

the standard deviation (%)



Source: Author's calculation

As the present model is augmented by incomplete pass-through working through the l.o.p gap, Monacelli (2005) presents explicitly the role of the l.o.p gap in volatility of inflation and the output gap. **Thus, our results in case of Mongolia warn that the low pass-through may influence higher volatility of the output gap, nominal exchange rate, and further real exchange rate.**

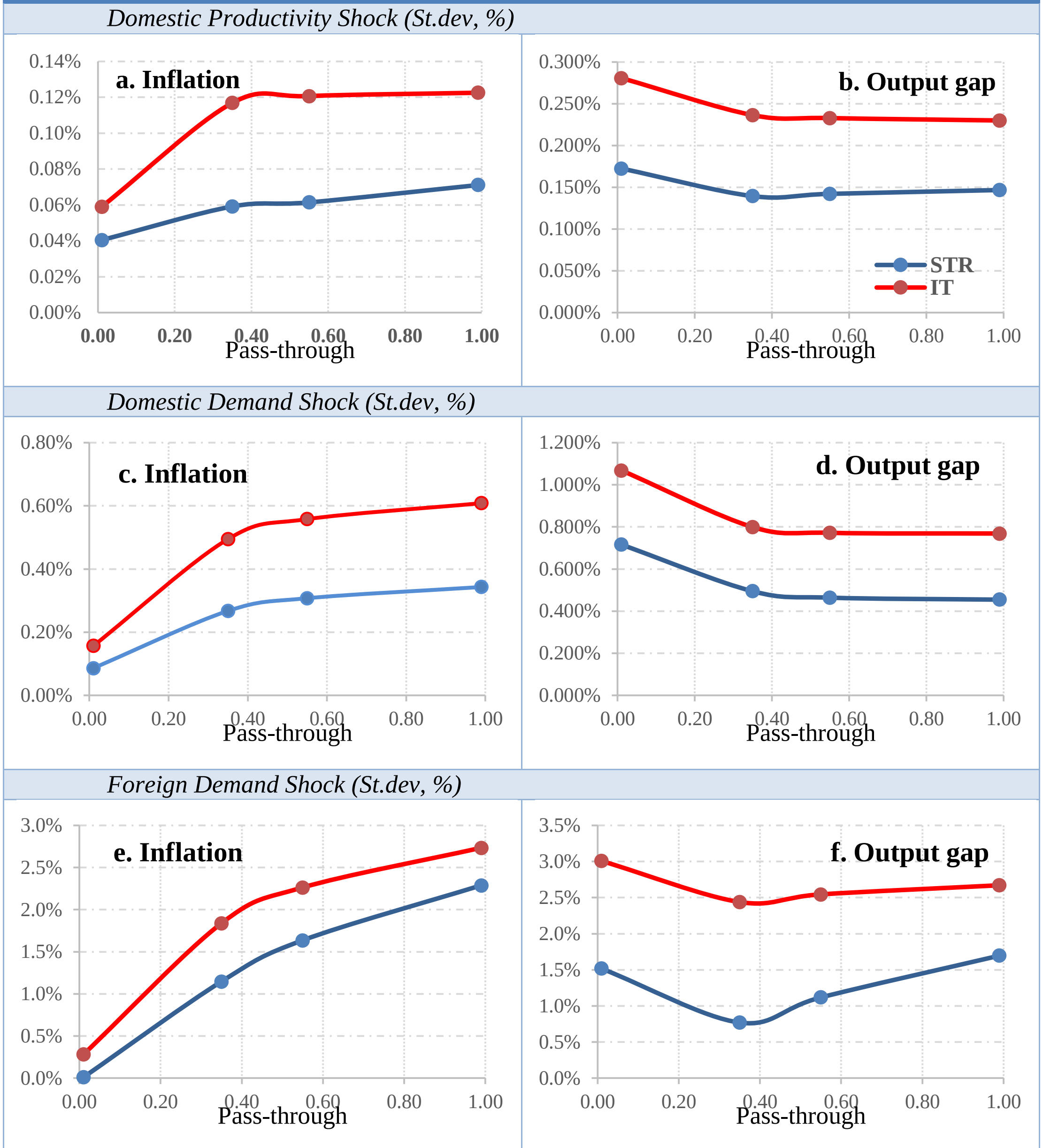
7.3. Alternative policy rule for different degrees of pass-through

In this section, we compare the performance of flexible IT rule as alternative policy regime with simple Taylor rule for different shocks and degrees of pass-through. The focus is to examine how above results change depending on policy regime.

The results for simple Taylor rule in the previous section are in line with flexible IT rule. However, under the flexible IT rule volatilities of inflation, the output gap, and nominal exchange rate are much higher than the ones under Taylor rule, irrespective of degrees of pass-through (see Figure 6 and Figure 7, in Appendix II).

Moreover, the volatility of inflation increases as the pass-through rises, regardless of the type of shocks and of monetary policy regimes. In addition, under the IT rule for both productivity and domestic demand shocks, **the variability of output gap tends to increase as the pass-through decreases.**

Figure 6. **Comparison of STR and IT rules under different pass-through**



Source: Author's calculation

For foreign demand shock, the volatility of output gap tends to increase as the pass-through rises (see Figure 6b and d, red lines). However, in the case of lowest pass-through, the volatility of output gap is still higher than other cases of larger pass-through (see Figure 6 f, red line).

Therefore, **simple Taylor rule has better performance than flexible IT rule**. Under IT rule, the nominal interest rate is required to adjust larger because the central bank must respond to the fluctuations of both inflation and real exchange rate. Consequently, the larger change in nominal interest rate can cause to fluctuate the exchange rate, the l.o.p gap, and thereby the output gap greater under the incomplete pass-through. Therefore, as introducing incomplete pass-through, the performances of monetary policy rules change compared to one with complete pass-through. This result is consistent with the result of Adolfson (2007) to some extent. He found that implementing the policy through exchange rate augmented policy rule in open economy with incomplete pass-through does not enhance social welfare compared to using an optimized Taylor rule, irrespective of degree of pass-through.

8 Conclusion

This study analyzes the impact of incomplete exchange rate pass-through on Mongolian economy and its implication on monetary policy under the different shocks. The analysis is concentrated on the importance of the degree of pass-through and pursued in a small open economy New Keynesian DSGE model with incomplete pass-through proposed by Monacelli (2005).

