Foreign Output Shock in Oil-Importing Open Economies: A Welfare Evaluation of Monetary Policy Regimes ☆

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Abstract

We examine the impact of adverse foreign output shock on the welfare of small open economies under different monetary policy regimes, namely (1) fixed exchange rate regime, and under flexible exchange rate regime, (2) CPI inflation targeting, (3) real output gap targeting, (4) Taylor rule and (5) nominal output growth targeting using a dynamic stochastic general equilibrium (DSGE) model with sticky prices and wages and incomplete exchange rate passthrough. The model includes oil as an input to production in addition to capital and labor. We calibrate the model for five non-oil producing small open economies and numerically solve for the welfare function to derive the welfare implications of various monetary policy regimes. We find that real output gap targeting delivers the highest welfare if an economy's domestic oil import to global oil import is relatively high but the nominal output growth targeting delivers the highest welfare if it is relatively low.

Keywords: Foreign output shocks; Monetary policy, Exchange rate regimes; Welfare; DSGE.

JEL Classification: E32, F41

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1. Introduction

Recent empirical literature finds substantial effect of foreign or global shocks on output fluctuations[1] and inflation gaps[2] of individual countries. This was clearly evident in small open economies during the global financial and economic crisis of 2008-2009. More specifically, the sharp recession in the advanced economies in 2008-2009 had a pronounced effect on the export and growth of non-oil producing small open economies. Table 1 shows that relative to the trend,real GDP contracted by between 11.80% and 13.08% in Singapore, Taiwan and Hong Kong, and 6.41% and 7.65 % in Israel and South Korea, respectively. The contraction of real export ranged from 10.47% to 23.00%. It is not surprising that exports of these heavily export-dependent small open economies. The ratio of exports to GDP exceeds 100% in Singapore and Hong Kong. The corresponding ratio is 50% in Taiwan, and more than 35% in South Korea and Israel. This suggests that trade was an important transmission channel of the global crisis in these small open economies.

Table 1 also shows that the five non-oil producing small open economies experienced low inflation during the 2008-2009 global crisis with an average change in CPI inflation of 0.14% to 2.64 %. The low inflation environment could have been partly due to the drastic drop in global oil prices due to low global demand of oil. Oil prices dropped by more than half in six months[3]. Since non-oil producing economies are highly dependent on oil imports, the sharp drop in oil prices would have put further downward pressure on overall prices. In fact, Table 1 shows that Hong Kong, Singapore, Korea, Taiwan and Israel import more than 80% of their energy needs. Despite the low inflationary pressures from weak aggregate demand and sharp drop in global oil prices, the central banks of these small open economies maintained their pre-crisis monetary policies. For instance, Hong Kong and Singapore have fixed and pegged exchange rate regimes, respectively while South Korea and Israel have adopted inflation targeting policies. Taiwan aims to do both – i.e. stabilize prices and intervene in the foreign exchange rate markets. As shown in Table 1, economies which target the exchange rate (Hong Kong, Taiwan and Singapore) show lower average changes in exchange rates than economies which target inflation (South Korea and Israel).[4] In addition, exchange rate

[1] Fernández et al.(2017) use structural vector autoregression models and estimate that foreign shocks could explain on average 33% of output fluctuations in a panel of 138 countries from 1960-2015. They identify foreign shocks from three commodity prices namely agricultural, metal and fuel prices.

[2] Kamber and Wong (2018) use factor-augmented vector autoregression and show that foreign shock could account for a large part of inflation gap among Australia, Canada, New Zealand, Norway and Sweden and 10 East Asian countries. They identify foreign shocks considering real GDP, industrial production and other output variables for US, UK, Germany, France and Japan.

[3] Oklahoma WTI spot rate dropped from US$145 in July 14, 2008 per barrel to US$30.28 in December 23, 2008 (http://tonto.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=RWTC&f=M downloaded, June 30, 2016).

[4] Hong Kong, Taiwan and Singapore experienced the smallest average percentage change in exchange rates of –0.42%, –3.01%

targeting economies have visibly larger cumulative declines in real GDP compared with inflation targeting economies.

The global financial crisis of 2008-2009 resulted in large declines in real GDP and inflation in non-oil producing small open economies prompting a call for a re–examination of the macroeconomic policies in general, and monetary and exchange rate policies in particular. Stiglitz (2008) argues that inflation targeting is inappropriate for emerging economies, where energy and commodities make up a larger share of the household budget than in industrialized countries. Blanchard et al. (2010) argue that there may be a case for some emerging-market central bankers' actual practice of targeting inflation and intervening in the foreign exchange markets. Despite the criticism of inflation targeting, Carvalho Filho (2010) finds that inflation targeting countries outperformed non-inflation targeting countries in the post-2008 period. He argues that during the crisis, inflation targeting countries lowered nominal interest rates by more, resulting in even larger real interest rate differentials and thus an even stronger monetary stimulus. A similar call for re-examination of policy had also been heard in the United States. Hatsius and Stehn (2011), Romer (2011) and Sumner (2011), among many others, have urged the Federal Reserve to consider nominal GDP targeting instead of the Taylor rule.[5]

Both theoretical and empirical literature suggest a number of rationales for why different monetary and exchange rate policy regimes may differ in their capacity to protect countries from external shocks. For example, it is often argued that countries with flexible exchange rate regimes can better insulate their economies from negative real shocks.[6] In a study that is highly relevant to the transmission of foreign output shocks to small open economies during the 2008-2009 crisis, Hoffmann (2007) uses data from a sample of 42 developing countries to test the hypothesis that flexible exchange rates serve as a shock absorber in small open economies, and mitigates the impact of external shocks more effectively than fixed exchange

and 3.98%, respectively. In contrast, South Korea and Israel experienced an average percentage change in exchange rates of 4.25% and 27.16%, respectively.

[4]We chose these five high-income emerging economies because of similarities in the structure of their economies: they are small open economies, with large export components mainly in manufacturing and economies dependent on imports of oil and other commodities; yet their central banks follow different monetary and exchange rate policies. We also use data from these five economies to calibrate some of the parameter values in our DSGE model.

[5]A debate on nominal GDP targeting among economists could be accessed online at http://economistsview.typepad.com/economistsview/2010/12/bernanke-and-mishkin-on-nominal-gdp-growth-targeting.html. As far as we know, nominal output targeting is hardly discussed as possible policy for emerging economies. Nevertheless, there is no reason why the advantages it offers to the Fed would not apply to central bankers of emerging economies.

[6]Please refer to Friedman (1953), Mundell (1961), Poole (1970), Dornbusch (1980), Laufer and Sundararajan (1994), Obstfeld and Rogoff (2000), Devereux (2004), Devereux et al. (2006), Broda (2004), Edwards and Levy Yeyati (2005), and Hoffmann (2007).

rate regimes. Hoffmann finds that countries with more flexible nominal exchange rates suffer from smaller declines in their real GDP. This is due to real exchange rate depreciation, which improves external competitiveness and thus partly offsets the negative impact of foreign output shocks.

