Small Open Economy DSGE Model with Natural Disaster and Foreign Aid

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Background and Motivation

The Philippines is one of the countries in the ASEAN region to be regularly hit by natural disasters. In an analysis of natural disaster hotspots, the Philippines is one among several countries where large percentages of the population reside in disaster-prone areas (Hazard Management Unit of the World Bank, 2005). Consequently, these catastrophic events also entail adverse macroeconomic impacts to the economy (Bergeijk & Lazzaroni, 2015). Raddatz (2007) estimated that climate-related disasters reduce real GDP per capita by 0.6%. In the Philippines, Benson (1997) reported a reduction in GDP growth rate forecast by 3.3% following the Luzon earthquake in July 1990. In reality, the actual reported GDP growth rate in 1990 was even lower than the forecasted with an actual value of only 3.0%. Benson (1997) also noted that there was also a reported stagflation or an increase in both inflation and unemployment at 14% and 10.6%, respectively. A more recent joint study prepared by the Philippine government with the Asian Development Bank (ABD) and World Bank (WB) also reports a reduction in GDP growth rate forecast, an increase in government spending, and a decline of tax revenue collection following the tropical depression Ketsana (Ondoy) in 2009 (Post-Disaster Needs Assessment, 2010).

In the advent of calamities, both Yang (2008) and Becerra et al. (2014) reported a surge of foreign aid in the form of humanitarian relief to developing countries after a natural disaster. As an example, the Philippines received an estimated amount of US$17.69 million of humanitarian aid in the aftermath of typhoon Bopha (Pablo), which struck the country in 2012 (United Nations Office for Coordination of Humanitarian Aid, 2013). However, foreign aid absorption by the recipient country may lead to Dutch disease effects such as volatility in the exchange rates and resource allocation. These Dutch disease effects may undermine recovery and economic stability efforts of the Philippine government in the aftermath of a natural disaster. Empirical studies such as those by Rajan and Subramanian (2011) and Fielding and Gibson (2012) have shown that foreign aid may lead to Dutch disease effects. Furthermore, Javaid (2011) observed that foreign aid in South-East Asian countries leads to a real exchange rate appreciation, which is an implicative sign of a Dutch disease.

Statement of the Problem

Given the inflationary impact of natural disasters and the foreign aid surge in its aftermath, there is a tradeoff in monetary policy response: whether the monetary authority should strive in continuing to only control for inflation or be concerned with any Dutch disease effects caused by foreign aid. The conflicting reactions made by the central banks of different countries to a natural disaster do not provide any insight and resolution as to which is the suitable policy response to these catastrophic events. Although there have been several studies done on the economic impact of natural disasters, unfortunately, minimal consideration has been given to the monetary aspect of natural disasters (Cavallo and Noy, 2011). Raschky and Schwindt (2009) mentioned that studies on the effects of natural disasters on developing nations have focused extensively on several aspects such as a country's political institution or income inequality, but foreign aid has received minor attention from any academic discourse. In addition, Okuyama (2007) also noted that previous studies on natural disaster impacts on the economy have remained fairly ad hoc, implying the lack of theoretical support. He recommended that future research on the economic modeling of natural disasters needed to focus more on providing plausible theoretical foundations. He added that theoretical formulations of aid, which may lead to behavioral changes under disaster situations, require more research in order to be incorporated in economic models. Keen and Pakko (2011) is the only paper, as of writing, that has tried to model natural disasters in a theoretically founded model with natural disasters as a specific shock to the economy. Although the paper is seminal in its study of natural disasters, the model is a closed economy and lacks a fiscal authority. The model was also developed for an advanced economy and therefore fails to account for any increases in foreign aid after a natural calamity. There is, therefore, a need to develop an open economy model for developing countries that are prone to natural disaster shocks.

Objectives of the Study

This study has the following objectives that it aims to resolve: (1) development of a small open economy DSGE model with natural disaster shocks and foreign aid for the Philippine economy; (2) study the effects of natural disasters on a small open economy; and (3) evaluate monetary policy rules amidst the possibility of natural disasters occurring and the surge in foreign aid afterwards.

Theoretical Framework

Determination of the optimal choice for a monetary policy rule was first analyzed by Poole (1970). He showed how the stochastic structure of the economy would determine the optimal instrument choice. In extension, following the works of Rotemberg and Woodford (1997, 1999), most of the recent literature has adopted a welfare-based criterion. The policy rule that minimizes welfare losses is deemed to be the optimal policy rule.

A large literature on macroeconomic policy has focused on the incentives policymakers face when setting their policy instrument. The seminal work of Kydland and Prescott (1977) has brought attention to the issues of credibility and the ability to commit to policies. A policy is said to be time-consistent if it remains optimal to implement in future time periods. Conversely, if the policymaker has an incentive to renege on its announced policy, then such a policy is said to be time-inconsistent. Barro and Gordon (1983) applied the concept of time-consistent policies to determine whether a discretionary or rule-based monetary policy is optimal. They concluded that discretionary policies are worse than rule-based ones since the former can be shown to produce inflation bias.

