Monetary policy in a CGE model

Ragchaasuren Galindev[†]* and Bernard Decaluwé**

*Economic Research Institute, National University of Mongolia

**Laval University, Partnership for Economic Policy

Abstract

This paper aims to develop a CGE model with an explicit monetary policy rule which replaces typical exogenous numeraire so that the model can have endogenous absolute price. A model with exogenous numeraire can be derived as a special case of the current model through a flexible parameterization. It shows that in the presence of nominal rigidities, simulation results for the same shock can be different depending on the choice of numeraire. The current model also gives different results for the same shock by creating inflation. The paper highlights the importance of choosing numeraire or considering the interest rate rule instead of fixed numeraire in the presence of nominal rigidities.

Key words: a CGE model, monetary policy, the interest rate rule
JEL: D58, E52

1. Introduction

All Walrasian CGE models have numeraire which is a price or a price index to which all the remaining prices are relative and cannot be determined endogenously because of the interrelationship of the equilibrium conditions – i.e., an equilibrium condition is a linear combination of another. However, this satisfies the Walras law. Suppose that there are N markets. Because of the efficiency conditions satisfying the budget constraints (e.g., the first order conditions of utility maximization and cost minimization problems), the sufficient condition for all markets to be in equilibrium is that N-1 markets are in equilibrium. One equilibrium condition becomes redundant so that numeraire can be any price to be determined from any market equilibrium condition. In practice, numeraire is usually either consumption price index or the nominal exchange rate in open economy CGE models. In real CGE models (i.e., no nominal rigidities), numeraire is exogenous and the choice of numeraire does not matter.

[†] Corresponding author. *Email address:* ragchaasuren@eri.mn

An increase in numeraire increases all the prices proportionally (this is known as the nominal homogeneity test) hence the relative prices are left unchanged – i.e., no real effects.

One may now ask "what are the implications of nominal rigidities which are common in real life, especially in the short-run?". The answer is that we could consider nominal rigidities in CGE models. In fact, there are some models such as the PEP standard models in which some nominal variables are exogenous. However, even such models must pass the nominal homogeneity test and show that the model is consistent with the classical dichotomy at least in the long-run. For that, nominal exogenous variables must maintain their ratios to numeraire in the closure. Because of nominal rigidities, however, a problem arises when the same shock could have different effects depending on the choice of numeraire. So what is numeraire in this context?

This paper argues that numeraire in CGE models with nominal rigidities represents the target of monetary authority. A redundant equilibrium condition, mentioned above, has a flipside which is a money market equilibrium condition. Numeraire is essentially a target of central banks. Central banks adjust their policy instruments to control numeraire. Different numeraire means different targets for central banks. In other words, if the nominal exchange rate (or consumption price index) is numeraire, a central bank controls it. Numeraire can increase or decrease exogenously which can have real effects because of nominal rigidities. This ban be interpreted that a central bank is adjusting its target and it is treated as an exogenous shock in the model. Depending on central bank's target, the same shock could have different effects. Basically, money or monetary policy could have real effects (i.e., money is not neutral) when nominal rigidities are present. Real effects are different for different numeraire. Moreover, real effects can be different for the same numeraire if the numeraire increases or decreases (i.e., a central banks adjusts its target). However, a money market operation is still implicit.

There is a body of literature that endogenises numeraire by developing detailed financial markets within CGE models (see Thissen, 1999; Xiao, 2009). These are called financial CGE models. Numeraire in such models is replaced by explicit financial market equilibrium conditions and hence monetary policy actions are explicit. Such financial models, however, can be data intensive.

Here we propose a simple approach to introduce an explicit monetary policy in CGE models. For this purpose, we consider the PEP-1-t (a recursive dynamic CGE in Decaluwé et al., 2013) model calibrated to a Mongolian SAM. Numeraire in the PEP-1-t model is replaced by a Taylor-type interest rate rule (e.g., Taylor, 1992). The Taylor rule is a kind of monetary policy rule used by central banks. Specifically, a central bank has a control over a short-term interest rate and adjusts it to reduce a gap between desired inflation rate and actual inflation rate as well as an output gap between the actual and natural levels. Whether a central bank cares the inflation gap more or less than the output gap is determined by the weights attached to the gaps. It is common that central banks care more about inflation and acts more aggressively to inflation by adjusting the interest rate. The modern macroeconomic (DSGE) models consider the interest rate rule commonly to study the short-run economic fluctuations (e.g., Christiana et al., 2005, Smets and Wouters, 2007). We first consider a more general interest rate rule which includes a gap between the desired and actual depreciation of the exchange rate in addition to the inflation and output gaps. The reason is to show that the PEP-1-t model with a particular choice of numeraire can be derived as a special case of the current model through a flexible parameterization. The nominal interest rate is linked with the real interest rate through the Fisher equation with expected inflation rate. The real interest rate in the PEP-1-t model determines the Tobin-Q condition through the user cost of capital. In the current model, given the expected inflation rate, a change in the nominal interest rate can change in the real interest rate which affects the Tobin-Q and hence real investment. If we place sufficiently high weight on the inflation gap, the current model replicates the PEP-1-t model in which consumption price index is the numeraire. Likewise, if we place sufficiently high weight on the the exchange rate depreciation gap, the model is the same as the PEP-1-t model in which the nominal exchange rate is the numeraire. If we assume that a central bank does not care about the gaps, the model is basically the PEP-1-t model in which the real interest rate is the numeraire. We demonstrate these arguments by simulating the PEP-1-t model and the current monetary model for the same shock. What is interesting is that the current model with the commonly used Taylor rule has absolute price (i.e., inflation). In response to a shock, now the monetary policy responds in accordance with the interest rate rule hence changes the absolute price level which could then have real effects because of nominal rigidities.