Our paper is related to the literature that evaluates central banks' targeting of output, inflation or a hybrid of output and inflation. These studies generally use closed-economy models calibrated using United States data. Hall and Mankiw (1994) use an aggregate supply equation and aggregate demand equation while Cecchetti (1995) uses vector autoregression including logs of aggregate price level, commodity prices and output and the interest rate to show in counterfactual simulations that nominal output targeting reduces the volatilities of real and nominal variables. McCallum and Nelson (1998) consider a small open economy model with sticky prices calibrated using United States data and find that nominal output targeting performs better than inflation targeting for certain parameter values. Erceg et al. (2000) use a dynamic stochastic general equilibrium (DSGE) model with staggered price and wage contracts alá Calvo (1983) and show that strict output gap targeting generates small welfare losses relative to the flexible price and wage benchmark whereas strict price inflation targeting generates relatively large welfare losses. Jensen (2002) uses a DSGE model with inflation persistence where central banks have discretion and socially optimal policy is time inconsistent. He finds that when shocks involve societal trade-offs of monetary policy, nominal output growth targeting is better than inflation targeting. Kim and Henderson (2005) build a simple DSGE model with one-period nominal contracts for prices and wages and find that simple monetary rules are suboptimal but nominal output growth targeting performs better than inflation targeting when labor elasticity is low and wage is sticky.

As mentioned above, the global financial crisis in 2008-2009 has reignited the debate on merits of nominal output targeting versus inflation targeting. Woodford (2012) and Billi (2014) discuss monetary policy rules including nominal output targeting considering the zero lower bound. Among the most recent papers, Garín et al. (2016) use a DSGE model with sticky prices and wages to examine the welfare characteristics of monetary policy rules such as inflation targeting, Taylor rule, nominal output targeting and output gap targeting. They find that output gap targeting generates the least welfare losses relative to flexible price and wage equilibrium with nominal output targeting performing just as well with supply shocks and when wages are more sticky than prices.

In this paper, we evaluate and compare conditional welfare under different monetary and exchange rate policy regimes in the presence of negative foreign output shocks to non-oil producing small open economies.

To do so, we develop a simple dynamic stochastic general equilibrium (DSGE) model characterized by imperfect competition in the goods market, price and wage rigidities, and incomplete pass-through of exchange rate to domestic prices and of global oil price to domestic oil price. We assume that investment is subject to adjustment costs. In contrast to many DSGE models which consider only two factor inputs, namely, labor and capital, we include oil as an factor of production. Oil prices are endogenously determined from global supply and global demand, and global demand is determined by global (foreign) output. Hence, a negative foreign output shock reduces global demand of oil and the global price of oil. Although the pass-through of foreign oil price to domestic oil price is assumed to be incomplete, the domestic price of oil drops as well.[7]

Since oil is a factor of production, the reduction in the domestic price of oil reduces the firms' marginal costs. This serves as one of three channels through which negative foreign output shock could affect the small open economy other than the usual terms-of-trade channel. The second channel is the reduction in exports which are directly affected by a negative foreign output shock. The third channel is the usual terms-of-trade channel i.e., foreign prices are affected by the decrease in the global oil price. This broadly addresses Fernández et al. (2017) criticism that the literature typically only consider the transmission of foreign shocks through terms of trade in both theoretical (Mendoza, 1995; Kose, 2002) and empirical models (Schmitt-Grohé and Uribe, 2018). Hence, theoretical models tend to overstate the impact of terms of trade while empirical models find that terms of trade alone can explain only 10% of the volatility in output and in other macroeconomic aggregates of emerging countries. [8]

We numerically solve and calculate the conditional welfare function of the DSGE model under five types of monetary and exchange rate policy regimes following Schmitt-Grohé and Uribe (2004). The five types of monetary and exchange rate policy regimes include (1) a fixed or pegged exchange rate rule, and under the flexible exchange rate regime, (2) a CPI inflation targeting rule, (3) real output gap targeting, (4) a conventional Taylor-type interest rate rule and (5) a nominal output growth targeting.[9] As far as we know,

[7] Alba et al. (2013) also use a similar methodology but focus on adverse oil supply shocks and positive oil demand shocks to examine the impact of higher oil prices on the emerging economies of non-oil producing countries. In addition, they consider complete pass-through and completely flexible wages in contrast to our model which considers incomplete pass through in exchange rate and in foreign oil price to domestic oil price and sticky wages.

[8] The only other paper we know that addresses Fernández et al. (2017) criticism is Fernández et al. (2018). Their paper is different from ours in that they study the impact of commodity price shocks on commodity exporting countries such as Brazil, Chile, Columbia and Peru in the post-2000 period using a dynamic stochastic multi-country business cycle model.

[9] The annual policy rates of South Korea, Israel, Singapore (SIBOR), Hong Kong and Taiwan were 5%, 3.75%, 1.25%, 3.5% and 3.655% in mid-2008, which dropped to 2%, 1.25%, 0.683%, 0.5% and 1.25% in late-2009, respectively. Source: CEIC database. Hong Kong had maintained the fixed exchange rate regime during the crisis even with negative (real) interest rates (http://www.hkma.gov.hk/eng/publications-and-research/reference-materials/viewpoint/20080214.shtml). More recently, with some European central banks and the Bank of Japan imposing neg-

McCallum and Nelson (1998) is the only other paper that considers nominal output targeting in a small open economy. In contrast to our paper, their model excludes capital as an input to production, and does not consider wage stickiness and measures of welfare. Their model is also calibrated for the United States.

In our model, monetary and exchange rate policies are differentiated by the weights we assign to overall CPI inflation, output gap (output growth) and exchange rate in the interest rate rule. Under different types of policy regimes, we then explicitly evaluate and compare conditional welfare as a result of foreign output shocks. Since we find that the fixed or pegged exchange rate regime has the lowest conditional welfare, we consider under flexible exchange rate regime combinations of the weights on inflation and on output gap that would give the highest welfare.

2. The Model

In this section, we describe our DSGE model. We retain most of the features of the small open economy model by Monacelli (2004). A continuum of households are assumed to live infinitely. They consume baskets of differentiated domestic and foreign tradable goods. They earn from supplying labor and renting physical capital to domestic firms. We incorporate wage rigidity in the model as in Galí and Monacelli (2016) and oil in the production function as in Kim and Loungani (1992). We also incorporate in the model a global oil market where oil prices are endogenously determined. Hence, firms are assumed to produce differentiated goods using three types of factors of production, namely labor, capital and oil. Firms are allowed to reset price only with a certain probability at any given period as in Calvo (1983).