We accomplish the analysis by comparing impulse responses for four different degrees of pass-through under the three shocks such as domestic productivity shock, domestic demand shock, and foreign demand shock. Moreover, contemporaneous policy reaction to these shocks, the trade-off between inflation-output gap variability, and flexible IT rule as alternative policy rule are examined and compared under the different pass-through.

Based on the results, we make three main conclusions. **First,** the exchange rate pass-through into import price is incomplete in Mongolian economy and the degree of pass-through has considerable impact on the economic fluctuations in terms of inflation and output gap variability. Stabilizing inflation becomes more costly in terms of output when the pass-through is sufficiently low. Therefore, to distinguish complete or incomplete pass-through is a significant effect on the implementing monetary policy. **Second,** the monetary policy reactions to shocks depend on considerably what shock hits the economy, in turn how the role of exchange rate changes in case of different shocks, and eventually whether the pass-through is complete or incomplete (high or low). Particularly, the BoM may needs to adjust the nominal interest rate more under the productivity shock where the exchange rate act as a shock absorber and the pass-through is incomplete. **Third,** the incomplete pass-through changes the performance of the monetary policy rule. The monetary authority should consider on stabilizing the l.o.p gap.

Therefore, considering incomplete pass-through in the conduct of monetary policy is significant to improve the effectiveness of the monetary policy for the central Bank of Mongolia.

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Appendix I: Model Solution

APPENDIX 1.1: DERIVATION OF EQUATION (5)

i. Domestic good demand

$$min \rightarrow \int_0^1 P_{H,t}(i) C_{H,t}(i) di$$

$$s.t.\ C_{H,t} \equiv \left(\int_0^1 C_{H,t}(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}}$$

$$L \equiv \int_0^1 P_{H,t}(i) C_{H,t}(i) di - \lambda_t^H \left[\left(\int_0^1 C_{H,t}(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}} - C_{H,t} \right]$$

FOC:

$$\frac{\partial L}{\partial C_{H,t}(i)} = 0 \rightarrow\ P_{H,t}(i) - \lambda_t^H \cdot \frac{\varepsilon}{\varepsilon-1} \cdot \left(\int_0^1 C_{H,t}(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}-1} \cdot \frac{\varepsilon-1}{\varepsilon} \cdot C_{H,t}(i)^{-\frac{1}{\varepsilon}} = 0$$

After rearranging FOC, we can define $\lambda_t^H = P_{H,t}$, and then plug it again into the result of FOC

$$P_{H,t}(i) = P_{H,t} \cdot C_{H,t}^{\frac{1}{\varepsilon}} \cdot C_{H,t}(i)^{-\frac{1}{\varepsilon}}$$

from this equation, we can find demand function for domestic i-th good as follows:

$$C_{H,t}(i) = \left[\frac{P_{H,t}(i)}{P_{H,t}} \right]^{-\varepsilon} C_{H,t} \qquad \text{(A1)}$$

Derivation of demand function for foreign good i is the same as above derivation.

APPENDIX 1.2: DERIVATION OF EQUATION (7)

ii. Optimal allocation of expenditures between domestic and foreign goods

min $\rightarrow P_{H,t} C_{H,t} + P_{F,t} C_{F,t}$

s.t: $C_t = \left[(1-\gamma)^{\frac{1}{\eta}} \left(C_{H,t} \right)^{\frac{\eta-1}{\eta}} + \gamma^{\frac{1}{\eta}} \left(C_{F,t}^{\frac{\eta-1}{\eta}} \right) \right]^{\frac{\eta}{\eta-1}}$

$$L \equiv P_{H,t} C_{H,t} + P_{F,t} C_{F,t} - \lambda_t \left\{ \left[(1-\alpha)^{\frac{1}{\eta}} \left(C_{H,t} \right)^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{\eta}} \left(C_{F,t}^{\frac{\eta-1}{\eta}} \right) \right]^{\frac{\eta}{\eta-1}} - C_t \right\}$$

FOC:

$$\begin{cases} \dfrac{\partial L}{\partial C_{H,t}} = 0 \rightarrow P_{H,t} = \lambda_t \left\{ \dfrac{\eta}{\eta-1} \left[(1-\alpha)^{\frac{1}{\eta}} \left(C_{H,t} \right)^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{\eta}} \left(C_{F,t}^{\frac{\eta-1}{\eta}} \right) \right]^{\frac{1}{\eta-1}} (1-\alpha)^{\frac{1}{\eta}} \dfrac{\eta-1}{\eta} C_{H,t}^{-\frac{1}{\eta}} \right\} \\ \dfrac{\partial L}{\partial C_{F,t}} = 0 \rightarrow P_{F,t} = \lambda_t \left\{ \dfrac{\eta}{\eta-1} \left[(1-\alpha)^{\frac{1}{\eta}} \left(C_{H,t} \right)^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{\eta}} \left(C_{F,t}^{\frac{\eta-1}{\eta}} \right) \right]^{\frac{1}{\eta-1}} \alpha^{\frac{1}{\eta}} \dfrac{\eta-1}{\eta} C_{F,t}^{-\frac{1}{\eta}} \right\} \end{cases}$$

After rearranging FOC, we can define $P_t = \lambda_t$ and then plug it again into the result of FOC:

$$P_{H,t} = P_t C_t^{\frac{1}{\eta}} (1-\gamma)^{\frac{1}{\eta}} \left(C_{H,t}\right)^{-\frac{1}{\eta}}$$

from this equation, we can find demand function for domestic good

$$C_{H,t} = (1-\gamma)\left[\frac{P_{H,t}}{P_t}\right]^{-\eta} C_t \tag{A2}$$

Demand function for foreign good using $P_{F,t} = P_t C_t^{\frac{1}{\eta}} \gamma^{\frac{1}{\eta}} \left(C_{F,t}\right)^{-\frac{1}{\eta}}$ is defined

$$C_{F,t} = \gamma\left[\frac{P_{F,t}}{P_t}\right]^{-\eta} C_t \tag{A3}$$

APPENDIX 1.3: DERIVATION OF EQUATION (9) and (10)

iii. Household problem

Households' lifetime utility maximization

$max \rightarrow E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\varphi}}{1+\varphi}\right]$

s.t: $P_t C_t + E_t\{Q_{t,t+1} D_{t+1}\} \leq D_t + W_t N_t + T_t$

$$L \equiv E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\varphi}}{1+\varphi}\right] + \lambda_t\left[D_t + W_t N_t + T_t - P_t C_t - E_t\{Q_{t,t+1} D_{t+1}\}\right]$$