Dutch Disease was first coined by *The Economist* in 1977 to describe the decline in the manufacturing sector in the Netherlands after the discovery of natural gas reserve in 1959. Corden and Neary (1982) was the first to model the phenomenon and was linked to capital inflows by van Wijnbergen (1984). Dutch disease occurs when a surge of capital inflow induces an increase in the non-tradable sectors such as construction efforts in the aftermath of a natural calamity. This causes the price of non-tradable goods to increase and with the price of tradable goods held fixed, the ratio of prices for non-tradable and tradable (i.e. the real exchange rate) increases. The outcome will then make tradable goods of the recipient country less competitive leading to loss of output. Empirical studies such as those by Rajan and Subramanian (2011) and Fielding and Gibson (2012) have shown that foreign aid may lead to Dutch disease effects.

The IMF (2005) distinguished between two policy responses to an increase in foreign aid, namely, absorption and spending of aid. Aid absorption is defined as the extent to which current account net of aid widens due to an increase in foreign aid, while aid spending is defined as the widening of the fiscal deficit net of aid that follows an increase in foreign aid. The monetary authority controls the absorption of aid through the sale of foreign exchange, while the fiscal authority controls the spending. Several papers have been done to study the effects of foreign aid surges and the appropriate monetary policy responses in low-income countries using a DSGE model, most of which were developed for Sub-Saharan African countries (e.g. Peiris and Saxegaard, 2007; Adam et al., 2009; and Berg et al., 2010). These studies have shown that monetary policy decisions are just as imperative as fiscal policy decisions in handling foreign aid; since it is only monetary policy alone that can contain the effects of foreign aid to the overall economy.

Review of Literature

Economic research on natural disasters and their consequences remain fairly limited. Previously, several research projects have examined the economic impact of specific natural disaster events (see Horwich, 2000; Selcuk and Yeldan 2001; Hallegatte, 2008; and Vigdor, 2008). These case studies were typically written immediately after the event and, thus, reported mostly on its short-term impact or the causes for some of the damages. However, a small, but growing empirical literature has emerged over the last few years on the macroeconomic and development impacts of natural disasters. Empirical studies such as those by Raddatz (2007) and Hochrainer (2009) documented the negative impact on short-term economic growth, while Herger et al. (2008) observed that growth collapses because climatic disasters are associated with the deterioration of fiscal and trade deficits. However, the works of Alabala-Bertrand (1993) and Skidmore and Toya (2002) suggested that natural disasters generate positive short-term economic growth due to reconstruction efforts of the economy. Eventually, Loayza et al. (2009) settled the conflicting results by distinguishing between small and large disasters with the former generating a positive impact on growth while the later deteriorates it. Moreover, the same study indicated that the macroeconomic impacts of natural disasters are smaller for advanced economies relative to developing ones and that those most affected by natural disasters are the ones that reside in developing countries.

Several papers have studied the economic damages and losses of natural disasters on interrelated industries by employing inter-industry analysis such as Input-Output (IO) models and Computable General Equilibrium (CGE) analysis. Examples of such papers are those by Okuyama (2004), Rose and Liao (2005), and Hallegatte (2008). These papers mostly explore the system-wide impact of indirect costs to inter-industry relationships. However, Rose and Liao (2005) warned that IO models were pessimistic in their estimates as substitution failed to take place in the production system. Conversely, CGE models were deemed too optimistic as these models failed to take into account nominal rigidity. Instead, the study deems CGE models best suited for long-run analysis.

Keen and Pakko (2011) have modeled natural disasters in a dynamic stochastic general equilibrium (DSGE) model using the Barro-Rietz rare disaster hypothesis. To distinguish their framework from the studies on rare disasters, they assumed that natural disaster shocks are infrequent events as opposed to rare occurrences. This characteristic of natural disaster shocks was then modeled using a two-state Markov switching process wherein the economy can either be in a "normal" or "disaster" state. Their study aimed at evaluating the impact of Hurricane Katrina in the U.S. economy as well as determining the optimal monetary policy response to natural disaster shocks. The study found that the optimal monetary policy design is to raise interest rates, which was contrary to prior public expectations at that time. This result holds whether the monetary authority follows a simple Taylor rule or an optimal policy setting that replicates the efficient markets solution.