2.1. Households

2.1.1. Household consumption and capital accumulation

The domestic economy is populated by infinitely lived households with a continuum of members indexed by $j \in [0, 1]$. They consume baskets of differentiated domestic goods and foreign goods that are tradable and indexed by i. Each member of household specializes in differentiated labor service $N_t(j)$ and household labor supply is $N_t^s = \int_0^1 N_t(j)dj$. A representative household seeks to maximize utility over time:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{1-\sigma}}{1-\sigma} - \frac{(N_t^s)^{1+\psi}}{1+\psi} \right) \tag{1}$$

ative interest rates, commercial banks in Hong Kong (http://www.thestandard.com.hk/section-news.php?id=168766) and Singapore (https://www.straitstimes.com/business/banking/julius-baers-singapore-branch-to-impose-negative-interest-rates-on-some-deposits) imposed negative interest rates on certain foreign currency deposits. The central banks of Israel and South Korea are reported to have also considered negative interest rates (https://www.haaretz.com/israel-news/business/bank-of-israel-no-longer-considering-negative-interest-rates-1.5440768) (http://pulsenews.co.kr/view.php?year=2016&no=683565).

where β is the discount factor, N_t^s is the labor supplied and C_t is a composite of consumption index which is defined by:

$$C_t = \left[\gamma^{\frac{1}{\rho}} C_{H,t}^{\frac{\rho-1}{\rho}} + (1-\gamma)^{\frac{1}{\rho}} C_{F,t}^{\frac{\rho-1}{\rho}}\right]^{\frac{\rho}{\rho-1}} \tag{2}$$

where $\gamma \in [0,1]$ is inversely related to the degree of home bias in preferences and can be used as a natural index of a country's degree of openness. ρ is the intertemporal elasticity of substitution between consumption of home goods, $C_{H,t}$ and consumption of foreign goods, $C_{F,t}$. $C_{H,t}$ and $C_{F,t}$ follow a constant elasticity of substitution (CES) form such that $C_{H,t} = \left(\int_0^1 C_{H,t}(i)^{\frac{\vartheta-1}{\vartheta}} di\right)^{\frac{\vartheta}{\vartheta-1}}$ and $C_{F,t} = \left(\int_0^1 C_{F,t}(i)^{\frac{\vartheta-1}{\vartheta}} di\right)^{\frac{\vartheta}{\vartheta-1}}$. The optimal allocation of any given expenditure within each category of goods yields the demand functions:

$$C_{H,t}(i) = \left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\vartheta} C_{H,t}; C_{F,t}(i) = \left(\frac{P_{F,t}(i)}{P_{F,t}}\right)^{-\vartheta} C_{F,t}$$

where $P_{H,t} = \left(\int_0^1 P_{H,t}(i)^{1-\vartheta} di\right)^{\frac{1}{1-\vartheta}}$ is the domestic price index and $P_{F,t} = \left(\int_0^1 P_{F,t}(i)^{1-\vartheta} di\right)^{\frac{1}{1-\vartheta}}$ is a price index for goods imported from foreign countries. The optimal allocation of expenditure between domestic and imported goods is given by:

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

where $P_t = \left[\gamma P_{H,t}^{1-\rho} + (1-\gamma) P_{F,t}^{1-\rho}\right]^{\frac{1}{1-\rho}}$ is the overall consumer price index (CPI).

Given the total consumption expenditure by domestic households, $P_{H,t}C_{H,t} + P_{F,t}C_{F,t} = P_tC_t$, the household maximizes Equation 1 subject to the budget constraint:

$$P_t(C_t + I_t) + E_t\{\nu_{t,t+1}B_{t+1}\} = W_tN_t^s + B_t + Z_tK_t + \tau_t \tag{3}$$

where I_t is the gross investment, $\nu_{t,t+1}$ is the stochastic discount factor and B_{t+1} is the nominal pay-off in period $t+1$ of the portfolio held at the end of period t. W_t is the nominal wage and τ_t denotes lump-sum transfers/taxes. Z_t is the nominal rental cost and K_t is capital accumulation:

$$K_{t+1} = (1-\delta)K_t + I_t\left[1 - \mathcal{S}\left(\frac{I_t}{I_{t-1}}\right)\right] \tag{4}$$

where δ is the physical depreciation rate of capital. The function $\mathcal{S}(\cdot)$ describes the investment adjustment cost that satisfies the condition of $\mathcal{S}(1) = \mathcal{S}'(1) = 0$. Following Schmitt-Grohé and Uribe (2004), we let this function to take the functional form of $\mathcal{S}\left(\frac{I_t}{I_{t-1}}\right) = \frac{\eta}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2$.

The first order conditions derived from maximizing the utility function subject to the budget constraint and capital accumulation can be written as:

$$C_t^{-\sigma} = \lambda_t P_t \tag{5}$$

$$\beta E_t\left[\left(\frac{C_{t+1}}{C_t}\right)^{-\sigma}\left(\frac{P_t}{P_{t+1}}\right)\right] = E_t\{\nu_{t,t+1}\} \tag{6}$$

$$tq_t = E_t\{\beta\left[\lambda_{t+1}Z_{t+1} + tq_{t+1}(1-\delta)\right]\} \tag{7}$$

$$\lambda_t P_t = tq_t\left[1 - \mathcal{S}\left(\frac{I_t}{I_{t-1}}\right) - \left(\frac{I_t}{I_{t-1}}\right)\eta\left(\frac{I_t}{I_{t-1}} - 1\right)\right] + E_t\{\beta tq_{t+1}\left[\left(\frac{I_{t+1}}{I_t}\right)^2\eta\left(\frac{I_{t+1}}{I_t} - 1\right)\right]\} \tag{8}$$

where tq_t represents Tobin's Q. By taking conditional expectations on both sides of Equation 8 and rearranging terms, we get the conventional stochastic Euler equation:

$$\beta R_t E_t\left(\frac{C_{t+1}}{C_t}\right)^{-\sigma}\left(\frac{P_t}{P_{t+1}}\right) = 1 \tag{9}$$

where $R_t = \frac{1}{E_t(\nu_{t,t+1})}$ is the gross return on a riskless one-period discount bond paying off one unit of domestic currency in $t+1$ with $E_t(\nu_{t,t+1})$ being its price.

The specification for the rest of the world assume foreign households have similar preferences as home country households. The foreign demand for home produced good i is $C^*_{H,t}(i) = \left(\frac{P^*_{H,t}(i)}{P^*_{H,t}}\right)^{-\vartheta} C^*_{H,t}$ where $C^*_{H,t} = (1-\gamma^*)\left(\frac{P^*_{H,t}}{P^*_t}\right)^{-\rho} C^*_t$.

2.1.2. Household wage setting

As in Galí and Monacelli (2016), the continuum of households is assumed to be monopolistically competitive in the labor market.[10] The household supplies a unit of differentiated labor to firms.

Now consider the optimal wage setting problem for household j:

$$\max E_t \sum_{k=0}^{\infty} (\beta\theta_w)^k\, U\left(C_{t+k|t}(j), N^s_{t+k|t}(j)\right),$$

Subject to

$$\begin{aligned} N^s_{t+k|t}(j) &= N^d_{t+k|t}(,j) \\ &= \left(\frac{\overline{W}_t(j)}{W_{t+k}}\right)^{-\vartheta_w} N^d_{t+k}. \end{aligned}$$

[10] The details of Galí and Monacelli model with wage rigidity are in their online appendix (http://www.crei.cat/wp-content/uploads/2016/09/OnlineAppendix˙final.pdf)

where $N^s_{t+k|t}(j)$ is time $t+k$ labor supply by household type j who last reset his/her wage in time t. At the chosen wage $\overline{W}_t(j)$, household type j is assumed to supply enough labor to satisfy labor demand. $N^d_t(.,j)$ is the optimal total demand for labor type j expressed as $N^d_t(.,j) = (\frac{W_t(j)}{W_t})^{-\vartheta_w} N^d_t$, where N^d_t denotes the aggregate demand for labor.