FOC:

$$\begin{cases} \frac{\partial L}{\partial C_t} = 0 \rightarrow E_t \beta^t [C_t^{-\sigma} - \lambda_t P_t] = 0 \rightarrow C_t^{-\sigma} = \lambda_t P_t \rightarrow \lambda_t = \frac{C_t^{-\sigma}}{P_t} & i) \\ \frac{\partial L}{\partial N_t} = 0 \rightarrow E_t \beta^t [-N_t^{\varphi} + \lambda_t W_t] = 0 \rightarrow \lambda_t W_t = N_t^{\varphi} \rightarrow \lambda_t = \frac{N_t^{\varphi}}{W_t} & ii) \\ \frac{\partial L}{\partial D_{t+1}} = 0 \rightarrow E_t \beta^t [\lambda_t(-E_t\{Q_{t,t+1}\}] + E_t \beta^{t+1}\{\lambda_{t+1}\} = 0 \rightarrow E_t\{Q_{t,t+1}\} = \beta E_t\left[\frac{\lambda_{t+1}}{\lambda_t}\right] & iii) \end{cases}$$

From equation i) and ii), one can obtain labor supply as follows:

$$\frac{W_t}{P_t} = C_t^{\sigma} N_t^{\varphi} \tag{A4}$$

From equation i) and iii), one can obtain Euler equation (Intertemporal optimal condition) as follows:

$$E_t\{Q_{t,t+1}\} = \beta E_t\left\{\left[\frac{C_{t+1}}{C_t}\right]^{-\sigma}\left[\frac{P_{t+1}}{P_t}\right]^{-1}\right\} \tag{A5}$$

APPENDIX 1.4: DERIVATION OF EQUATION (13)

i. Log-linearization of CPI around a steady state

$$P_t = \left[(1-\gamma) P_{H,t}^{1-\eta} + \gamma P_{F,t}^{1-\eta}\right]^{\frac{1}{1-\eta}}$$

We can rewrite CPI equation as the following form

$$\underbrace{\exp(\log P_t)}_{LHS} = \underbrace{\exp\left\{\frac{1}{1-\eta}\log\left[(1-\gamma)P_{H,t}^{1-\eta} + \gamma P_{F,t}^{1-\eta}\right]\right\}}_{RHS}$$

In the steady state, $P_t = P_{H,t} = P_{F,t} = P$ holds and CPI index is defined in log form

$$e^p = e^{\frac{1}{1-\eta}\left[(1-\gamma)p^{1-\eta}+\gamma p^{1-\eta}\right]} = e^{s.s}$$

After log-linearizing LHS and RHS separately, then we equalize these two sides.

$$e^{s.s}\big(1+(p_t-p)\big) = e^{s.s}\left[1+(1-\alpha)\big(p_{H,t}-p\big)+\alpha\big(p_{F,t}-p\big)\right]$$

Log-linearized form of CPI equation is as follows

$$p_t = (1-\gamma)p_{H,t} + \gamma p_{F,t} \qquad \text{(A6)}$$

APPENDIX 1.5: DERIVATION OF EQUATION (21)

$$\underbrace{max}_{P_{H,t}^{new}} \rightarrow \sum_{k=0}^{\infty}\theta^k E_t\left\{Q_{t,t+k}\left[Y_{t+k|t}(i)\left(P_{H,t}^{new} - MC_{t+k}^n\right)\right]\right\}$$

s.t: $Y_{t+k}(i) = C_{H,t+k}(i) + C_{H,t+k}^*(i)$

$P_{H,t}^{new}(i) = P_{H,t}^{new} \rightarrow$ we can rewrite constraint as

$$Y_{t+k|t}(i) = \left(\frac{P_{H,t}^{new}}{P_{H,t+k}}\right)^{-\varepsilon}\left[C_{H,t+k} + C_{H,t+k}^*\right] \equiv Y_{t+k}^d(P_{H,t}^{new})$$

$Y_{t+k}^d -$ demand of domestic firms' product k $-$period after reset its price. It depends on optimal price.

$$\underbrace{max}_{P_{H,t}^{new}} \rightarrow \sum_{k=0}^{\infty}\theta^k E_t\left\{Q_{t,t+k}\left[P_{H,t}^{new}\left(\frac{P_{H,t}^{new}}{P_{H,t+k}}\right)^{-\varepsilon}\left(C_{H,t+k} + C_{H,t+k}^*\right) - TC_{t+k}^n(Y_{t+k}(i))\right]\right\}$$

$TC_{t+k}^n\big(Y_{t+k}(i)\big) -$ total cost function of $Y_{t+k}(i)$

FOC:

$$\frac{\partial\Pi_{t+k|t}}{\partial P_{H,t}^{new}} = 0 \rightarrow \sum_{k=0}^{\infty}\theta^k E_t\left\{Q_{t,t+k}\left[(1-\varepsilon)\underbrace{\left(\frac{P_{H,t}^{new}}{P_{H,t+k}}\right)^{-\varepsilon}\left(C_{H,t+k} + C_{H,t+k}^*\right)}_{a)\,Y_{t+k}(i)} - \underbrace{\frac{\partial TC_{t+k|t}^n}{\partial Y_{t+k|t}(i)}}_{b)\,MC_{t+k}^n}\cdot\underbrace{\frac{\partial Y_{jt+k|t}(j)}{\partial P_{H,t}^{new}}}_{c)}\right]\right\} = 0$$

One can rewrite the FOC

$$\sum_{k=0}^{\infty}\theta^k E_t\left\{Q_{t,t+k}Y_{t+k|t}(i)\left[P_{H,t}^{new} + \frac{\varepsilon}{1-\varepsilon}\cdot MC_{t+k|t}^n(j)\right]\right\} = 0$$