Methodology

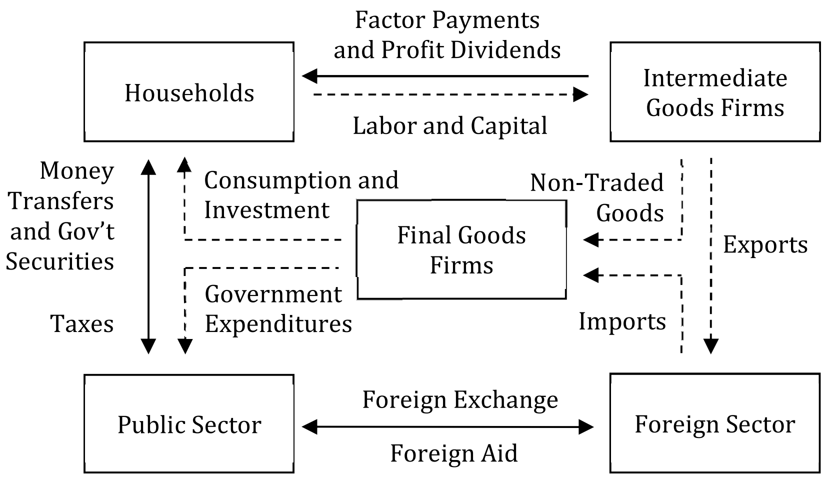
This paper employs a dynamic stochastic general equilibrium (DSGE) model to determine the optimal monetary policy strategy in response to natural disasters. DSGE models have several benefits, which make them ideal for macroeconomic policy analysis. They are micro-founded in the sense that equations in the model are derived from optimizing the behavior of economic agents. They, thus, describe the behavior of the economic agents in terms of parameters that are not expected to change as a result of changes in economic policy, thereby validating the analysis of alternative policies. The structural characteristic of DSGE models also allows policy interventions and their transmission mechanism to be clearly identified. This is because each equation in the model has an economic interpretation which assists in the discussion of alternative policies. DSGE models are also forward-looking that requires economic agents to form rational expectations on the evolution of the economy. Lastly, the stochastic nature of DSGE models permits the analysis of the effects of unanticipated random shocks to the economy. These features of DSGE models make them less susceptible to the Lucas critique and, therefore, are suitable for policy analysis. DSGE models have also been found to empirically outperform traditional autoregressive models (Smets and Wouters, 2003).

Model

The model closely follows Peiris and Saxegaard (2007) in introducing foreign aid to a small open-economy model. The basic structure of the DSGE model consists of perfectly competitive final goods firms whose output is eventually consumed by both the domestic private and public sector. The inputs used in the production of the non-tradable final good are either produced domestically or imported by monopolistically competitive intermediate goods firms. The domestically produced goods, which are produced using non-destroyed capital and labor, are sold either in the domestic intermediate goods market or exported abroad. The model assumes that the capital account is closed. The markets for capital and labor are assumed to be perfectly competitive. In accordance with Dutch disease literature, learning-by-doing in the production of domestic intermediate goods is incorporated in the model (see Van Wijnbergen, 1984; Krugman, 1987; Matsumaya, 1992; Sach and Warner, 1995; Pratti and Tressel, 2006). The public sector is composed of the government and a central bank which serves as the fiscal and monetary authority, respectively. The study assumes that the government commits to the fiscal rule of fully spending any foreign aid received, while the central bank follows a policy rule on foreign exchange intervention and open-market operations.

The DSGE model is also structured in the tradition of New Keynesian models with market inefficiencies in the form of real and nominal rigidities. Three sources of inefficiency included in the model are: (1) monopolistically competitive intermediate goods market, (2) price rigidity in the domestic intermediate goods market, and (3) capital adjustment costs. These market inefficiencies provide a rationale for monetary and fiscal stabilization policy. Money is introduced in the model using the conventional money-in-the-utility function model developed by Sidrauski (1967).