For firm i, its labor demand is $N^d_t(i,.)$ and it employs all differentiated labor types. Hence, total labor demand by firm i is written as $N^d_t(i,.) = (\int_0^1 N^d_t(i,j)^{\frac{\vartheta_w-1}{\vartheta_w}} dj)^{\frac{\vartheta_w-1}{\vartheta_w}}$.

From the optimal wage setting of the household, its budget constraint in Equation 3 could be rewritten as:

$$P_{t+k}\left(C_{t+k|t} + I_{t+k|t}\right) + E_t\{\nu_{t+k,t+k+1} B_{t+k+1|t}\} = \overline{W}_t(j) N^s_{t+k|t}(j) + B_{t+k|t} + Z_{t+k} K_{t+k|t} + \tau_{t+k} \tag{10}$$

As each household j re-optimizing the wage at a given time t will choose the same optimal wage, we leave out the index j.

The (relevant portion of the) Lagrangian of the household's wage setting problem is:

$$L^w = E_t \sum_{k=0}^{\infty} (\beta\theta_w)^k \{U\left(C_{t+k|t}, N^s_{t+k|t}\right) - \lambda_{t+k|t}\left[P_{t+k}C_{t+k|t} - \overline{W}_t N^s_{t+k|t}\right]\}$$

The optimality condition reads:

$$\sum_{k=0}^{\infty} (\beta\theta_w)^k E_t\{U_{n,t+k|t} N^s_{t+k|t} M_w + U_{c,t+k|t} N^s_{t+k|t} \frac{\overline{W}_t}{P_{t+k}}\} = 0,$$

where $M_w \equiv \frac{\vartheta_w}{\vartheta_w - 1}$.

The above expression can be rewritten as:

$$\sum_{k=0}^{\infty} (\beta\theta_w)^k E_t\{U_{c,t+k|t} N^s_{t+k|t}\left[\frac{\overline{W}_t}{P_{t+k}} + \frac{U_{n,t+k|t}}{U_{c,t+k}} M_w\right]\} = 0.$$

Assuming the average wage markup to be M_w, we have $w_t = M_w C^\sigma_t N^\psi_t$ where $w_t \equiv W_t/P_t$ denotes the real wage. Further rewrite the equation to be:

$$E_t \sum_{k=0}^{\infty} (\beta\theta_w)^k N^s_{t+k|t} C^{-\sigma}_{t+k} \frac{\overline{W}_t}{P_{t+k}} = E_t \sum_{k=0}^{\infty} (\beta\theta_w)^k N^s_{t+k|t} M_w (N^s_{t+k|t})^\psi$$

Using the optimal labor demand condition that $N^s_{t+k|t} = (\frac{\overline{W}_t}{W_{t+k}})^{-\vartheta_w} N^d_{t+k}$ and defining $\overline{w}_t \equiv \overline{W}_t/P_t$, we get:

$$\overline{w}_t^{1+\vartheta_w\psi} E_t \sum_{k=0}^{\infty} (\beta\theta_w)^k w_{t+k}^{\vartheta_w} (\Pi_{s=1}^k \Pi_{t+s})^{\vartheta_w - 1} N_{t+k}^d C_{t+k}^{-\sigma} = M_w E_t \sum_{k=0}^{\infty} (\beta\theta_w)^k w_{t+k}^{\vartheta_w(1+\psi)} (N_{t+k}^d)^{\psi+1} (\Pi_{s=1}^k \Pi_{t+s})^{\vartheta_w(1+\psi)}$$

Suppose we define $F_{1,t}^w$ and $F_{2,t}^w$ such that:

$F_{1,t}^w \equiv E_t \sum_{k=0}^{\infty} (\beta\theta_w)^k w_{t+k}^{\vartheta_w} (\Pi_{s=1}^k \Pi_{t+s})^{\vartheta_w-1} N_{t+k}^d C_{t+k}^{-\sigma}$ and $F_{2,t}^w \equiv E_t \sum_{k=0}^{\infty} (\beta\theta_w)^k w_{t+k}^{\vartheta_w(1+\psi)} (N_{t+k}^d)^{\psi+1} (\Pi_{s=1}^k \Pi_{t+s})^{\vartheta_w(1+\psi)}$

then, wage setting equations can be rewritten recursively as:

$$F_{1,t}^w = w_t^{\vartheta_w} N_t^d C_t^{-\sigma} + \beta\theta_w \Pi_{t+1}^{\vartheta_w - 1} F_{1,t+1}^w; \; F_{2,t}^w = w_t^{\vartheta_w(1+\psi)} (N_t^d)^{1+\psi} + \beta\theta_w \Pi_{t+1}^{\vartheta_w(1+\psi)} F_{2,t+1}^w \tag{11}$$

We also have from the optimality condition that:

$$\overline{w}_t^{1+\vartheta_w\psi} F_{1,t}^w = M_w F_{2,t}^w \tag{12}$$

Wage aggregation is: $1 = \theta_w (\Pi_{w,t})^{\vartheta_w - 1} + (1-\theta_w)(\frac{\overline{w}_t}{w_t})^{1-\vartheta_w}$, where $\Pi_{w,t}$ is wage inflation defined as $\frac{w_t}{w_{t-1}}$.

2.2. *Firms*

2.2.1. *Production*

There is a continuum of monopolistically competitive firms indexed by $i \in [0,1]$. A typical firm is assumed to produce a differentiated good using labor (N_t), capital (K_t), and oil (O_t) as factor inputs and has a production function following Kim and Loungani (1992):

$$Y_t(i) = A_t \left[\iota K_t^{1-\upsilon}(i) + (1-\iota) O_t^{1-\upsilon}(i) \right]^{(1-\alpha)/(1-\upsilon)} N_t^{\alpha}(i)$$

where Y_t is output and A_t is the technology with $0 < \alpha < 1$, $\iota > 0$ and $\upsilon > 0$. The elasticity of substitution between capital and oil is equal to $1/\upsilon$ while labor share in production is given by α.

The efficiency conditions for labor, capital and oil are given as:

$$\Psi_t^r \frac{\partial Y_t}{\partial N_t} = \frac{W_t}{P_{H,t}}; \; \Psi_t^r \frac{\partial Y_t}{\partial K_t} = \frac{Z_t}{P_{H,t}}; \; \Psi_t^r \frac{\partial Y_t}{\partial O_t} = \frac{P_{o,t}}{P_{H,t}} \tag{13}$$

where Ψ_t^r is the real marginal cost and $P_{o,t}$ is the domestic price of oil. Accordingly, we also derive the capital-to-oil ratio as $\left(\frac{K_t}{O_t}\right)^{-\upsilon} = \frac{(1-\iota)}{\iota} \frac{Z_t}{P_{o,t}}$. Rewrite in real terms: $\left(\frac{K_t}{O_t}\right)^{-\upsilon} = \frac{(1-\iota)}{\iota} \frac{Z_t^r}{P_{o,t}^r}$, where $Z_t^r \equiv \frac{Z_t}{P_t}$ and $P_{o,t}^r \equiv \frac{P_{o,t}}{P_t}$