The PEP-1-t model has some exogenous nominal variables such as the government spending and foreign savings. In that respect the choice of numeraire matters in response to any shocks. Since the PEP-1-t model with different numeraire is a special case of of the current model, we then compare the simulation results of three cases – a) the common Taylor rule in which the interest rate responds to the inflation and output gaps, b) a central banks cares only about the exchange rate depreciation (i.e., the exchange rate is the numeraire in the PEP-1-t model) and c) a central bank cares only about the inflation gap (i.e., consumption price index is the numeraire in the PEP-1-t model). The shock is 10% increase in government spending in period 3 for the simulation over 10 periods. The results are quite different. The current model with the common Taylor rule generates inflation while the other two cases have no absolute prices (i.e., exogenous numeraire). All three simulations generate different results which highlights the importance of the choice of numeraire. A model with exogenous numeraire can derive misleading results in the presence of nominal rigidities as it does not consider the response of a central bank. Interestingly, when we shock the exogenous numeraire with those determined in Case a), the results of the two cases with the exogenous numeraire converge to those in Case a).

The paper is organized as follows. Section 2 outlines the PEP-1-t model and the modifications. Section 3 discusses the scenarios and simulations. Section 4 concludes the paper.

2. Model

2.1 The PEP-1-t model

We extend the PEP-1-t model, a recursive dynamic CGE model, of Decaluwé et al., (2013). Here we briefly outline the main specifications of this model.

The production side of an economy is divided into different activities/sectors. Each sector has a nested structure and each level uses a production function with constant returns to scale. Specifically, the first level of production is a Leontief function of value added and intermediate consumption. At the next level, value added is a constant elasticity of substitution (CES) function of composite labor and composite capital. Each composite input is a CES function of different types. Intermediate consumption of each commodity, on the other hand, is proportional to sectorial production. Each sector may produce multiple commodities, which are aggregated by a constant elasticity of transformation (CET) function. Finally, quantities to sell domestically or to export are governed by a CET function and relative prices.

On the demand side, the consumption of a commodity is a CES function of domestic and imported quantities. A representative household allocates its disposable income, which derives from capital, labor and transfers from other agents, between consumption and savings. Its demand for commodities is governed by a linear-expenditure system (LES). This is a savings-driven-investment model, and the sum of household, government, and foreign savings determines the total amount of investment. Investment demand distinguishes between gross fixed-capital formation and changes in inventories. Direct government revenue (income), indirect taxes (production, commodities, and foreign trade), and transfers from other agents are divided among savings, spending on commodities, and transfers to other agents. The demand for commodities for investment and government spending purposes is proportional to respective total expenditures.

Export demand for domestic commodities is an isoelastic function of relative prices (foreign price in domestic currency divided by domestic price). Current account balance in the balance of payments is determined by the amount of exogenous foreign savings. The numeraire is normally the nominal exchange rate. Stock of each type of capital increased by investment but decreased by depreciation in growth model such as the one proposed by Solow (1956). Investment in public services sectors is normally exogenous while that in other sectors is endogenous depending on the return (ratio between the rental rate and user cost of capital—the depreciation and interest rate).

The model has nominal rigidities, as mentioned earlier. Nominal variables such as government spending and foreign savings are treated as exogenous variables.

The model considers positive a population growth, but not technological change so that in the Balanced Growth Path (BGP) all real and nominal variables grow at the same same rate as the population growth rate while all prices remain the same.

2.2 Extensions

We first introduce a positive constant domestic inflation rate, $d\_PD\_SS(t)$, in the BGP (or in the steady state growth path) which can also be considered as an inflation target for the central bank. At this inflation rate, a general price index, $PD\_SS(t)$, grows steadily in the BGP. We also consider a constant foreign inflation rate, $d\_PF\_SS(t)$, and a foreign general price index, $PF\_SS(t)$. This allows us to consider the relative Purchasing Power Parity (PPP) condition so that the nominal exchange rate is determined in the BGP as:

$$d\_E\_SS(t) = \frac{1 + d\_PD\_SS(t)}{1 + d\_PF\_SS(t)} - 1. \tag{1}$$

As a consequence of the above extension, all nominal variables (denoted by $X(t)$) are initialized as

$$X.l(t) = XO \cdot PD\_SS(t) \cdot POP(t) \tag{2}$$

where XO is an initial value calibrated in the base year and $POP(t)$ is the population index updated with the population growth rate, $n(t)$. All domestic prices, $P(t)$, including wages, capital rental prices and various price indices are initialized as

$$P.l(t) = PO \cdot PD\_SS(t) \tag{3}$$

where PO for each price and price index are calibrated in the base year. All world prices, $PWX(i,t)$ and $PWM(i,t)$, are initialized as

$$PWX.l(i,t) = PWXO(i) \cdot PF\_SS(t) \tag{4}$$

$$PWM.l(i,t) = PWMO(i) \cdot PF\_SS(t) \tag{5}$$

where $PWXO(i)$ and $PWMO(i)$ are initial prices calibrated in the base year.

In the BGP, one closes the model by fixing exogenous nominal variables and volume variables at $XO \cdot PD\_SS(t) \cdot POP(t)$ and $XO \cdot POP(t)$ respectively.

Our objective to bring out an explicit monetary policy. Now we introduce the Fisher equation linking the nominal and real interest rates as

$$ir(t) = \frac{1 + i(t)}{1 + d\_PD\_exp(t+1)} - 1 \tag{6}$$

where $ir(t)$ is the real interest rate, $i(t)$ is the nominal interest rate set by the central bank and $d\_PD\_exp(t+1)$ is the expected inflation rate measured by consumption price index.