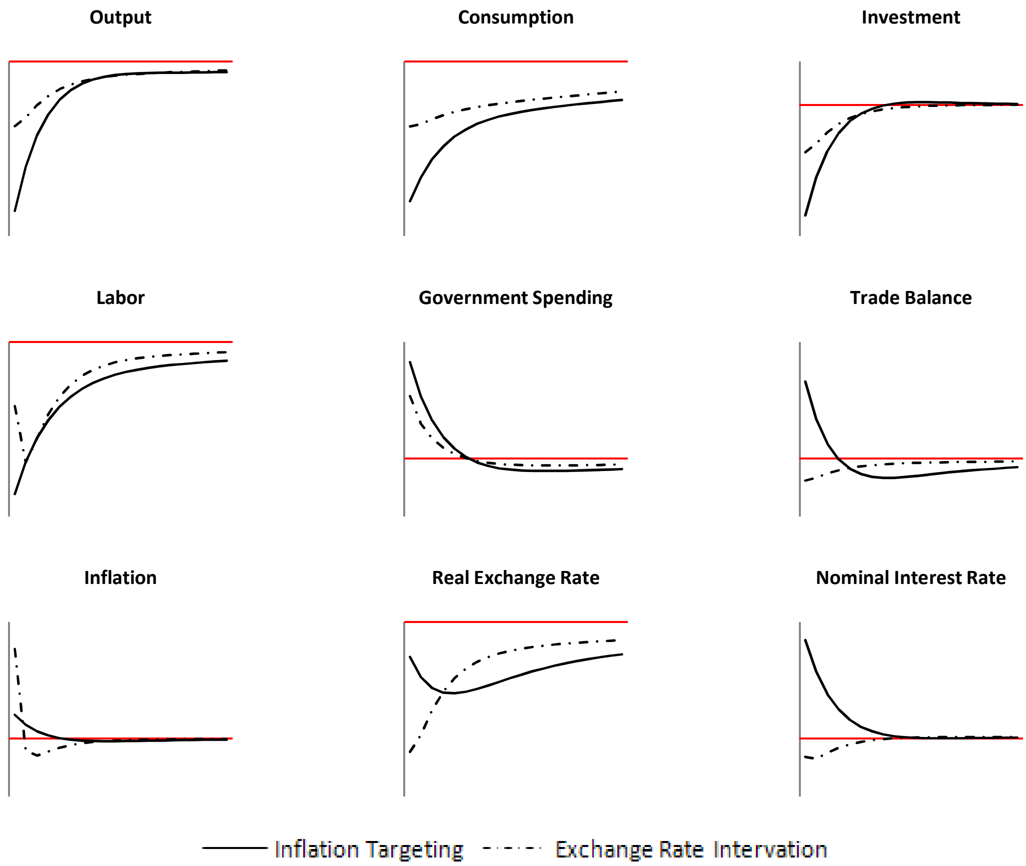
Determination of the optimal monetary policy rule follows that of Rotemberg and Woodford (1997, 1999). Sources of uncertainty in the model are several stochastic shocks that are either real or nominal. The natural disaster shocks are incorporated into the model using the framework of Keen and Pakko (2011) and transmission mechanism of these shocks is through the Barro-Rietz rare disaster hypothesis. The study contributes to the literature by allowing foreign aid and other economic shocks to be affected by natural disaster in order to capture the surge of capital flow and changes in the economic environment in the aftermath of a climatic disaster.



The figure above provides a schematic diagram of the DSGE model, which details the circular flow of the model economy. Solid lines illustrate the circulation of nominal variables, while dashed lines represent the flow of real variables.

Monetary Policy in a Natural Disaster-Prone Economy

This section will now explore the impact of natural disaster shocks under two alternative monetary policy rules, namely: an inflation targeting policy and an exchange rate intervention policy; the former being the primary policy followed by the BSP and the latter as a way to control for Dutch disease effects. The analysis is achieved by performing policy simulation exercises using the small open economy DSGE model developed in the previous section.



The figure above shows the small open economy contracts in the aftermath of an unanticipated natural disaster shock. This contraction is evidenced by the decrease in final output production, household consumption, and investments. The graphs also reflect the inflationary nature of natural disasters, disruptions in employment or labor hours, as well as the increase in government expenditures in the form of rehabilitation and reconstruction expenditures that is financed by foreign aid received from the foreign sector. The rise in the overall inflation rate in the economy and along with the Dutch disease effects causes the real exchange rate for the country to appreciate as expected. The simulated response for trade balance and nominal interest rate vary with the respective monetary policy rule implemented by the monetary authority.

The sluggish convergence of final output production to its steady state is attributed mostly to household consumption being unable to converge to its own steady state. The other components of GDP, such as investments and government expenditures, eventually converge to their own respective steady states. This result characterizes the transitory effects of natural disasters on final output in the economy, while the high persistence of natural disaster shock is reflected in household consumption. Without any policy mechanism to bring household consumption to its steady state, the simulated results evidently show the long-term real effects of natural disaster to the small open economy.

The effects of both alternative monetary policies differ only in the short-run and both policies are indistinguishable in the medium- to long-run. Inflation greatly increases under an exchange rate intervention policy than in inflation targeting rule. Unsurprisingly, volatility in the inflation rate is also more pronounced under an exchange rate intervention than in inflation targeting. The real exchange rate greatly appreciates initially under an exchange rate intervention due to the higher inflation response of the said policy and the lack of consideration to stabilize the rising overall inflation rate. In comparison, the real exchange rate converges faster and monotonically to its steady state under an exchange rate intervention policy. The quick response to the appreciating real exchange rate minimizes the deviation in the trade balance that is also eventually reflected in the final output production.

There is an apparent contrast in the monetary policy response to an unanticipated natural disaster shock wherein the nominal interest rate increases under inflation targeting, but falls under exchange rate intervention. The former result is consistent with the findings of Keen and Pakko (2011). They argued that when the monetary authority uses a Taylor-style inflation targeting rule, an increase in the nominal interest rate is an optimal monetary policy response to an unanticipated natural disaster shock. However, nominal interest rates fall under an exchange rate intervention policy in order for the real exchange rate to depreciate and promptly return to its corresponding steady state value.