2.2.2. *Price-setting*

Following Calvo (1983), each firm may reset its price only with a probability of $1-\theta_p$ in any given period, independent of the time elapsed since it last adjusted its price. Thus, in each period only a fraction of $1-\theta_p$ producers reset their prices, while the rest keep their prices unchanged. As in Galí and Monacelli (2016), a firm which adjusts its price in period t will have to maximize its profit subject to a sequence of demand constraints as follows:

$$\max \sum_{k=0}^{\infty} \theta_p^k E_t \{ \nu_{t,t+k} \left(\frac{1}{P_{H,t+k}} \left[\overline{P}_{H,t} Y_{t+k|t} - C_{t+k} \left(Y_{t+k|t} \right) \right] \right) \}$$

subject to the sequence of demand constraints:

$$Y_{t+k|t} = \left(\frac{\overline{P}_{H,t}}{P_{H,t+k}} \right)^{-\vartheta} Y_{t+k}$$

for $k = 0, 1, 2, ...$ where $\nu_{t,t+k} \equiv \beta^k \frac{C_{t+k}^{-\sigma} P_t}{C_t^{-\sigma} P_{t+k}}$ is the stochastic discount factor, $C_t(\cdot)$ is the nominal cost function, and $Y_{t+k|t}$ denotes output in period $t+k$ for a firm that last reset its price in period t. The optimality condition associated with the price setting is:

$$\sum_{k=0}^{\infty} \theta_p^k E_t \{ \nu_{t,t+k} Y_{t+k|t} \left(\frac{1}{P_{H,t+k}} \right) \left(\overline{P}_{H,t} - \mathcal{M} \Psi_{t+k} \right) \} = 0$$

where Ψ_{t+k} denotes the nominal marginal cost in period $t+k$ for a firm which last reset its price in period t and $\mathcal{M} \equiv \frac{\vartheta}{\vartheta - 1}$.

Denote Ψ_t^r as the real marginal cost in which $\Psi_t^r = \frac{\Psi_t}{P_t}$, and define $F_{1,t}^p \equiv E_t \{ \sum_{k=0}^{\infty} \theta_p^k \nu_{t,t+k} Y_{t+k} \left(\prod_{s=1}^k \Pi_{H,t+s} \right)^{\vartheta} \}$ and $F_{2,t}^p \equiv E_t \sum_{k=0}^{\infty} \theta_p^k \{ \nu_{t,t+k} Y_{t+k} \Psi_{t+k}^r \left(\prod_{s=1}^k \Pi_{H,t+s} \right)^{\vartheta} \}$, then the recursive representation for the domestic price inflation dynamics can be written as:

$$F_{1,t}^p = Y_t + \theta_p \nu_{t,t+1} \Pi_{H,t+1}^{\vartheta} F_{1,t+1}^p ; F_{2,t}^p = Y_t \Psi_t^r + \theta_p \nu_{t,t+1} \Pi_{H,t+1}^{\vartheta+1} F_{2,t+1}^p \quad (14)$$

And the optimality condition indicates that:

$$\left(\bar{P}_{H,t} / P_{H,t} \right) F_{1,t}^p = \mathcal{M} F_{2,t}^p \quad (15)$$

and we also have:

$$1 = \theta_p \left(\Pi_{H,t} \right)^{\vartheta - 1} + \left(1 - \theta_p \right) \left(\frac{\bar{P}_{H,t}}{P_{H,t}} \right)^{1-\vartheta} \quad (16)$$

where $\Pi_{H,t}$ is domestic good price inflation defined as $P_{H,t}/P_{H,t-1}$.

2.3. Monetary policy and exchange rate regimes

We assume deviations of CPI inflation, output, nominal exchange rate and lagged nominal interest rate from their long-run target will have feedback effects on the short-run movements of the nominal interest rate target given by the following interest rate rule:

$$\left(R_t/R_{t-1}^{\chi}\right)^{1/(1-\chi)}/(R) = \Pi_t^{\varpi_\pi}\,(Y_t/Y)^{\varpi_y}\,\epsilon_t^{\varpi_\epsilon/(1-\varpi_\epsilon)} \tag{17}$$

where Y and R are steady state output and interest rate, respectively. ϵ_t is the nominal exchange rate and ϖ_π, ϖ_y and ϖ_ϵ are weights assigned to the movements of CPI inflation, output deviation from steady state (output gap) and nominal exchange rate, respectively. χ determines the desire of the monetary authority to smooth changes in the nominal interest rate. $\varpi_\epsilon = 0.99$ and the other weights equal to zero under fixed or pegged exchange rate regime. $\varpi_\epsilon = 0.01$ under flexible exchange rate regime which include monetary policy regimes of (strict) CPI inflation targeting with weights $\varpi_\pi = 1.5$ and $\varpi_y = 0$, of the Taylor rule with weights $\varpi_\pi = 1.5$ and $\varpi_y = 0.5$ and of real output gap targeting with weights $\varpi_\pi = 0$ and $\varpi_y = 1.5$. For the nominal output growth targeting rule, Equation (17) is modified by replacing steady state Y with Y_{t-1} and assigning weights of $\varpi_\epsilon = 0.01$, $\varpi_\pi = 1.5$ and $\varpi_y = 1.5$.

2.4. Domestic inflation, CPI inflation, real exchange rate and terms of trade

Bilateral terms of trade between the domestic economy and the foreign country is defined as $S_t = P_{F,t}/P_{H,t}$ and domestic inflation is defined as $\Pi_{H,t} \equiv P_{H,t}/P_{H,t-1}$. Foreign price level is determined by the prices of non-oil goods and oil. Written in real terms, we have $P_t^{*r} = \left(P_{no,t}^{*r}\right)^{1-\gamma_o}\left(P_{o,t}^{*r}\right)^{\gamma_o}$ where $P_{no,t}^{*r} \equiv P_{no,t}^{*}/P_t$ is the real non-oil price and $P_{o,t}^{*r} \equiv P_{o,t}^{*}/P_t$ is the real oil price denominated in foreign currency. For simplicity, we normalize $P_{no,t}^{*r}$ to one. Real imported oil price denominated in home currency is defined as $P_{o,t}^{r} = (\varepsilon_t P_{o,t}^{*r})^{\gamma_{op}}$. γ_{op} captures the pass-through from world oil price to domestic oil price.

As the home economy is a small open economy, it is reasonable to assumed that the home economy is a price taker. As a result, $P_{F,t}^{r} = \varepsilon_t^{\gamma_{ep}} P_t^{*r} = \varepsilon_t^{\gamma_{ep}} (P_{o,t}^{*r})^{\gamma_o}$, where $P_{F,t}^{r} \equiv P_{F,t}/P_t$ is the real imported goods price. ε_t denotes nominal exchange rate measured as home currency per foreign currency, and γ_{ep} captures the exchange rate pass-through. Real home goods price is defined as $P_{H,t}^{r} = P_{H,t}/P_t$. Real exchange rate is defined as $Q_t \equiv P_{F,t}/P_t$. The no arbitrage condition is written as $R_t^*/R_t = \varepsilon_t/\varepsilon_{t+1}$.