Using Euler equation and definition of real marginal cost $\frac{MC_{t+k|t}^n}{P_{H,t+k}} = MC_{t+k}^r$, one can rewrite the above conditions as:

$$\sum_{k=0}^{\infty}(\theta\beta)^k E_t\left\{C_{t+k}^{-\sigma}Y_{t+k|t}(j)\frac{P_{H,t-1}}{P_{t+k}}\left[\frac{P_{H,t}^{new}}{P_{H,t-1}} - \frac{\varepsilon}{\varepsilon-1}\cdot\Pi_{t-1,t+k}^H\cdot MC_{t+k}^r\right]\right\} = 0 \qquad \text{(A7)}$$

Where: $\Pi_{t-1,t+k}^H = \frac{P_{H,t+k}}{P_{H,t+k-1}}\cdot\frac{P_{H,t+k-1}}{P_{H,t+k-2}}\cdot\ldots\cdot\frac{P_{H,t-3}}{P_{H,t-2}}\cdot\frac{P_{H,t-2}}{P_{H,t-1}} = \frac{P_{H,t+k}}{P_{H,t-1}}$

Log-linearize the equation (A7) around zero inflation around steady state with balanced trade

Steady state:

$P_{H,t-1} = P_{t+k} = P_{H,t}^{new} = \bar{P}\ ; C_{t+k} = \bar{C}, MC_{t+k}^{r} = \overline{MC^{r}}, Y_{t+k|t}(j) = \bar{Y}$

$$\rightarrow \sum_{k=0}^{\infty} (\theta\beta)^k E_t\{\bar{C}^{-\sigma}\bar{Y}\} = \sum_{k=0}^{\infty} (\theta\beta)^k E_t\left\{\bar{C}^{-\sigma}\bar{Y}\frac{\varepsilon}{\varepsilon-1}\overline{MC^{r}}\right\}$$

$$\rightarrow \frac{1}{1-\theta\beta}\bar{C}^{-\sigma}\bar{Y} = \frac{1}{1-\theta\beta}\bar{C}^{-\sigma}\bar{Y}\frac{\varepsilon}{\varepsilon-1}\overline{MC^{r}}$$

$$\rightarrow \overline{MC^{r}} = \frac{\varepsilon-1}{\varepsilon}$$

LHS: log-linearize the left hand side of the equation (A7)

$$\sum_{k=0}^{\infty} (\theta\beta)^k E_t\{\bar{C}^{-\sigma}\bar{Y}\}\{1 - \sigma(c_{t+k} - \bar{c}) + \left(y_{t+k|t}(i) - \bar{y}\right) + \left(p_{H,t}^{new} - p\right) - (p_{t+k} - p)\}$$

$$= \sum_{k=0}^{\infty} (\theta\beta)^k E_t\{\bar{C}^{-\sigma}\bar{Y}\}\{1 - \sigma c_{t+k} + y_{t+k|t}(i) + p_{H,t}^{new} - p_{t+k} + \sigma\bar{c} - \bar{y}\}$$

RHS: log-linearize the right hand side of the equation (A7)

$$\frac{\varepsilon}{\varepsilon-1}\sum_{k=0}^{\infty} (\theta\beta)^k \left\{\bar{C}^{-\sigma}\bar{Y}\frac{\varepsilon}{\varepsilon-1}\overline{MC^{r}}\right\}\{1 - \sigma(c_{t+k} - \bar{c}) + \left(y_{t+k|t}(i) - \bar{y}\right) + \left(p_{H,t+k} - p\right) - (p_{t+k} - p) - (mc_{t+k}^{r} - \overline{mc^{r}})\}$$

$$\rightarrow \frac{\varepsilon}{\varepsilon-1}\sum_{k=0}^{\infty} (\theta\beta)^k \left\{\bar{C}^{-\sigma}\bar{Y}\frac{\varepsilon}{\varepsilon-1}\overline{MC^{r}}\right\}\{1 - \sigma c_{t+k} + y_{t+k|t}(i) + p_{H,t+k} - p_{t+k} + mc_{t+k}^{r} + \sigma\bar{c} - \bar{y} - \overline{mc^{r}}\}$$

LHS ≈ RHS

$$p_{H,t}^{new} = (1-\theta\beta)\sum_{k=0}^{\infty} (\theta\beta)^k E_t\{p_{H,t+k} + mc_{t+k}^{r} - \overline{mc^{r}}\}$$

Let impose a constant real marginal cost (inverse of domestic markup) in the steady state. Newly set optimal price is defined as

$$p_{H,t}^{new} = (1-\theta\beta)\sum_{k=0}^{\infty} (\theta\beta)^k E_t\{p_{H,t+k} + mc_{t+k}^{r}\} \quad \text{(A8)}$$

APPENDIX 1.6: DERIVATION OF EQUATION (23)

i. The dynamics of the Domestic Price Index

Equation (22) can be rewritten as:

$$\left[\frac{P_{H,t}}{P_{H,t-1}}\right]^{1-\varepsilon} = \theta + (1-\theta)\left[\frac{P_{H,t}^{new}}{P_{H,t-1}}\right]^{1-\varepsilon} \quad \text{(A9)}$$

Log-linearize the equation (A9) around zero inflation

$$\pi_{H,t} = (1-\theta)\left(p_{H,t}^{new} - p_{H,t-1}\right) \tag{A10}$$

Inflation results from the fact that domestic firms re-optimizing in any given period choose a price that differs from the economy's average price.

i. Inflation dynamics of domestic goods in the small open economy

Let's drive inflation dynamics of domestic goods using equation (21) and (A10).

$$p_{H,t}^{new} = (1-\theta\beta)\sum_{k=0}^{\infty}(\theta\beta)^k E_t\left\{mc_{t+k}^r + p_{H,t+k}\right\}$$

$$p_{H,t}^{new} - p_{H,t-1} = (1-\theta\beta)\sum_{k=0}^{\infty}(\theta\beta)^k E_t\left\{mc_{t+k}^r + p_{H,t+k} - p_{H,t-1}\right\}$$

$$p_{H,t}^{new} - p_{H,t-1} = (1-\theta\beta)\sum_{k=0}^{\infty}(\theta\beta)^k E_t\{mc_{t+k}^r\} + \sum_{k=0}^{\infty}(\theta\beta)^k E_t\left\{\pi_{H,t+k}\right\} \tag{A11}$$