In the PEP-1-t model, investment is divided into exogenous and endogenous parts. In pub sectors such as education health and public administration, real investment in type k capital, $IND(k, pub,t)$, is exogenous. On the contrary, $IND(k,bus,t)$ is endogenous and depends on the user cost of capital, $U(k,bus,t)$, which is defined as follows:

$$U(k,bus,t) = PK\_PRI(t) \cdot \left(delta(k,bus) + ir(t)\right) \tag{7}$$

where $PK\_PRI(t)$ is the investment price index and $delta(k,bus)$ is the depreciation rate. In the PEP_1-t model, the real interest rate is determined from the loanable fund market equilibrium condition – total savings equal total investment:

$$IT\_PUB(t) + IT\_PRI(t) = SH(t) + SG(t) + SROW(t) - \sum_i PC(i,t) \cdot VSTK(i,t) \tag{8}$$

$$IT\_PUB(t) = PK\_PUB(t) \cdot \sum_k IND(k, pub,t) \tag{9}$$

$$IT\_PRI(t) = PK\_PRI(t) \cdot \sum_k IND(k,bus,t) \tag{10}$$

where $IT\_PUB(t)$ is nominal public investment expenditure, $IT\_PRI(t)$ is nominal private investment expenditure, $SH(t)$ is private sector savings, $SG(t)$ is government savings, $SROW(t)$ is savings from the rest of the world, $VSTK(i,t)$ is a change in inventory for commodity i, $PC(i,t)$ is the composite price of commodity i and $PK\_PUB(t)$ is the public investment price index.

In the current model, the central bank controls the nominal interest rate, $i(t)$. In doing so, it follows the so-called Taylor-type interest rate rule:

$$\begin{aligned} i(t) = ir\_SS(t) + d\_PD(t) + \alpha_1\left(y(t) - y\_SS(t)\right) + \alpha_2\left(d\_PD(t) - d\_PD\_SS(t)\right) + \\ + \alpha_3\left(d\_E(t) - d\_E\_SS(t)\right) + i\_shock(t) \end{aligned} \tag{11}$$

where ir_SS is the steady-state (BGP) real interest rate, $y(t)$ is the growth rate of real GDP, $y\_SS(t)$ is the BGP growth rate and $i\_shock(t)$ is a discretionary monetary policy shock. According to this rule, the central bank adjusts its policy rate in response to the gaps occurring in the GDP growth rate, the inflation rate and the nominal exchange rate depreciation from their respective BGP values. The degree of reaction is captured by the coefficients α_1, α_2 and α_3 respectively. In general, the literature does not consider the last component – i.e., it is normally $\alpha_3 = 0$. If it is included, they also include the lagged exchange depreciation rate gap and set its reaction coefficient as $-\alpha_3$ so that the sum of the response coefficients is zero (e.g., Svensson, 2000). Here we consider this particular interest rate rule for a purpose. Through the flexible parameterization, we could consider the following possibilities.

1. If the central bank does not care about any gaps – i.e., $\alpha_1 = \alpha_2 = \alpha_3 = 0$, the model becomes the same as the PEP-1-t model in which the real interest rate is the numeraire.
2. If the central bank cares only about inflation (α_2 is relatively large enough), the model becomes a PEP-1-t model in which $PIXCON(t)$ is the numeraire and the real interest rate absorbs the impact of the shock. Consequently, $IND(k,bus,t)$ responds.
3. If the central bank cares only about the exchange rate (α_3 is relatively large enough), the model is the PEP-1-t model in which the nominal exchange rate, $E(t)$, is the numeraire and the real interest rate absorbs the impact of the shock. Consequently, $IND(k,bus,t)$ responds.
4. However, it is common to consider a case in which $\alpha_1 = \alpha_2 = 0.5$ and $\alpha_3 = 0$ in the literature. Accordingly the central bank responds to the inflation more aggressively as the joint coefficient on $d\_PD(t)$ is 1.5.

In the real PEP-1-t model, foreign savings, $SROW(t)$, is exogenous and determines the current account balance. Given the nominal interest rate, the inflation rate and the expected depreciation of domestic currency in the current model, financial assets could move across economies and help determine the nominal exchange rate. Thus the following modification can be carried out on the balance of payments equation. The capital account, $SROW(t)$, is split into 2 parts – $FDI(t)$ (foreign direct investment) and $NCF(t)$ (net capital flow):

$$SROW(t) = FDI(t) + NCF(t)\,. \tag{12}$$

Foreign direct investment is exogenous and fixed as $FDI(t) = FDIO \cdot POP(t) \cdot PD\_SS(t)$ in the BGP. Net capital flow, on the other hand, is endogenous and depends on the ratio of domestic and foreign nominal interest rates as follows:

$$NCF(t) = NCFO \cdot POP(t) \cdot PD\_SS(t) \cdot \left(\frac{1 + i(t)}{\left(1 + i\_F(t)\right) \cdot \left(1 + d\_E\_exp(t+1)\right)} \right)^{\psi} \tag{13}$$

where $i\_F(t)$ is the exogenous foreign nominal interest rate that satisfies the UIP (Uncovered Interest Parity) condition and the parameter $\psi \geq 0$ exhibits the degree of flexibility in the financial market for investors in shifting their assets across economies. Larger the elasticity, the faster the assets move and the difference between expected interest rates diminish quickly.