2.5. The global oil market and exogenous shocks

Global demand of oil, O_t^{D*}, is a function of foreign output, Y_t^*, and the real foreign oil price, $P_{o,t}^{*r}$:

[10] Garín et al. (2016) show that nominal output growth targeting and nominal output level targeting may be equivalent in logs.

$$O_t^{D*} = O^{D*} \frac{\left(Y_t^*\right)^{\rho_{od*}^{y^*}}}{\left(P_{o,t}^{*r}\right)^{\rho^{p_o^*}}} \tag{18}$$

Global supply of oil, O_t^{s*}, is assumed to be exogenous and follows a first order autoregressive process, $\log\left(O_t^{S*}\right) = \log\left(O^{S*}\right) + \rho_{os*}\left(\log\left(O_{t-1}^{S*}\right) - \log\left(O^{S*}\right)\right) + \epsilon_t^{os*}$. Equilibrium in the oil market requires $O_t^{D*} = O_t^{S*}$. Demand for oil by the small open economy, O_t, takes a share of γ_{ho} out of total global oil demand, and can be written as $O_t = \gamma_{ho} O_t^{D*}$. Firms in the small open economy then use the imported oil for production. Foreign output, foreign interest rate and domestic technology are described by the stochastic processes, $\log\left(Y_t^*\right) = \log\left(Y^*\right) + \rho_{y*}\left(\log\left(Y_{t-1}^*\right) - \log\left(Y^*\right)\right) - \epsilon_t^{y*}$, $R_t^* = R_{t-1}^{*\rho_{r*}} R^{*(1-\rho_{r*})} \exp\left(-\epsilon_t^{r*}\right)$ and $\log\left(A_t\right) = \rho_a \log\left(A_{t-1}\right) + \epsilon_t^a$. Note that O^{D*}, O^{S*}, Y^* and R^* are steady states of global oil demand, global oil supply, foreign output, and foreign interest rate respectively.

2.6. *Equilibrium and steady states*

2.6.1. *Consumption and output in the small open economy*

Goods market clearing for good j in the home economy requires:

$$\begin{aligned} Y_t(i) &= C_{H,t}(i) + C_{H,t}^*(i) + I_t(i) \\ &= \left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\vartheta} \left[\gamma\left(\frac{P_{H,t}}{P_t}\right)^{-\rho}\left(C_t + I_t\right) + \left(1-\gamma^*\right)\left(\frac{P_{H,t}}{\varepsilon_t^{\gamma_{ep}} P_t^*}\right)^{-\rho} C_t^*\right] \end{aligned} \tag{19}$$

Plugging in Equation (19) into the definition of aggregate domestic output $Y_t \equiv \left[\int_0^1 Y_t(i)^{\frac{\vartheta-1}{\vartheta}} di\right]^{\frac{\vartheta}{\vartheta-1}}$, and making use of the assumption that $C_t^* = Y_t^*$ and $P_{F,t} = \varepsilon_t^{\gamma_{ep}} P_t^*$, we can rewrite the above equilibrium conditions as:

$$Y_t = \gamma\left(\frac{P_{H,t}}{P_t}\right)^{-\rho}\left(C_t + I_t\right) + \left(1-\gamma^*\right) S_t^{\rho} Y_t^* \tag{20}$$

Current account balance is given by the difference between foreign consumption of home goods and domestic households' consumption of imported goods. Written in real terms, we have: $CA_t = P_{H,t}^r C_{H,t}^* - P_{F,t}^r C_{F,t} - (1-\gamma) P_{F,t}^r I_t - P_{o,t}^r O_t$, where $C_{H,t}^* = \left(1-\gamma^*\right)\left(\frac{P_{H,t}^*}{P_t^*}\right)^{-\rho} C_t^* = \left(1-\gamma^*\right)\left(\frac{\varepsilon_t^{\gamma_{ep}} P_{H,t}^*}{\varepsilon_t^{\gamma_{ep}} P_t^*}\right)^{-\rho} C_t^* = \left(1-\gamma^*\right)\left(\frac{P_{H,t}}{P_{F,t}}\right)^{-\rho} C_t^* = \left(1-\gamma^*\right) S_t^{\rho} Y_t^*$.

2.6.2. *The supply side: Price dispersion and equilibrium*

Consider the following equilibrium condition:

$$Y_t\left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\vartheta} = A_t\left[\iota K_t^{1-\upsilon}(i) + (1-\iota) O_t^{1-\upsilon}(i)\right]^{(1-\alpha)/(1-\upsilon)} N_t^{\alpha}(i)$$

Integrating over i, we get:

$$Y_t \Delta_{p,t} = A_t \left[\iota K_t^{1-\upsilon} + (1-\iota) O_t^{1-\upsilon} \right]^{(1-\alpha)/(1-\upsilon)} N_t^{\alpha} \tag{21}$$

where $\Delta_{p,t} \equiv \int_0^1 \left(\frac{P_{H,t}(i)}{P_{H,t}} \right)^{-\vartheta} di$ is the price dispersion which evolves according to:

$$\Delta_{p,t} = (1-\theta) \left(\bar{P}_{H,t} / P_{H,t} \right)^{-\vartheta} + \theta \Pi_{H,t}^{\vartheta} \Delta_{p,t-1} \tag{22}$$

2.6.3. Labor market equilibrium

Labor market equilibrium requires that $N_t^s(j) = N_t^d(j)$. Integrating over household j, we get $N_t^s \equiv \int_0^1 N_t^s(j) dj = \int_0^1 N_t^d(j) dj = \int_0^1 (\frac{W_t(j)}{W_t})^{-\vartheta_w} dj N_t$. Define wage dispersion to be $\Delta_{w,t} \equiv \int_0^1 (\frac{W_t(j)}{W_t})^{-\vartheta_w} dj$, hence the labor market equilibrium condition reads:

$$N_t^s = \Delta_{w,t} N_t^d, \tag{23}$$

the wage dispersion evolves according to:

$$\Delta_{w,t} = (1-\theta_w)(\frac{\overline{w}_t}{w_t})^{-\vartheta_w} + \theta_w (\Pi_{w,t})^{\vartheta_w} \Delta_{w,t-1} \tag{24}$$