Due to the large difference between alternative monetary policies on the decrease of the real exchange rate, the effect of an unanticipated natural disaster shock to the trade balance differs under each respective monetary policy rule. The small open economy experiences an initial widening of the trade deficit due to the appreciation of the real exchange rate under an exchange rate intervention policy. In contrast, there is an initial trade surplus that deteriorates to a trade deficit subsequently under inflation targeting rule. This simulated result of the trade balance under inflation targeting can be attributed to an inverted J-curve response the trade balance to the initial real exchange rate appreciation.

Welfare Evaluation

Following the works of Rotemberg and Woodford (1997, 1999), most of the recent literature on optimal monetary policy has adopted a welfare-based criterion. The policy rule that minimizes social losses is deemed to be the optimal policy rule. Social loss is assumed to depend on the deviations of output and inflation from their steady state. In extension to an open economy DSGE model, the welfare criterion should include not only variation in output and inflation but also on the real exchange rate. Following Parrado (2004), the welfare criterion used in the study is specified as follows:

$$L = \Phi_Y \mathbb{V}[Y_t] + \Phi_\pi \mathbb{V}[\pi_t] + \Phi_\epsilon \mathbb{V}[\epsilon_t]$$

where ϵ_t denotes the real exchange rate in terms of domestic goods per foreign goods and the parameters Φ_Y, Φ_π, and Φ_ϵ reflect the weights attached to each macroeconomic indicator. Similar to Parrado (2004), the parameter weights are assigned the following values: $\Phi_Y = 0.5$, $\Phi_\pi = 1.5$, and $\Phi_\epsilon = 0.5$. While the assignment of weight values is arbitrary, Rotemberg and Woodford (1997) showed that the social welfare loss, expressed in terms of household utility losses as a consequence of deviations from the optimal allocation, can be approximated by the intertemporal quadratic objective function. This results to the welfare losses parameters as being functions of the model's structural parameters only and, therefore, independent to the stochastic shocks in the economy. In addition, Parrado (2004) stated that the results from the welfare evaluation does not differ with alternative parameter values. In summary, the design of optimal monetary policy response involves minimizing equation above by comparing the alternative monetary policy rules of inflation targeting and exchange rate intervention.

Optimal Monetary Policy

The monetary policy rules under consideration in the analysis of the optimal policy are inflation targeting and exchange rate intervention. Within the context of the small open economy DSGE model developed in the study, inflation targeting is achieved through a Taylor rule and implemented by the monetary authority by conducting open market operations, while exchange rate intervention follows a crawling peg rule and implemented through a sterilized accumulation or diminution of foreign exchange reserves. To determine the optimal monetary policy amidst natural disaster, welfare losses under alternative monetary policy rules were computed and compared. The table below summarizes the variances of total output, inflation, and real exchange rates as well as the welfare losses computed using the equation in the previous section for each monetary policy regime.

Monetary Policy Rule	Y	π	ϵ	L
Inflation Targeting	6.78E-04	1.08E-06	4.00E-05	3.61E-04
Exchange Rate Intervention	2.14E-04	1.02E-05	3.36E-05	1.39E-04

Comparison of the variances of each macroeconomic indicator in the table shows that inflation targeting is better at stabilizing inflation, while exchange rate intervention is better at stabilizing the real exchange rate and final output. As seen in the IRF graphs, the former result is evidenced by the small deviation of inflation from its steady state and its monotonic converge, while the latter is reflected on the monotonic and prompt convergence of the real exchange rate to its steady state. The immediate response of an exchange rate intervention policy to an appreciation of the real exchange rate only leads to a small deviation of the trade balance from its steady state under the said policy as compared to an inflation targeting rule. This result is then reflected in the final output production, where the initial deviation from its steady state is minimized under an exchange rate policy, relative to an inflation targeting rule. In accordance to these simulated results, comparison of the welfare losses amidst natural disasters and in an environment where natural disasters have economic consequences shows that exchange rate intervention is the optimal monetary policy in such situations. This result is due to the fact that exchange rate intervention as a selected monetary policy responds to the Dutch disease effects whereas an inflation targeting policy does not.

Concluding Remarks

The study has found that an exchange rate intervention policy is the optimal monetary response to a simulated natural disaster shock. The rationale is that the exchange rate intervention policy insulates the economy from any Dutch disease effects thereby stabilizing the economy faster than an inflation targeting rule. Although an inflation targeting policy does stabilize inflationary pressure of natural disasters faster, its slow response to a real exchange rate appreciation causes fluctuations in the trade balance and, therefore, to the economy's final output. In addition, the study found that monetary policy response alone cannot mitigate the long-term real effects of natural disasters, as evidenced by the failure of consumption and final output to converge back to their steady state values. Furthermore, the exchange rate intervention policy also implies that a post-disaster expansionary monetary policy is also optimal.