Another additional variable for the balance of payments equation is a change in the official foreign reserves, $d\_FXR(t)$, which is defined as:

$$CAB(t) = SROW(t) + d\_FXR(t)\,. \tag{14}$$

$d\_FXR(t)$ is the difference between the current account balance, $CAB(t)$, and financial account balance, $SROW(t)$. In a fully flexible exchange rate system, it is set to zero. In a system where the central bank intervenes the exchange rate market to some extent, it could be either exogenous or an endogenous depending on the exchange rate.[1]

We consider adaptive expectations for the expected inflation and the exchange rate depreciation.

$$d\_E\_exp(t+1) = d\_E(t) \tag{15}$$

$$d\_E(t) = \frac{E(t)}{E(t-1)} - 1 \tag{16}$$

$$d\_PD\_exp(t+1) = d\_PD(t) \tag{17}$$

$$d\_PD(t) = \frac{PIXCON(t)}{PIXCON(t-1)} - 1 \tag{18}$$

3. Calibrations and Simulations

3.1 Calibrations

We consider the 2017 Mongolian SAM.[2] For modifications in the current model, we consider the following calibrated values in the BGP.

$$d\_PD\_SS(t) = 0.06$$

$$d\_PF\_SS(t) = 0.02$$

$$d\_E\_SS(t) = 0.03922$$

$$i\_SS(t) = 0.145$$

$$ir\_SS(t) = 0.08$$

In the BGP, the expected inflation rate and the expected depreciation of the exchange rate are calibrated as

$$d\_PD\_exp(t+1) = d\_PD\_SS(t) = 0.06$$

$$d\_E\_exp(t+1) = d\_E\_SS(t) = 0.03922\,.$$

The foreign interest rate is calibrated from the UIP condition as

[1] More on this in connection with the interest rate rule is left for future work.

[2] See Appendix for the tables showing the structure of the Mongolian economy.

$$i\_F(t)=\frac{1+i\_SS(t)}{1+d\_E\_\exp(t+1)}-1=0.1016.$$

In addition, the real interest rate and the growth rate of GDP in the BGP are

$$ir\_SS(t)=0.08$$

$$y\_SS(t)=n(t)=0.018.$$

We set $\psi=0$ to show eliminate the impact through the UIP condition.[3] Consequently, $NCF(t)$ and $SROW(t)$ are exogenous – i.e., it has the same feature as in the PEP-1-t model. In addition, we assume that $d\_FXR(t)$ is exogenous – i.e., $d\_FXR.fx(t)=FXRO\cdot PD\_SS(t)\cdot POP(t)$. As a result, $CAB(t)$ adjusts to the exogenous value of $SROW(t)+d\_FXR(t)$.

Given the calibrations and assumptions, the model exhibits the BGP for any α_1, α_2 and α_3.

3.2 Simulations

This section has two subsections. In the first subsection, we aim to demonstrate that the current model can replicate the results of the PEP-1-t model for the same shock. In the second subsection, we consider the conventional interest rate rule and compares the model results with those generated from the PEP-1-t model with different numeraires.

As mentioned earlier, the PEP-1-t model has a degree of nominal rigidities as some nominal variables are exogenous. For example, the government spending on goods and services and foreign savings are nominal exogenous variables. Consequently, the choice of the numeraire matters as shown below.

3.2.1 Replicating the PEP-1-t model

In this previous subsection, I aim to demonstrate that the PEP-1-t model can be a special case of the current monetary model in the presence of nominal rigidities.

We consider three cases in the PEP-1-t model and each case has different numeraire.

A. The real interest rate, $ir(t)$, is the numeraire.
B. The consumption price index, $PIXCON(t)$, is the numeraire.
C. The nominal exchange rate, $E(t)$, is the numeraire.

Case A is a special case of the current model with $\alpha_1=\alpha_2=\alpha_3=0$ in equation (11). To replicate Case B, we set $\alpha_1=\alpha_3=0$ and $\alpha_2=50$ in equation (11). Case C can be replicated by setting $\alpha_1=\alpha_2=0$ and $\alpha_3=50$ in equation (11).

[3] This is for future work.

We simulate the two models over 10 periods. The shock is 10% increase in government spending in period 3. We compare the results (in terms of the percentage deviations from the BGP values) for some selected variables. The following tables compare the simulation results. Note that PEP is for the PEP-1-t model and M-PEP is for the monetary version of the PEP-1-t model.

Table 1. The real interest rate is the numeraire (% deviations from the BGP values)

	GDP (real)		Consumption (nominal)		Export (nominal)		Government spending (real)		Import (nominal)		Investment (nominal)		Consumption price index		Exchange rate	
T	PEP	M-PEP	PEP	M-PEP	PEP	M-PEP	PEP	M-PEP	PEP	M-PEP	PEP	M-PEP	PEP	M-PEP	PEP	M-PEP
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	**-0.1**	**-0.1**	**12.5**	**12.5**	**17.8**	**17.8**	**-3**	**-3**	**15.3**	**15.3**	**15.8**	**15.8**	**14.88**	**14.88**	**17.08**	**17.08**
4	0	0	-0.4	-0.4	-0.6	-0.6	0.3	0.3	-0.5	-0.5	-0.6	-0.6	-0.413	-0.413	-0.538	-0.538
5	0	0	-0.2	-0.2	-0.3	-0.3	0.2	0.2	-0.2	-0.2	-0.3	-0.3	-0.211	-0.211	-0.284	-0.284
6	0	0	-0.1	-0.1	-0.1	-0.1	0.1	0.1	-0.1	-0.1	-0.2	-0.2	-0.099	-0.099	-0.143	-0.143
7	0	0	0	0	-0.1	-0.1	0	0	-0.1	-0.1	-0.1	-0.1	-0.039	-0.039	-0.066	-0.066
8	0	0	0	0	0	0	0	0	0	0	0	0	-0.007	-0.007	-0.026	-0.026
9	0	0	0	0	0	0	0	0	0	0	0	0	0.008	0.008	-0.005	-0.005
10	0	0	0	0	0	0	0	0	0	0	0	0	0.015	0.015	0.005	0.005

As can be seen from Table 1, the results of the two models are almost exactly the same in Case A.