2.6.4. Steady states

At steady states, nominal exchange rate $\varepsilon = 1$, prices are equal, $P_o^* = P_F = P_H = P = S = \bar{P}_H = 1$, and price dispersion $\Delta_p = 1$. All prices in real terms are also equal to 1. Also, $O^{S*} = O^{D*} = 1$ and $Y^* = 1$. Domestic oil demand at steady state is computed to be $O = \gamma_{ho} O^{D*}$. Due to the no arbitrage condition, domestic and foreign interest rates are equal at steady states, $R = R^* = 1/\beta$. Steady state marginal cost is computed to be $\Psi = (\vartheta - 1)/\vartheta$ and steady state rental cost is $Z = Z^r = 1/\beta - 1 + \delta$. From the oil-to-capital ratio, we calculate the steady state value of capital to be $K = \left(\frac{(1-\iota)}{\iota} \frac{Z^r}{P_o^r} \right)^{-\frac{1}{\upsilon}} O$. Investment at steady state is given by $I = \delta K$. Steady state value of employment demand, N^d, is computed numerically in Matlab using the marginal cost equation derived in Equation 13. In steady state, labor supply is equal to labor demand, hence $N^s = N^d$. Combining the marginal cost function and the wage-consumption relationship equation, steady state value of consumption, C, is computed as $C = \left(\frac{\Psi^r}{\alpha Y M_w (N^d)^{1+\psi}} \right)^{1/\sigma}$, where Y is derived from the goods market equilibrium condition. From Equation 14, we compute the steady state value of F_1^p and F_2^p to be $F_1^p = Y / \left(1 - \beta\theta_p\right)$ and $F_2^p = \Psi^r Y / \left(1 - \beta\theta_p\right)$. Imports, C_F, and exports, C_H^*, are computed to be $C_F = (1-\gamma) C$ and $C_H^* = (1-\gamma^*) S^{\rho} Y^*$ at steady state. Current account is $CA = C_H^* - C_F - (1-\gamma) I - O$ since all real prices are 1 in steady states. Real wage is equal to $w = (N^s)^{\psi} C^{\sigma} M_w$ in steady state. We also have $\overline{w} = w$

in steady state. Wage dispersion $\Delta_w = 1$, $F_1^w = w^{\vartheta_w} N^d C^{-\sigma}/(1-\beta\theta_w)$ and $F_2^w = w^{\vartheta_w(1+\psi)}(N^d)^{1+\psi}/(1-\beta\theta_w)$. Wage inflation $\Pi_w = 1$.

2.7. Model parameterization

The model is solved numerically using Dynare. We adopt most of the parameter values, shown in Table 2, following the literature. The inverse of the elasticity of substitution of capital and oil, υ, is calculated from the expression of the steady state of the capital-oil ratio as a function of the parameters υ, δ, β and ι. Given the parameter values of δ, β and ι from Table 2, υ for Hong Kong and Taiwan (China), Singapore, Korea and Israel are calculated based on the respective energy-to-capital ratio of these countries. Data sources and calculated υ values are detailed in the notes of Table 2.

3. Simulation results

In this section, we examine in detail the simulation results of a one-unit negative shock to foreign output on various macroeconomic variables under five different types of monetary policy and exchange rate regimes, i.e. (1) the conventional Taylor-type interest rate rule, (2) the real output gap targeting rule, (3) the (strict) CPI inflation targeting rule and (4) nominal output growth targeting under the flexible exchange rate regime, and (5) the fixed (pegged) exchange rate regime. In our setup above, when a negative foreign output shock hits a small open economy, two effects occur. On the demand side, a decline in foreign output reduces foreign consumption of home produced goods (exports) ($C_{H,t}^*$) of the country. As a result, domestic output (Y_t) also decreases since it consists of domestic consumption of home produced goods ($C_{H,t}$), foreign consumption of home produced goods (exports) ($C_{H,t}^*$) and investment (I_t). On the supply side, a decline in foreign output also leads to a fall in global oil price after one period as global demand for oil is a function of foreign output. The oil price decline serves as a positive supply shock and affects the domestic economy in two ways. First, the quantity demand for oil should increases as domestic firms in the small open economy substitute oil for capital in their production. Second, a decrease in oil price depresses domestic prices, thus increasing real wages and overall consumption. Hence, the fall in oil price tempers the impact of the demand shock. The effects of the foreign output shock on the domestic economy maybe either mitigated or exacerbated by monetary policy.

Figure 1 shows the impulse responses of nominal exchange rate (ϵ_t), real exchange rate (Q_t), exports ($C_{H,t}^*$), imports ($C_{F,t}$), real wage (w_t), CPI inflation (Π_t) and domestic output (Y_t) for the Taylor-type interest rate rule, the real output gap targeting rule, the CPI inflation targeting rule, the nominal output growth targeting rule under flexible exchange rate regime, and the fixed exchange rate regime. Figure 2 shows the impulse responses of domestic consumption (C_t) and labor (N_t) under the five monetary and exchange rate regimes. Our discussion below follows the order of the monetary and exchange regimes in Figure 1 and Figure 2.

We start with a detailed look at the impulse responses under Taylor rule because this regime sets prudent interest rate for short term stabilization of the the economy by setting in the interest rate rule (Equation 17) a weight of 1.5 on inflation ($\varpi_\pi = 1.5$) and a weight of 0.5 on output gap ($\varpi_y = 0.5$). When negative foreign output shock hits, exports ($C^*_{H,t}$) decline and domestic output (Y_t) decreases. As domestic output falls, this will induce the economy to reduce interest rate causing overall domestic consumption (C_t) to increase. The reduction in interest rate also affects the two components of overall domestic consumption which are domestic consumption of home produced goods ($C_{H,t}$) and domestic consumption of foreign goods or imports, ($C_{F,t}$). Lower interest rate would unambiguously increase domestic consumption of home produced goods. In contrast, the effect on imports could be ambiguous. On one hand, lower interest rate directly causes imports to increase along with overall consumption. On the other hand, lower interest rate causes nominal exchange rate to depreciate which makes imports more expensive and thus tends to reduce imports. In our set-up with incomplete exchange rate pass-through, the direct effect of lower interest rate through overall consumption dominates its indirect effect through exchange rate depreciation so imports increase. In addition, the Taylor rule imposes a weight of 1.5 on inflation so there is hardly any change in CPI inflation despite the fall in oil price. From Figure 1 and Figure 2, we can see that the net effect of a negative foreign output shock is a decrease in domestic output as the rise in domestic consumption (C_t) is less than the drop in the current account (exports ($C^*_{H,t}$) - imports($C_{F,t}$)). The decrease in domestic output also implies that the rise in domestic consumption of home produced goods ($C_{H,t}$) is less than the fall in exports ($C^*_{H,t}$).

Under real output gap targeting, unlike the Taylor rule, the monetary authority would stop targeting inflation ($\varpi_\pi = 0$) and put all weight on output gap deviation from steady state ($\varpi_y = 1.5$). When a negative foreign output shock hits the small open economy, the monetary authority allows CPI inflation to fall. The fall in CPI inflation, reinforced by the fall in oil price, increases real wage. With higher real wage, overall domestic consumption (C_t) as well as domestic consumption of home produced goods ($C_{H,t}$) increase. With the rise in domestic consumption of home produced goods ($C_{H,t}$) greater than the fall in foreign consumption of home produced goods ($C^*_{H,t}$), the goods market clearing condition in the economy then suggests that domestic output is higher. The higher domestic output also raises demand for labor, which sustains the higher real wage.[11] When domestic output rises, the monetary authority which aims to stabilize domestic output responds by raising interest rate under real output targeting. It is noteworthy that despite the rise in interest rate which tends to decrease consumption, overall domestic consumption remains higher since the increase in consumption due to higher real wages tends to dominate the decrease in consumption due to the higher interest rate. Imports, which is a fraction of overall consumption, increases as well. It is also interesting to note that the economy experiences a nominal exchange rate appreciation since output and interest rate rise, which causes a real exchange rate to appreciate. The currency appreciation reduces import prices and further depresses CPI inflation. The real exchange rate appreciation also further boosts imports.