After rearranging equation (A11), it can be rewritten as

$$p_{H,t}^{new} - p_{H,t-1} = \theta\beta E_t\left\{p_{H,t+1}^{new} - p_{H,t}\right\} + (1-\theta\beta)mc_t^r + \pi_{H,t} \tag{A12}$$

Combining (A15) and (10) equations, domestic inflation dynamic can be defined

$$p_{H,t}^{new} - p_{H,t-1} = \theta\beta E_t\left\{p_{H,t+1}^{new} - p_{H,t}\right\} + (1-\theta\beta)mc_t^r + (1-\theta)(p_{H,t}^{new} - p_{H,t-1})$$

$$\pi_{H,t} = \beta E_t\left\{\pi_{H,t+1}\right\} + \lambda mc_t^r \tag{A13}$$

where $\lambda \equiv \frac{(1-\theta)(1-\theta\beta)}{\theta}$

APPENDIX 1.7: DERIVATION OF EQUATION (25)

i. Import Pricing

$$\underbrace{max}_{P_{F,t}^{new}(j)} \rightarrow \quad E_t\left\{\sum_{k=0}^{\infty}\beta^k \Lambda_{t,t+k}\theta_F^k\left(P_{F,t}^{new}(j) - \mathcal{E}_{t+k}P_{F,t+k}^*(j)\right)C_{F,t+k}(j)\right\}$$

$$s.t: C_{F,t+k}(j) = \left(\frac{P_{F,t}^{new}(j)}{P_{F,t+k}}\right)^{-\varepsilon} \cdot C_{F,t+k}$$

$$\underbrace{max}_{P_{F,t}^{new}(j)} \rightarrow \quad E_t\left\{\sum_{k=0}^{\infty}\beta^k \Lambda_{t,t+k}\theta_F^k\left(P_{F,t}^{new}(j) - \mathcal{E}_{t+k}P_{F,t+k}^*(j)\right)\left(\frac{P_{F,t}^{new}(j)}{P_{F,t+k}}\right)^{-\varepsilon} \cdot C_{F,t+k}\right\}$$

$$\frac{\partial \Pi_{F,t}(j)}{\partial P_{F,t}^{new}(j)} = 0 \rightarrow$$

$$E_t\left\{\sum_{k=0}^{\infty}\beta^k \Lambda_{t,t+k}\theta_F^k\left((1-\varepsilon)\left(\frac{P_{F,t}^{new}(j)}{P_{F,t+k}}\right)^{-\varepsilon} C_{F,t+k} - \mathcal{E}_{t+k}P_{F,t+k}^*(j)(-\varepsilon)\left(\frac{P_{F,t}^{new}(j)}{P_{F,t+k}}\right)^{-\varepsilon} C_{F,t+k}P_{F,t}^{new}(j)^{-1}\right)\right\} = 0$$

$$P_{F,t}^{new}(j) = \frac{\varepsilon}{\varepsilon - 1} \cdot \frac{E_t\left\{\sum_{k=0}^{\infty} \beta^k \Lambda_{t,t+k}\theta_F^k \left(\mathcal{E}_{t+k}P_{F,t+k}^*(j)C_{F,t+k}(j)\right)\right\}}{E_t\{\sum_{k=0}^{\infty} \beta^k \Lambda_{t,t+k}\theta_F^k C_{F,t+k}(j)\}} \tag{A14}$$

Using Euler equation, equation (A14) can be rewritten as

$$E_t\left\{\sum_{k=0}^{\infty}(\theta_F\beta)^k C_{t+k}^{-\sigma}P_{t+k}^{-1}\left((\varepsilon-1)\cdot C_{F,t+k}(j)\right)\right\} = E_t\left\{\sum_{k=0}^{\infty}(\theta\beta)^k C_{t+k}^{-\sigma}P_{t+k}^{-1}\left(\varepsilon\mathcal{E}_{t+k}\frac{P_{F,t+k}^*(j)}{P_{F,t}^{new}(j)}\cdot C_{F,t+k}(j)\right)\right\}$$

Log-linearization of equation (A14)

Steady state:

$C_{t+k} = \bar{C}$; $\quad C_{F,t+k}(j) = \overline{C_F}$; $\quad P_{t+k} = P_{F,t}^{new}(j) = \bar{P}$;
$P_{F,t+k}^* = \overline{P^*}$; $\quad \mathcal{E}_{t+k} = \bar{\mathcal{E}}$

Real exchange rate in the steady state: $\bar{\mathcal{E}} \cdot \frac{\overline{P^*}}{\bar{P}} = 1$

$$\underbrace{E_t\left\{\sum_{k=0}^{\infty}(\theta_F\beta)^k\bar{C}^{-\sigma}\bar{P}^{-1}\left((\varepsilon-1)\cdot\bar{C}_F\right)\right\}}_{s.s\ of\ LHS} = \underbrace{E_t\left\{\sum_{k=0}^{\infty}(\theta_F\beta)^k\bar{C}^{-\sigma}\bar{P}^{-1}\left(\varepsilon\cdot\bar{\mathcal{E}}\cdot\frac{\overline{P^*}}{\bar{P}}\cdot\overline{C_F}\right)\right\}}_{s.s\ of\ RHS}$$

LHS:

$$E_t\left\{\sum_{k=0}^{\infty}(\theta_F\beta)^k exp\{-\sigma c_{t+k} - p_{t+k} + \log(\varepsilon-1) + c_{F,t+k}(j)\}\right\} =$$

$$= E_t\left\{\sum_{k=0}^{\infty}(\theta_F\beta)^k \underbrace{\overline{C}^{-\sigma}\overline{P}^{-1}(\varepsilon-1)\cdot\overline{C}_F}_{s.s}\left(1 - \sigma c_{t+k} - p_{t+k} + c_{F,t+k}(j) + \sigma\bar{c} + \bar{p} - \overline{c_F}\right)\right\}$$