Given the progress in analyzing natural disaster shocks to a small open economy such as the Philippines, there are still avenues for further research to be made and explored. One possible extension to the current DSGE model is to expand the role of fiscal policy and distinguish between the national and local government as developed by Tamegawa (2012). As the effects of natural disasters tend to be localized in affected areas, specifying different roles for a national and local government should provide a better policy recommendation on the fiscal side of policymaking. Another possible extension is the incorporation of a financial market as well as differentiating households as either Ricardian or non-Ricardian as in Gali et al. (2007). Extending the study in such a manner could determine whether the optimal monetary policy is robust in the presence of financial market imperfections. Incorporation of non-Ricardian households also provides a more realistic perception of the economy, especially since the Philippines is a developing nation where the majority do not have access to financial markets. Lastly, since the Philippine economy receives a large amount of remittances, analysis of the effects of both foreign aid and remittances to a small open economy is also needed.

In conclusion, the findings and policy recommendations of Keen and Pakko (2011) may be valid for advanced economies such as the US where open market considerations can be omitted from the analysis; however, for developing countries that are export reliant and recipients of foreign aid, open market considerations are indeed paramount in policy analysis. The key contribution of this study to the literature is that it provides sufficient evidence that the optimal monetary policy response may vary in certain economic problems. As the results of this study have shown, occasional discretion on the part of the monetary authority may be advised.

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Appendix

This appendix provides a detailed discussion on the small open economy DSGE model developed in the study. The private sector in the economy is composed of households, the domestic intermediate goods firms, and the final goods firms. Both the domestic intermediate goods firms and the final goods firms are assumed to be owned by households and therefore profits generated by these firms in the economy are accrued to said households. The model is completed with a description of the public sector, the aggregation process, and market clearing conditions.

Households

The economy is assumed to be comprised of a unit mass of identical households indexed by $j \in (0,1)$. Households derive utility from consumption, leisure, and real money holdings. The expected lifetime utility for household j is summarized as follows

$$\mathbb{E}_t \sum_{s=0}^{\infty} \beta^{t+s} \left[\ln C_{t+s}(j) - \frac{\vartheta}{1+\psi} L_{t+s}(j)^{1+\psi} + \frac{1}{1-\eta} \left(\frac{M_{t+s}(j)}{P_{t+s}} \right)^{1-\eta} \right]$$

where C_t is consumption, L_t is labor supplied, and M_t/P_t is real money holdings, and P_t is the consumer price index. $\beta \in (0,1)$ denotes the household's subjective discount factor, ϑ is the disutility of labor parameter, and ψ is the inverse Frisch elasticity of labor supply. Households supply labor and capital to the factor markets and are assumed as equal owners of domestic firms. Households also hold money and interest-earning government securities. Household j's nominal intertemporal budget constraint is given by

$$\begin{aligned} M_t(j) + B_t^p(j) + P_t[C_t(j) + I_t(j)] \\ = M_{t-1}(j) + (1+i_{t-1})B_{t-1}^p(j) + \int_0^1 \Pi_t^d(i)di + W_t L_t(j) + R_t K_t(j) - T_t \end{aligned}$$

where B_t^p is household holdings of government securities that pays a nominal interest rate of i_t, I_t is the level of investments, $\Pi_t^d$is profit from domestic firms, W_t is nominal wages, R_t is nominal rental rate on capital, and T_t is lump-sum taxes (or transfers) from the government. Households also engage in capital investment activities in the model economy. Following Hayashi (1982), each household faces a capital adjustment cost of the following functional form

$$\frac{\phi}{2} \left(\frac{I_t(j)}{K_t(j)} - \delta \right)^2 K_t(j)$$

where $\phi \geq 0$ and $\delta \in (0,1)$ denotes the depreciation rate of capital. In words, household j must pay an increasing and convex cost of net investment, where net investment is given by $I_t - \delta K_t$ and it is the level of investment over and above what is necessary to replace depreciated capital. The capital stock evolves according to the following capital accumulation rule

$$K_{t+1}(j) = (1-\delta)K_t(j) + I_t(j) - \frac{\phi}{2}\left(\frac{I_t(j)}{K_t(j)} - \delta\right)^2 K_t(j)$$

Household j seeks to maximize lifetime expected utility subject to the inter-temporal budget constraint and capital accumulation equations.

Final Goods Production

Final goods market is assumed to be perfectly competitive. Final goods Y_t are produced using non-tradable goods Q_t^n and imported goods Q_t^m. Production of final goods is given by a CES production function

$$Y_t = \left[\varphi^{\frac{1}{\sigma}}(Q_t^n)^{\frac{\sigma-1}{\sigma}} + (1-\varphi)^{\frac{1}{\sigma}}(Q_t^m)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}$$

where $\varphi \in (0,1)$ is the degree of home bias in production and σ denotes the elasticity of substitution between non-tradable and imported goods. Profit maximization should yield the demand for each intermediate good.