The following table compares the results of the two models by selecting the nominal exchange rate as the numeraire in the PEP-1-t model and imposing significant weight on the exchange rate gap in the interest rate rule in the M-PEP-1-t model (Case B).

Table 2. The nominal exchange rate is the numeraire (% deviations from the BGP values)

	GDP (real)		Consumption (nominal)		Export (nominal)		Government spending (real)		Import (nominal)		Investment (nominal)		Consumption price index		Exchange rate	
T	PEP	M-PEP	PEP	M-PEP	PEP	M-PEP	PEP	M-PEP	PEP	M-PEP	PEP	M-PEP	PEP	M-PEP	PEP	M-PEP
1	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	**0.00**	**0.00**	**0.30**	**0.30**	**-0.30**	**-0.20**	**-0.20**	**-0.20**	**-0.20**	**-0.20**	**-3.10**	**-3.10**	**0.73**	**0.75**	**0**	**0.03**
4	-0.10	-0.10	-0.10	-0.10	0.00	0.00	-0.10	0.00	-0.10	0.00	-0.10	0.00	0.09	0.12	0	0.03
5	-0.10	-0.10	-0.10	-0.10	0.00	0.00	-0.10	0.00	-0.10	0.00	-0.10	0.00	0.10	0.13	0	0.03
6	-0.20	-0.20	-0.10	-0.10	0.00	0.00	-0.10	0.00	-0.10	0.00	-0.10	0.00	0.11	0.14	0	0.04
7	-0.20	-0.20	-0.20	-0.10	0.00	0.00	0.00	0.00	0.00	0.00	-0.10	0.00	0.11	0.14	0	0.04
8	-0.20	-0.20	-0.20	-0.10	0.00	0.00	0.00	0.00	0.00	0.00	-0.10	0.00	0.11	0.14	0	0.04
9	-0.20	-0.20	-0.20	-0.10	0.00	0.00	0.00	0.00	0.00	0.00	-0.10	0.00	0.11	0.14	0	0.04
10	-0.20	-0.20	-0.20	-0.10	0.00	0.00	0.00	0.00	0.00	0.00	-0.10	0.00	0.10	0.14	0	0.04

Notice that the results of the two models are very close in period 3 when the shock hits. In the following periods, the results are slightly different for some variables because of the dynamics reflected in the expected variables.

In the following table, we compare the results of the models when consumption price index is chosen as the numeraire in the PEP-1-t model and the inflation gap takes a significantly high weight in the interest rate rule in the monetary model (Case C). Again the results are close, especially in period 3. Slight differences in the subsequent periods could again be because of the changes in the expected variables.

Table 3. Consumption price index is the numeraire (% deviations from the BGP values)

	GDP (real)		Consumption (nominal)		Export (nominal)		Government spending (real)		Import (nominal)		Investment (nominal)		Consumption price index		Exchange rate	
T	PEP	M-PEP	PEP	M-PEP	PEP	M-PEP	PEP	M-PEP	PEP	M-PEP	PEP	M-PEP	PEP	M-PEP	PEP	M-PEP
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	**0**	**0**	**0.3**	**0.3**	**-1.2**	**-1.1**	**8.4**	**8.4**	**-1**	**-1**	**-4.1**	**-4.1**	**0**	**0.025**	**-0.874**	**-0.843**
4	-0.1	-0.1	-0.1	-0.1	-0.2	-0.1	0.2	0.1	-0.2	-0.1	-0.2	-0.2	0	0.029	-0.116	-0.081
5	-0.1	-0.1	-0.1	-0.1	-0.2	-0.1	0.2	0.1	-0.2	-0.1	-0.2	-0.2	0	0.032	-0.131	-0.093
6	-0.2	-0.2	-0.1	-0.1	-0.2	-0.1	0.2	0.1	-0.2	-0.1	-0.2	-0.2	0	0.034	-0.139	-0.097
7	-0.2	-0.2	-0.2	-0.1	-0.2	-0.1	0.2	0.1	-0.2	-0.1	-0.3	-0.2	0	0.036	-0.142	-0.097
8	-0.2	-0.2	-0.2	-0.1	-0.2	-0.1	0.2	0.1	-0.2	-0.1	-0.3	-0.2	0	0.038	-0.142	-0.095
9	-0.2	-0.2	-0.2	-0.1	-0.2	-0.1	0.1	0.1	-0.2	-0.1	-0.3	-0.2	0	0.04	-0.14	-0.091
10	-0.2	-0.2	-0.2	-0.1	-0.2	-0.1	0.1	0.1	-0.2	-0.1	-0.3	-0.2	0	0.042	-0.138	-0.085

Based on the results shown in the above tables, one can argue that the current monetary model is set up to be a general version of the PEP-1-t model with nominal rigidities. The interest rate rule can be seen as a hybrid yet endogenous numeraire so that the current model has an absolute price. Alternatively, the interest rate rule represents the money market equilibrium condition (that is the LM curve equation). Without it, we fix the nominal or the real interest rate which pins down a particular equilibrium point on the IS curve – the goods market equilibrium. The interest rate rule satisfies both the real and monetary side of the economy. It is one side of a coin while the other side is the real economy – the IS curve.

3.2.2 Comparison simulations

Since the PEP-1-t model with nominal rigidities is a special case of the monetary PEP-1-t model, a question arises – which specification is the right one? Is it the monetary model with the popular Taylor rule? Or is it the one in which either the nominal exchange rate or the consumption price index is the numeraire? Below we compare the simulation results of the monetary model with the widely used interest rate rule in the literature ($\alpha_1 = \alpha_2 = 0.5$ and $\alpha_3 = 0$ in (11)) to those of the PEP-1-t model with different numeraire. The former is represented by "Taylor", the one with the exchange rate as the numeraire is represented by "Exchange rate" and the last one with consumption price index as the numeraire is "CPI". The shock is 10% increase in government spending in period 3.