RHS:

$$E_t\left\{\sum_{k=0}^{\infty}(\theta\beta)^k exp\{-\sigma c_{t+k} - p_{t+k} + log\varepsilon + e_{t+k} + p_{F,t+k}^*(j) - p_{F,t}^{new}(j) + c_{F,t+k}(j)\}\right\}$$

$$= E_t\left\{\sum_{k=0}^{\infty}(\theta_F\beta)^k \underbrace{\overline{C}^{-\sigma}\overline{P}^{-1}\varepsilon\cdot\overline{C}_F}_{s.s}\left(1 - \sigma(c_{t+k} - \bar{c}) - \left(p_{t+k} - \bar{p}\right) + \left(e_{t+k} - \bar{e}\right)\right.\right.$$
$$\left.\left. + \left(p_{F,t+k}^*(j) - \overline{p^*}\right) - \left(p_{F,t}^{new}(j) - \bar{p}\right) + \left(c_{F,t+k}(j) - \overline{c_F}\right)\right)\right\}$$

$LHS \approx RHS$

$$E_t\left\{\sum_{k=0}^{\infty}(\theta_F\beta)^k\left(p_{F,t}^{new}(j)\right)\right\} = E_t\{\sum_{k=0}^{\infty}(\theta_F\beta)^k\left(\psi_{F,t+k} + p_{F,t+k}\right)\}$$

$$p_{F,t}^{new}(j) = (1-\theta_F\beta)E_t\left\{\sum_{k=0}^{\infty}(\theta_F\beta)^k\left(\psi_{F,t+k} + p_{F,t+k}\right)\right\} \tag{A15}$$

APPENDIX 1.8: DERIVATION OF EQUATION (27)

i. The dynamics of the Import Price Index

Equation (26) can be rewritten as:

$$\left[\frac{P_{F,t}}{P_{F,t-1}}\right]^{1-\varepsilon} = \theta_F + (1-\theta_F)\left[\frac{P_{F,t}^{new}}{P_{F,t-1}}\right]^{1-\varepsilon} \tag{A16}$$

Log-linearize the equation (A16) around zero inflation

$$\pi_{F,t} = (1-\theta_F)\left(p_{F,t}^{new} - p_{F,t-1}\right) \tag{A17}$$

i. Inflation dynamics of imported goods in the small open economy

Let's drive inflation dynamics of imported goods using equation (A15) and (A17).

$$p_{F,t}^{new} - p_{F,t-1} = (1-\theta_F\beta)\sum_{k=0}^{\infty}(\theta_F\beta)^k E_t\{\psi_{F,t+k}\} + (1-\theta_F\beta)\sum_{k=0}^{\infty}(\theta_F\beta)^k E_t\{p_{F,t+k} - p_{F.t-1}\}$$

After some rearrangement, it can be rewritten

$$p_{F,t}^{new} - p_{F,t-1} = (1-\theta_F\beta)\sum_{k=0}^{\infty}(\theta_F\beta)^k E_t\{\psi_{F,t+k}\} + \sum_{k=0}^{\infty}(\theta_F\beta)^k E_t\{\pi_{F,t+k}\} \tag{A18}$$

$$p_{F,t}^{new} - p_{F,t-1} = (1-\theta_F\beta)\sum_{k=1}^{\infty}(\theta_F\beta)^k E_t\{\psi_{F,t+k}\} + \sum_{k=1}^{\infty}(\theta_F\beta)^k E_t\{\pi_{F,t+k}\} + (1-\theta\beta)\psi_{F,t} + \pi_{F,t}$$

$$p_{F,t}^{new} - p_{F,t-1} = \theta_F\beta E_t\{p_{F,t+1}^{new} - p_{F,t}\} + (1-\theta\beta)\psi_{F,t} + \pi_{F,t} \tag{A19}$$

Combining (A19) and (A17) equations

$$p_{F,t}^{new} - p_{F,t-1} = \theta_F\beta E_t\{\pi_{F,t+1}\} + (1-\theta_F\beta)\psi_{F,t} + (1-\theta_F)(p_{F,t}^{new} - p_{F,t-1})$$

$$\pi_{F,t} = \beta E_t\{\pi_{F,t+1}\} + \lambda_F\psi_{F,t} \tag{A20}$$

Where $\lambda_F = \frac{(1-\theta_F)(1-\theta_F\beta)}{\theta_F}$

APPENDIX 1.9: DERIVATION OF EQUATION (30)

i. International risk sharing

Combining Euler equations (10) for domestic and foreign households and using definition of real exchange rate, we can obtain the relationship between home country's consumption and foreign country's consumption.

Let equalize above two Euler equations

$$\left(\frac{C_{t+1}^*}{C_t^*}\right)^{-\sigma}\left(\frac{P_t^*}{P_{t+1}^*}\right)\left(\frac{\mathcal{E}_t}{\mathcal{E}_{t+1}}\right) = \left(\frac{C_{t+1}}{C_t}\right)^{-\sigma}\left(\frac{P_t}{P_{t+1}}\right) \rightarrow$$

$$\left(\frac{P_t^*\mathcal{E}_t}{P_t}\right)\left(\frac{C_{t+1}^*}{C_t^*}\right)^{-\sigma} = \left(\frac{P_{t+1}^*\mathcal{E}_{t+1}}{P_{t+1}}\right)\left(\frac{C_{t+1}}{C_t}\right)^{-\sigma}$$

$$Q_t\left(\frac{C_{t+1}^*}{C_t^*}\right)^{-\sigma} = Q_{t+1}\left(\frac{C_{t+1}}{C_t}\right)^{-\sigma} \rightarrow \; C_t = \frac{C_{t+1}}{C_{t+1}^*}\cdot\left(\frac{1}{Q_{t+1}}\right)^{\frac{1}{\sigma}}\cdot Q_t^{\frac{1}{\sigma}}C_t^*$$

$$C_t = E_t\left[\frac{C_{t+1}}{C_{t+1}^* Q_{t+1}^{1/\sigma}}\right]Q_t^{1/\sigma}C_t^*$$

Let denote $\vartheta = \frac{C_{t+1}}{C_{t+1}^* Q_{t+1}^{1/\sigma}}$ → constant that depends on initial conditions regarding relative net asset position

$$C_t = \vartheta C_t^* Q_t^{1/\sigma} \tag{A21}$$

Under which assumption $\vartheta = 1$, take logarithm from both side of equation (A21)

$$c_t = c_t^* + \frac{1}{\sigma} q_t \qquad \text{(A22)}$$

Combining (A22) and (16) equations, then

$$c_t = c_t^* + \frac{1}{\sigma}\left[(1-\gamma)s_t + \psi_{F,t}\right] \qquad \text{(A23)}$$

APPENDIX 1.10: DERIVATION OF EQUATION (31)

ii. Uncovered Interest parity

Under the assumption of complete international financial markets, household can invest both in domestic and foreign bonds (D_t and D_t^*).