Intermediate Goods Production

Domestic intermediate goods market is assumed to be monopolistically competitive and is composed of a unit mass of firms. Since the firms in the economy are the same, domestic intermediate goods are produced by the following aggregate Cobb-Douglas production function

$$Y_t^d = Z_t(K_t')^{\alpha} L_t^{1-\alpha}$$

where Z_t is productivity, K_t' is non-destroyed capital that is available for production, and $\alpha \in (0,1)$ denotes the share of capital. Domestic intermediate goods are sold to both domestic and foreign final goods market. Cost minimization subject to the production function yields the firm's labor and capital demand.

Non-Traded Goods

Following Rotemberg (1982) and Schmitt-Grohe and Uribe (2004), firm i is assumed to face quadratic price adjustment costs of the following form

$$\frac{\theta}{2}\left(\frac{P_t^n(i)}{P_{t-1}^n(i)} - 1\right)^2 Q_t^n$$

when setting prices, where P_t^n is the price of nontradable goods and θ is a measure of price rigidity in the economy. Albeit most New Keynesian models use Calvo pricing wherein there is a constant probability of firms having the opportunity of adjust prices, Brede (2013) argues that, in the advent of an economic disaster, the Calvo parameter cannot remain constant. The assumption of price adjustment being costly appears to be more valid in a two-state of nature economy. Recalling that domestic firms are owned by households, the firm's objectives are aligned with the household's. Firm i is assumed to maximize its expected lifetime profits summarized as follows

$$\mathbb{E}_t \sum_{s=0}^{\infty} \rho_{t,t+s} \left[P_{t+s}^n(i) Q_{t+s}^n(i) - \Psi'_{t+s} Q_{t+s}^n(i) - \frac{\theta}{2} \left(\frac{P_{t+s}^n(i)}{P_{t+s-1}^n(i)} - 1 \right)^2 P_{t+s}^n Q_{t+s}^n \right]$$

where $\rho_{t,t+s}$ is the stochastic discount factor determined from the household's optimization problem and is given by $\rho_{t,t+s} = \beta^s (P_t^n / P_{t+s}^n)(C_t / C_{t+s})$. The necessary first-order condition to the firm's optimization problem gives the non-tradable inflation equation

$$1 - \frac{\nu}{\nu - 1} \frac{\Psi'_t}{P_t^n} = -\frac{\theta}{\nu - 1} (\pi_t^n - 1) \pi_t^n + \frac{\theta}{\nu - 1} \beta \mathbb{E}_t \left[\frac{\lambda_{t+1}^1}{\lambda_t^1} \frac{Q_{t+1}^n}{Q_t^n} (\pi_{t+1}^n - 1) \pi_{t+1}^n \right]$$

Imported Goods

Importing firms are assumed to purchase foreign goods at the exogenous world price P_t^* and resell them in the domestic market such that

$$P_t^m = \frac{\nu}{\nu - 1} e_t P_t^*$$

where P_t^m is price of imported intermediate goods and e_t is the nominal exchange rate in terms of domestic currency per foreign currency. The markup set by importing firms is assumed to be the same as that of the domestic firms.

Exported Goods

The demand for exported goods Q_t^x is assumed to have the same structure as the domestic non-traded demand

$$Q_t^x = \varphi \left(\frac{P_t^x}{P_t^*} \right)^{-\varsigma} Y_t^F$$

where P_t^x is the price of exported goods, Y_t^F is exogenous foreign demand, and ς is the foreign elasticity of substitution. The law of one price is also assumed to hold in the export market such that $e_t P_t^x = P_t^n$.

Public Sector

The central bank balance sheet is given by

$$\Delta M_t = e_t \Delta X_t + \Delta B_t$$

where X_t is the foreign exchange reserves and B_t is the government securities held by the central bank maturing next period. For simplicity, we assume that no interest is earned on foreign exchange reserves. Under the assumption that profits of the central bank are transferred to the government, the government budget constraint is given by

$$\Delta B_t + \Delta B_t^p = P_t G_t + i_{t-1} B_{t-1}^p - T_t - e_t A_t$$

where G_t is assumed to be a form of unproductive government expenditures and A_t is the foreign aid received by the country. Combing both budget constraints gives the public sector's consolidated budget constraint

$$T_t + B_t^p + \Delta M_t + e_t A_t = P_t G_t + (1 + i_{t-1}) B_{t-1}^p + e_t \Delta X_t$$