Table 4 shows that the changes in real GDP are almost the same in the three cases, the changes in nominal consumption and export are quite different. Especially, the direction of changes in export is opposite in the "Taylor" case to those in the other two cases in period 3. The reason is that more inflation is created in the "Taylor" case while there are no absolute price in the other two cases. However, the real export decreases by 0.3% in the "Taylor" case as well.

Table 4. Results under different numeraire (% deviations from the BGP values)

	GDP (real)			Consumption (nominal)			Export (nominal)		
T	Taylor	Exchange rate	CPI	Taylor	Exchange rate	CPI	Taylor	Exchange rate	CPI
1	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0
3	**0.0**	**0.0**	**0.0**	**2.0**	**0.9**	**0.3**	**1.5**	**-0.3**	**-1.2**
4	-0.1	-0.1	-0.1	1.7	0.0	-0.1	2.7	0.0	-0.2
5	-0.1	-0.1	-0.1	1.7	0.0	-0.1	2.7	0.0	-0.2
6	-0.1	-0.2	-0.2	1.6	-0.1	-0.1	2.6	0.0	-0.2
7	-0.1	-0.2	-0.2	1.5	-0.1	-0.2	2.4	0.0	-0.2
8	-0.1	-0.2	-0.2	1.4	-0.1	-0.2	2.2	0.0	-0.2
9	-0.1	-0.2	-0.2	1.2	-0.1	-0.2	2.0	0.0	-0.2
10	-0.1	-0.2	-0.2	1.1	-0.1	-0.2	1.7	0.0	-0.2

The results in Table 5 show that the changes in real government spending in all three cases are comparable in period 3. Investment expenditure decreases in all three cases although the magnitude is smaller in the “Taylor” case. The value of import increases in the “Taylor” case but decreases in the other two cases. However, the volume of import decreases in the “Taylor” case.

Table 5. Results under different numeraire (% deviations from the BGP values)

	Government spending (real)			Import (nominal)			Investment (nominal)		
T	Taylor	Exchange rate	CPI	Taylor	Exchange rate	CPI	Taylor	Exchange rate	CPI
1	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0
3	**6.6**	**7.8**	**8.4**	**1.3**	**-0.2**	**-1.0**	**-1.2**	**-3.1**	**-4.1**
4	-1.6	0.1	0.2	2.3	-0.1	-0.2	2.8	-0.1	-0.2
5	-1.6	0.1	0.2	2.3	-0.1	-0.2	2.8	-0.1	-0.2
6	-1.6	0.1	0.2	2.2	-0.1	-0.2	2.6	-0.1	-0.2
7	-1.5	0.1	0.2	2.1	0.0	-0.2	2.5	-0.1	-0.3
8	-1.4	0.1	0.2	1.9	0.0	-0.2	2.3	-0.1	-0.3
9	-1.2	0.0	0.1	1.7	0.0	-0.2	2.0	-0.1	-0.3
10	-1.1	0.0	0.1	1.5	0.0	-0.2	1.8	-0.1	-0.3

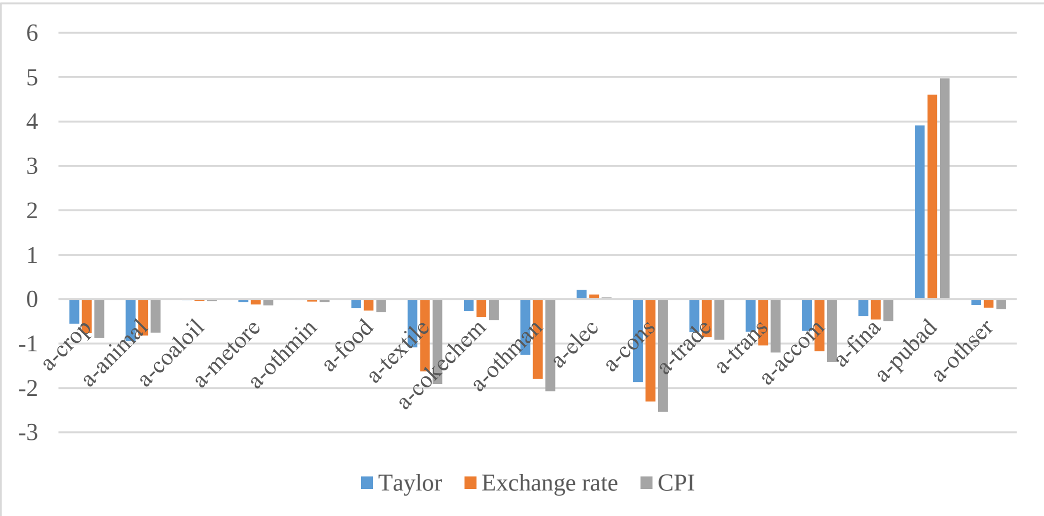
Table 6 compares the changes in consumption price index, the nominal exchange rate and nominal wage in the three cases. Evidently, all three prices increase in the “Taylor” case in period 3 indicating that model has an absolute price. In the presence of nominal rigidities, an increase in the absolute price level can have a real effect.