Household's problem rewritten as

$$\max \rightarrow E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\varphi}}{1+\varphi}\right]$$

s.t: $P_t C_t + E_t\{Q_{t,t+1} D_{t+1} + Q_{t,t+1}^* \mathcal{E}_{t+1} D_{t+1}^*\} \leq D_t + \mathcal{E}_t D_t^* + W_t N_t + T_t$

$$L \equiv E_0 \sum_{t=0}^{\infty} \beta^t \left\{\frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\varphi}}{1+\varphi} + \lambda_t\left[D_t + \mathcal{E}_t D_t^* + W_t N_t + T_t - P_t C_t - E_t\{Q_{t,t+1} D_{t+1} + Q_{t,t+1}^* \mathcal{E}_{t+1} D_{t+1}^*\}\right]\right\}$$

<u>FOC:</u>

$$\begin{cases} \dfrac{\partial L}{\partial C_t} = 0 \rightarrow \lambda_t = \dfrac{C_t^{-\sigma}}{P_t} \quad (a) \\ \dfrac{\partial L}{\partial N_t} = 0 \rightarrow \lambda_t = \dfrac{N_t^{\varphi}}{P_t} \quad (b) \\ \dfrac{\partial L}{\partial D_{t+1}} = 0 \rightarrow E_t\{Q_{t,t+1}\} = \beta E_t\left\{\dfrac{\lambda_{t+1}}{\lambda_t}\right\} \quad (c) \\ \dfrac{\partial L}{\partial D_{t+1}^*} = 0 \rightarrow E_t \beta^t\{\lambda_t(-)E_t\{Q_{t+1}^* \mathcal{E}_{t+1}\}\} + E_t \beta^{t+1}\{\lambda_{t+1}\mathcal{E}_t\} = 0 \quad d) \end{cases}$$

Equation d) of FOC equations can be rewritten

$$\lambda_t E_t\{Q_{t+1}^* \mathcal{E}_{t+1}\} = \beta E_t\{\lambda_{t+1}\mathcal{E}_t\} \quad \rightarrow 1 = \beta E_t\left\{\left(\frac{\lambda_{t+1}}{\lambda_t}\right) {Q_{t+1}^*}^{-1} \left(\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t}\right)^{-1}\right\}$$

Combining a) and c), we can obtain equation (10). Also, combining a) and d), we can obtain equation

$$1 = \beta E_t\left\{\left(\frac{C_{t+1}}{C_t}\right)^{-\sigma} \left(\frac{P_{t+1}}{P_t}\right)^{-1} {Q_{t,t+1}^*}^{-1} \left(\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t}\right)^{-1}\right\} \qquad \text{(A24)}$$

It is optimal condition for the foreign asset. Dividing the equation (10) by the equation (A24), the following optimal condition is defined:

$$\frac{Q_t^*}{Q_t} = E_t\left\{\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t}\right\} \qquad \text{(A25)}$$

Log-linearization of the equation (A25) around the steady state

$\exp(\log Q_t^* - \log Q_t) = \exp(E_t\{\log \mathcal{E}_{t+1} - \log \mathcal{E}_t\})$

$\exp(i_t - i_t^*) = \exp(E_t\{e_{t+1} - e_t\})$

$$i_t - i_t^* = E_t\{\Delta e_{i,t+1}\} \quad \text{(A26)}$$

APPENDIX 1.11: DERIVATION OF EQUATION (44)

iii. The l.o.p gap for domestic flexible price level

Now we obtain a reduced form expression for the l.o.p gap as a function of relative productivity.

$$\overline{\psi_{F,t}} = \left(\frac{\sigma(1+\varphi)}{\sigma+\varphi w_\psi}\right)(z_t - z_t^*) - \left(\frac{\sigma+\varphi w_s}{\sigma+\varphi w_\psi}\right)\overline{p_{F,t}} \quad \text{(A27)}$$

From equation (A27), we can define $\overline{p_{F,t}}$

$$\overline{p_{F,t}} = \left(\frac{\sigma(1+\varphi)}{\sigma+\varphi w_s}\right)(z_t - z_t^*) - \left(\frac{\sigma+\varphi w_\psi}{\sigma+\varphi w_s}\right)\overline{\psi_{F,t}} \quad \text{(A28)}$$

By combing (A27) and (27) equations,

$$\pi_{F,t} = \beta E_t\{\pi_{F,t+1}\} + \lambda_F\left[\left(\frac{\sigma(1+\varphi)}{\sigma+\varphi w_s}\right)(z_t - z_t^*) - \left(\frac{\sigma+\varphi w_s}{\sigma+\varphi w_\psi}\right)\overline{p_{F,t}}\right]$$

Let denote $\delta_F = 1 + \beta + \lambda_F\left(\frac{\sigma+\varphi w_s}{\sigma+\varphi w_\psi}\right)$

$$\delta_F\overline{p_{F,t}} = \overline{p_{F,t-1}} + \beta E_t\{\overline{p_{F,t+1}}\} + \lambda_F\left(\frac{\sigma(1+\varphi)}{\sigma+\varphi w_s}\right)(z_t - z_t^*) \quad \text{(A29)}$$

Under the assumption, for the sake of simplicity, that $\rho = \rho^*$, the above equation has a unique stationary solution of the form as

$$\overline{p_{F,t}} = \mu_1\overline{p_{F,t-1}} + \Omega(z_t - z_t^*) \quad \text{(A30)}$$

where $\mu_1 = \left(\frac{\delta_F}{2}\right)\left(1 - \left(1 - \left(\frac{4\beta}{\delta_F^2}\right)\right)^{1/2}\right) < 1$ and $\Omega = \frac{\lambda_F\beta\mu_1\sigma(1+\varphi)}{\left((\sigma+\varphi w_\psi)(1-\rho\beta\mu_1)\right)} > 0$