From equation, the government finances its expenditures through an imposed lump-sum tax on households, issuances of government securities, seignoirage income, and foreign aid donations received from the foreign sector. Following Adam and O'Connell (2005) in the specification of fiscal and monetary policy rules, we assume that the government commits to the fiscal rule of fully spending any foreign aid received

$$P_t G_t = PG + (e_t A_t - eA)$$

The central bank follows a policy rule on foreign exchange intervention and open-market operations. The foreign exchange intervention is governed by the following equation

$$\Delta X_t = \gamma_{11}(X - X_{t-1}) + (1 - \gamma_{12})(A_t - A) + \gamma_{13} \ln\left(\frac{g_t}{g}\right) + \gamma_{14} \ln\left(\frac{\pi_t}{\pi}\right)$$

where $g_t = e_t / e_{t-1}$ denotes the gross depreciation rate of the nominal exchange rate, γ_{11} is the commitment to a constant level of reserves, γ_{12} is the commitment to an absorb as you spend scenario, γ_{13} is the commitment to a crawling peg, and γ_{14} determines the extent to which the sale of foreign exchange reserves are used to achieve a given target of the inflation rate. Any foreign exchange rate intervention will have an impact on the monetary base and the nominal exchange rate with possible implications for inflation and output volatility. The central bank has the option of conducting open-market operations on a temporary basis in order to sterilize foreign exchange intervention.

$$\Delta B_t^p = \gamma_{21} e_t \Delta X_t + \gamma_{22} \ln\left(\frac{\pi_t}{\pi}\right) + \gamma_{23}(Y_{t-1} - Y) + \gamma_{24}\left(B^p - B_{t-1}^p\right)$$

where γ_{21} is the extent of bond operations used to sterilize the impact of foreign exchange interventions, γ_{22} is the commitment to inflation output, γ_{23} is output gap considerations, and $\gamma_{24} > 0$ entails that all bond operations unwound overtime.

Aggregation and Market Clearing

Households are assumed to be equal shareholders in the domestic firms, aggregate profits are given by

$$\int_0^1 \Pi_t^d(i)di = P_t^n Q_t^n + e_t P_t^x Q_t^x - W_t L_t - R_t K_t$$

which is just total revenue from sales to the domestic and export markets less total production costs. Since households are assumed to be identical, the aggregation of household-related variables simplifies to $\int_0^1 H_t(j)\,dj = H_t$, where $H_t = \{C_t, I_t, L_t, K_t, B_t^p\}$. Therefore, the aggregated household budget constraint is thusly given by the equation

$$\Delta M_t + \Delta B_t^p + P_t(C_t + I_t) = i_{t-1}B_{t-1}^p + P_t^n Q_t^n + e_t P_t^x Q_t^x - T_t$$

Market equilibrium in the intermediate and final goods markets are, respectively:

$$Y_t^d = Q_t^n + Q_t^x$$

$$Y_t = C_t + I_t + G_t$$

Combining all budget constraint equations gives the balance of payments equation

$$e_t \Delta X_t = e_t A_t + e_t P_t^x Q_t^x - P_t^m Q_t^m$$

Calibration

Most of the structural parameters in the model are calibrated using values that can be commonly found in existing DSGE literature for the Philippines (see Del Rosario and McNelis, 2010; McNelis et al., 2010; and Majuca, 2014). The other parameter values, such as those associated with natural disaster and the monetary policy rules, have been based on the works of Keen and Pakko (2011), Becerra et al. (2014), and Peiris and Saxegaard (2007). The calibration exercise is summarized in the table below. To explore the impact of unanticipated shocks to the economy under two alternative monetary policy rules[1], the response of the system is analyzed under the assumption that the authorities aim to stabilize either CPI inflation ($\gamma_{14} = \gamma_{22} = 10$) or the rate of depreciation of the nominal exchange rate ($\gamma_{13} = 10$).

[1] Since the capital account is assumed to be closed, the monetary authority can actually implement a hybrid policy of flexible inflation targeting with exchange rate intervention. However, after running the policy simulations, the hybrid policy yields results similar to that of a pure flexible inflation targeting.

Parameter	Symbol	Value
Discount Factor	β	0.990
Depreciation Rate	δ	0.025
Share of Capital	α	0.330
Home Bias	φ	0.450
Degree of Learning-by-Doing	υ	0.300
Inverse Frisch Elasticity	ψ	1.000
Disutility of Labor	ϑ	3.000
Inverse Money Elasticity	η	2.000
Elasticity of Substitution Between Domestic and Imported Goods	σ	1.500
Elasticity of Substitution Among Domestic Intermediate Goods	ν	10.00
Price Elasticity of Foreign Intermediate Goods	ς	3.500
Capital Adjustment Cost	ϕ	1.000
Price Adjustment Cost	θ	10.00
Disaster Elasticity to Capital	κ	1.000
Disaster Elasticity to Productivity	ζ	1.540
Disaster Elasticity to Foreign Aid	ϱ	0.700