Table 6. Results under different numeraire (% deviations from the BGP values)

	Consumption price index			Nominal exchange rate			Nominal wage		
T	Taylor	Exchange rate	CPI	Taylor	Exchange rate	CPI	Taylor	Exchange rate	CPI
1	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0
3	**2.137**	**0.726**	**0**	**1.698**	**0**	**-0.874**	**2.904**	**1.860**	**1.323**
4	2.213	0.092	0	2.565	0	-0.116	1.380	-0.211	-0.295
5	2.196	0.104	0	2.541	0	-0.131	1.401	-0.209	-0.303
6	2.107	0.109	0	2.443	0	-0.139	1.378	-0.204	-0.304
7	1.965	0.110	0	2.285	0	-0.142	1.319	-0.197	-0.301
8	1.783	0.110	0	2.084	0	-0.142	1.231	-0.190	-0.296
9	1.576	0.107	0	1.852	0	-0.140	1.120	-0.183	-0.289
10	1.354	0.104	0	1.603	0	-0.138	0.995	-0.176	-0.281

The results on the selected macroeconomic variables show that price inflation is created because of the shock in the "Taylor" case. The following figure is an example showing the percentage change in the value added of each industry in period 3. It is clear that the choice of the numeraire matters in the PEP-1-t model in the presence of nominal rigidities. Except for a-animal and a-elec sectors, the changes are greatest in the "CPI" case but smallest in the "Taylor" case in all sectors.

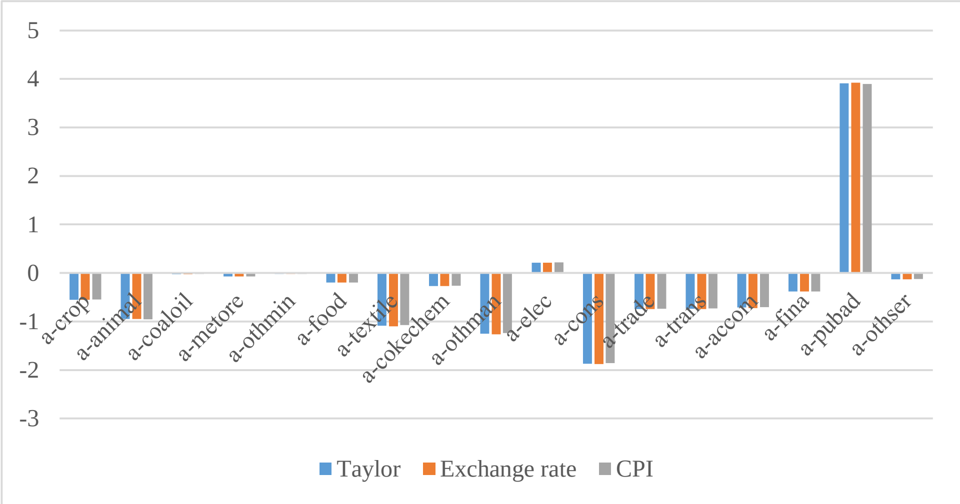
Figure 1. Results under different numeraire (% deviations from the BGP values)



Based on the above results, we argue that the PEP-1-t model could give results in the presence of nominal rigidities as it ignores the change in absolute price. Interestingly, when we shock the numeraire in the PEP-1-t model with a value generated in the "Taylor" case, the results of the three cases become very close. This is an attempt to incorporate the impact of the change in absolute price in the PEP-1-t model. As an example, we show below Figure 1 after the shocks to the respective numeraire in the "Exchange rate" and "Taylor" cases. Specifically, we fix consumption price index in period 3 at 1.148

in the “CPI” case and the nominal exchange rate at 1.098 in the “Exchange rate” case together with the 10% increase in government spending in period 3. Figure 2 shows the results.

Figure 2. After shocking the numeraire (% deviations from the BGP values)



3.2.3 Simulation in a sticky wage situation

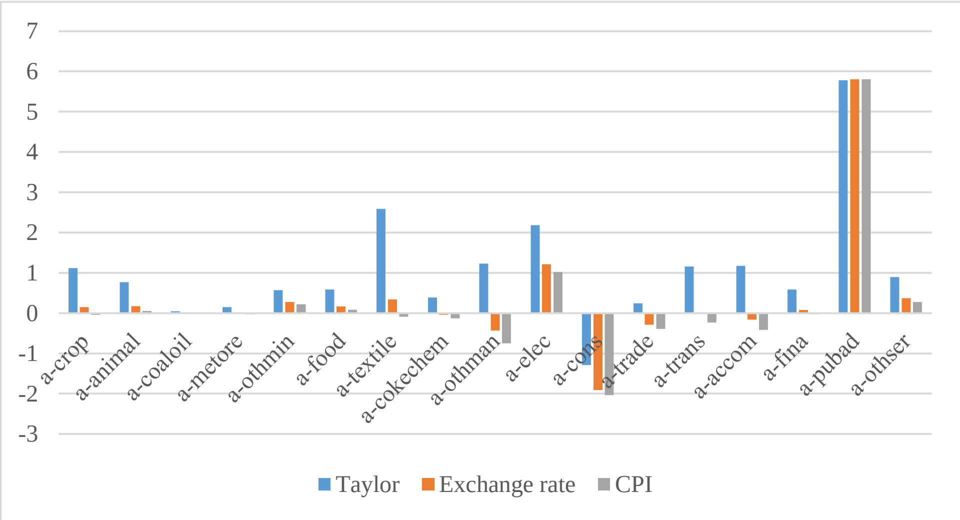
In the previous simulations, nominal wage is flexible and the economy operates at full employment. Yet the shock has distributional impacts. In the modern state-of-art macroeconomic research such as DSGE models (e.g., Christiana et al., 2005, Smets and Wouters, 2007), it is common to consider a form of sticky wage, price and inflation. In this subsection, we consider sticky wage in the PEP-1-t and the current model with the Taylor rule – i.e., nominal wage grows uninterrupted in the simulation over the 10 periods. The level of employment absorbs the impact of shocks. Our focus is on period 3 under the same shock – 10% increase in nominal government spending. The results are shown below where “Taylor” represents the current model with the Taylor rule, “Exchange rate” represents the PEP-1-t model in which the nominal exchange rate is the numeraire and “CPI” represents the PEP-1-t model in which consumption price index is the numeraire.