By substituting (A30) into (A27) equation, we can obtain a reduced form expression for the l.o.p gap.

$$\overline{\psi_{F,t}} = \left(\frac{\sigma(1+\varphi)}{\sigma+\varphi w_\psi}\right)(z_t - z_t^*) - \left(\frac{\sigma+\varphi w_s}{\sigma+\varphi w_\psi}\right)\left[\mu_1\overline{p_{F,t-1}} + \Omega(z_t - z_t^*)\right]$$

$$\overline{\psi_{F,t}} = \left[\left(\frac{\sigma(1+\varphi)}{\sigma+\varphi w_\psi}\right) - \left(\frac{\sigma+\varphi w_s}{\sigma+\varphi w_\psi}\right)\Omega\right](z_t - z_t^*) - \left(\frac{\mu_1(\sigma+\varphi w_s)}{\sigma+\varphi w_\psi}\right)\overline{p_{F,t-1}}$$

Let denote $\Gamma \equiv \left(\frac{\sigma(1+\varphi)}{\sigma+\varphi w_\psi}\right) - \left(\frac{\sigma+\varphi w_s}{\sigma+\varphi w_\psi}\right)\Omega = \left(\frac{\sigma(1+\varphi)}{\sigma+\varphi w_\psi}\right)\left[1 - \frac{(\sigma+\varphi w_s)\beta\mu_1\lambda_F}{\left((\sigma+\varphi w_\psi)(1-\rho\beta\mu_1)\right)}\right]$

$$\overline{\psi_{F,t}} = \Gamma(z_t - z_t^*) - \left(\frac{\mu_1(\sigma+\varphi w_s)}{\sigma+\varphi w_\psi}\right)\overline{p_{F,t-1}} \quad \text{(A31)}$$

Appendix II: SVAR estimation result

Table 7. Estimation Result of Exchnage rate pass-through in Mongolia

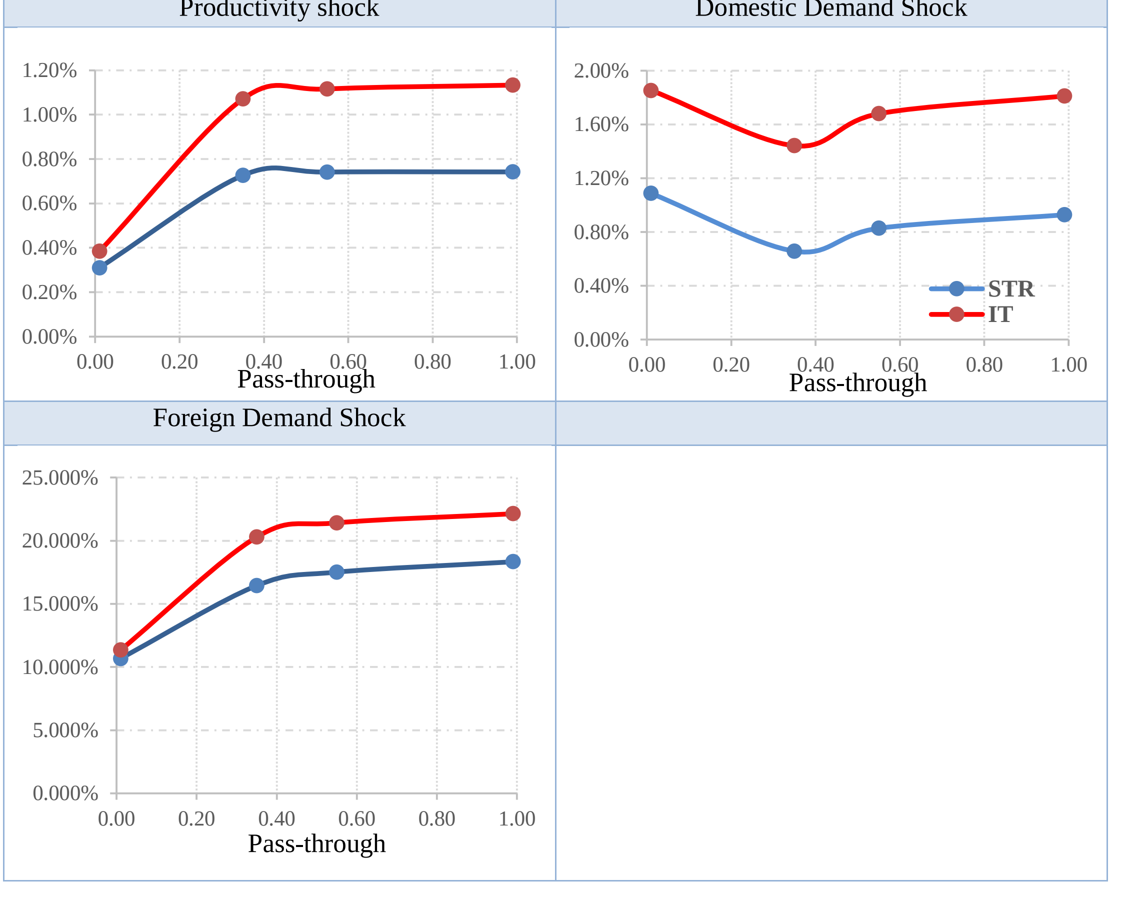
Dependent Variable: EXR_A
Method: Least Squares
Date: 04/15/14 Time: 15:06
Sample (adjusted): 2000Q2 2013Q4
Included observations: 55 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.001069	0.004934	0.216699	0.8293
EXR_A(-1)	**0.750985**	0.097620	7.692920	0.0000

R-squared	0.527549	Mean dependent var	-0.000279
Adjusted R-squared	0.518635	S.D. dependent var	0.052710
S.E. of regression	0.036570	Akaike info criterion	-3.743470
Sum squared resid	0.070882	Schwarz criterion	-3.670476
Log likelihood	104.9454	Hannan-Quinn criter.	-3.715242
F-statistic	59.18102	Durbin-Watson stat	1.576412
Prob(F-statistic)	0.000000		

Source: Author's estimation

Figure 7. **Comparison of STR and IT rules for exchange rates**



Appendix III: Enclosed DVD

Enclosed DVD including detailed model solution and code in Dynare, Matlab.