Table 7. Macroeconomic variables (% deviations from the BGP values)

	Taylor	Exchange rate	CPI
GDP (real)	0.7	0.4	0.4
Consumption (nominal)	2.4	0.8	0.5
Government spending (real)	7.9	8.8	8.9
Investment (nominal)	-1.3	-3.3	-3.7
Export (nominal)	0.5	0.0	-0.5
Import (nominal)	-0.3	-0.1	-0.1
Consumption price index	1.9	0.3	0.0
Nominal exchange rate	2.2	0.0	-0.4
Employment	2.3	1.3	1.1

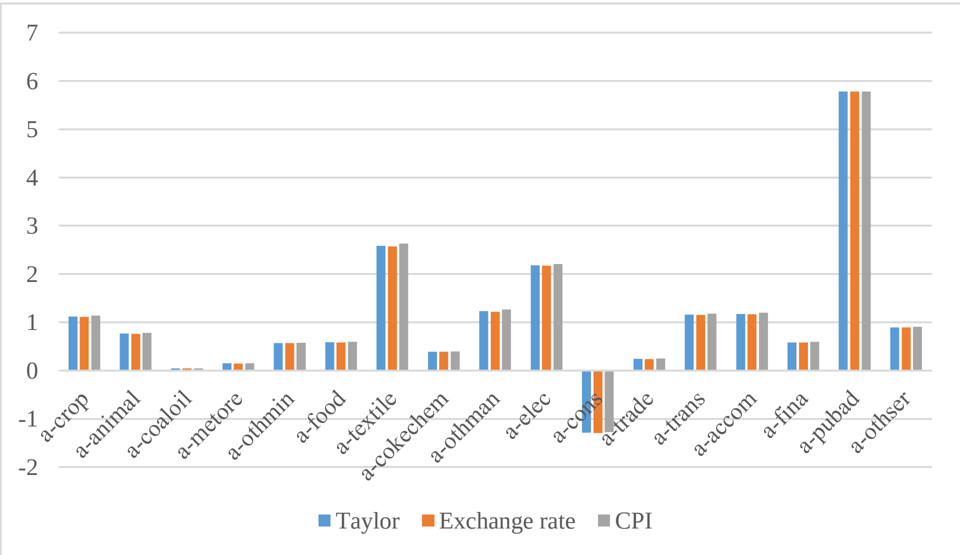
As can be seen, the current model with the Taylor rule generates inflation so that real wage falls and creates an opportunity for producers to increase their employment and production. In the other two cases, however, almost no inflation is created as the central bank adjusts its policy to maintain the constant numeraire so that the real effect is much smaller. The impact of the shock on the production of sectors is very different as shown in the following figure.

Figure 3. Production by sectors (% deviations from the BGP values)



Interestingly, if we shock the numeraire in the "Exchange rate" and "CPI" cases with those generated from the "Taylor" case (1.104 and 1.145 respectively) in addition to the common shock, the results in the three cases are again very similar. For instance, see the following figure for the changes in production by sectors.

Figure 3. Production after shocking the numeraire (% deviations from the BGP values)



5. Conclusion

In this paper, we intend to show that the choice of numeraire matters in a CGE model with nominal rigidities. Simulation results under fixed exogenous numeraire could be misleading as it does not account for changes in absolute price. Based on these findings, we suggest a simple monetary policy interest rate rule. The interest rate rule replaces numeraire. A model with fixed numeraire can be derived as a special case of the monetary model. The interest rate determines absolute price level endogenously. Consequently, the same shock could have different effects from those in a model with fixed numeraire. A model with fixed numeraire can generate the same results as as the monetary model if we know exactly how to shock the numeraire. We demonstrate these findings using the PEP-1-t model.

References

Christiano, L., Eichenbaum, M., and Evans, C. (2005). *Nominal rigidities and the dynamic effects of a shock to monetary policy*. Journal of Political Economy, 113 (1), pp. 1–45.

Decaluwé, B., Lemelin, A., Robichaud, V., and Maissonnave, H. (2013). *The PEP Standard Single-Country, Recursive Dynamic CGE Model.* Partnership for Economic Policy. Available at https://www.pep-net.org/pep-standard-cge-models.

Smets, F., and Wouters, R. (2007). *Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach*. American Economic Review, 97(3), pp. 586-606.

Svensson, Lars E. O., (2000). *Open-Economy Inflation Targeting.* Journal of International Economics, 50 (1), pp. 155-183.

Taylor, John B., (1993). *Discretion Versus Policy Rules in Practice*. Carnegie-Rochester Conference Series on Public Policy, 39, pp. 195-214.

Appendix

Mongolian macro SAM 2017 (% of GDP)

		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1	**Labor**								0.6	45.2						46
2	**Capital**								0.1	45.4						45
3	**Households**	44.8	33.6		11.6				2.1							92
4	**Government**			3.2		13.1	1.7	7.4	0.2	0.4		0.0				26
5	**Direct taxes**			13.1												13
6	**Import duties**										1.7					2
7	**Indirect taxes**										7.4					7
8	**Rest of the world**	0.9	11.9	0.7	2.0						56.3					72
9	**Sectors**										126.2	53.8				180
10	**Commodities**			53.5	12.7					89.1	15.2	4.9	18.7	5.9	6.7	207
11	**Export**								58.7							59
12	**Private invest**			17.4	-0.3				8.3							26
13	**Public invest**			4	-0.1				1.9							6
14	**Inventories**												6.7			7
15	**TOTAL**	46	45	92	26	13	2	7	72	180	207	59	25	6	7	