Under CPI inflation targeting, the monetary authority puts a weight of 1.5 on CPI inflation ($\varpi_\pi = 1.5$) and zero on the output gap ($\varpi_y = 0$). When a negative foreign output shock hits, foreign consumption of home produced goods (exports) ($C^*_{H,t}$) decreases. Domestic output falls sharply since the monetary authority focuses only on CPI inflation. Presumably, the monetary authority mitigates the deflationary pressure from the shock by initially reducing the interest rate which causes the nominal exchange rate to depreciate substantially. The nominal exchange rate depreciation partially passes through to CPI inflation so the monetary authority then raises the interest rate slightly in the first period. With higher inflation in the first period, real wage is lower. The rise in the interest rate and the drop in real wage reinforce each other causing a decrease in overall consumption. Since overall consumption includes home consumption on foreign goods (imports), imports drop as well. In addition, real exchange rate depreciates which causes a further drop in imports. The decreases in home consumption of home produced goods ($C_{H,t}$) and foreign consumption of home produced goods (exports) ($C^*_{H,t}$) mean a decrease in domestic output. However, in the next period, the oil price drops and reduces CPI inflation which is again mitigated by the monetary authority's reduction in the interest rate. This causes the nominal exchange rate to depreciate further and overall consumption to slightly recover. Nevertheless, in the next period, the slight rise in consumption of home produced goods is still dominated by the drop in exports so the negative output gap persists.

Under fixed exchange rate regime, the monetary authority puts a weight of 0.99 on the exchange rate ($\varpi_\epsilon = 0.99$) and weights of zero on CPI inflation and the output gap. Both nominal and real exchange rates

[11] Figure 2 shows labor rises only under real output targeting but declines under the other types of monetary policies. Figure 1 also shows that real wage rises only under real output targeting but declines under the other types of monetary policies.

remain relatively fixed. With a negative foreign output shocks, foreign consumption on home produced goods (exports) ($C^*_{H,t}$) falls. The monetary authority allows both CPI inflation and domestic output to decline. Interest rate is unchanged and overall consumption slightly increases. The rise in overall consumption is smaller than the drop in exports, so domestic output decreases.

Under nominal output growth targeting, the interest rate rule (Equation (17)) is modified for output growth ($\frac{Y_t}{Y_{t-1}}$) to replace output gap ($\frac{Y_t}{Y}$). Hence the monetary authority aims to stabilize both output growth ($\frac{Y_t}{Y_{t-1}}$) and inflation (π_t) with equal weights on both targets ($\varpi_Y = \varpi_\pi$). Since $\pi_t = \frac{P_t}{P_{t-1}}$, then Equation (17) could be expressed in terms of $\frac{P_t Y_t}{P_{t-1} Y_{t-1}}$ or the nominal output growth. In the simulation, we assign weights of $\varpi_Y = \varpi_\pi = 1.5$ and $\varpi_\epsilon = 0.01$. With a negative foreign output shock, exports and domestic output drop. The monetary authority responds by reducing interest rate by more than one-for-one the decrease in nominal output growth. As discussed above, the reduction in interest rate has two opposing effects on overall consumption in an open economy. On one hand, lower interest rate increases overall consumption. On the other hand, lower interest rate causes the nominal and real exchange rates to depreciate which then reduce consumption of imports and overall consumption. The depreciation also partially passes-through to CPI inflation helping to stabilize prices. Figure 1 shows that the largest nominal and real exchange rate depreciation among the monetary policy rules occur under nominal output growth targeting. The lower oil price in the next period slightly tempers the effect of the large depreciation. With sticky nominal wage, higher CPI inflation implies lower real wage (Figure 1). Equilibrium labor declines as well. In addition, the reduction in real wage puts further pressure on overall consumption to decline (Figure 2).

In summary, the fluctuations of the key macroeconomic variables such as exports, imports, domestic consumption, CPI inflation, domestic output, real wage and nominal and real exchange rates are found to be sensitive to monetary policy regimes. Specifically for domestic output, our analysis suggests that a negative foreign output shock reduces domestic output for all regimes except real output targeting which leaves domestic output largely unchanged. Among the other four regimes, domestic output drops the least under Taylor rule as it aims to stabilize both inflation and the real output gap. Instantaneous decline in domestic output is most visible CPI inflation targeting since this regime partially shuts down the positive supply side effect Stemming from the fall in oil price. Put differently, disparities in the simulation responses between regimes could be explained by disparities in interest rate responses to change in domestic output, CPI inflation and nominal exchange rate under a negative foreign output shock. In Figure 2, we see that differences in monetary regimes and hence interest rate rate responses trigger different dynamics. It is particularly noteworthy that the increase in overall consumption is the largest under real output targeting. The increase in overall consumption is dominated by the rise in real wages, which is a result of fall in CPI inflation that is reinforced by the fall of global oil price.

4. Welfare analysis

4.1. *Welfare calculation*

We follow Schmitt-Grohé and Uribe (2004) in measuring conditional welfare, V_0^a, associated with a given monetary regime, say regime a, as the conditional expectation of lifetime utility at $t = 0$ which could be written as:

$$\mathbb{V}_0^a = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t U\left(C_t^a, N_t^a\right).$$

Schmitt-Grohé and Uribe (2004) assume that at $t = 0$, the values of the state variables are their steady state values. They note that since the deterministic steady state is the same for all policy regimes, the computation of "expected welfare conditional on the initial state being in the nonstochastic steady state ensures that the economy begins from the same initial point for all possible policies". [12]

4.2. *Welfare analysis*

In this subsection, we simulate the welfare of five non-oil producing economies namely, Hong Kong, Singapore, Korea, Taiwan and Israel. While we mostly follow the parameter values in Table 2, we vary elasticity of substitution of capital and oil ($\frac{1}{\upsilon}$), share of home goods in private consumption (γ) and share of oil import in world oil consumption (γ^{ho}) to better reflect the actual conditions of these economies. For both Hong Kong and Singapore, policy parameters are set such that $\varpi_\pi = 0$, $\varpi_y = 0$ and $\varpi_e = 0.99$, since Hong Kong has a fixed exchange rate regime under currency board and Singapore pegs its currency to a basket of currencies under a managed float exchange rate regime. For the other countries which mostly aim to stabilize inflation, we let $\varpi_\pi = 1.5$, $\varpi_y = 0$ and $\varpi_e = 0.01$. In general, these five non-oil producing economies follow either a fixed exchange rate regime or an inflation targeting rule. Table 3 reports the simulated welfare of these five economies with a one-unit fall in foreign output. The simulated welfare is reported as value of 10^4. The results show that economies that aim to stabilize inflation tend to have higher

[12] We implement Schmitt-Grohé and Uribe (2004) in Dynare by writing the welfare function recursively as $\mathbb{V}_t = \frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\psi}}{1+\psi} + \beta\mathbb{V}_{t+1}$ and approximated up to the second order by $\mathbb{V}_t \approx \mathbb{V} + 0.5\Delta^2$ where $\mathbb{V}$ refers to the steady state value of the welfare function and Δ^2 is the shift effect of the variance of future shocks, both of which can be retrieved from the output in Dynare as indicated section 4.13.4 of Dynare Reference Manual 4.5.5.

welfare than economies that follow fixed exchange rate regime when hit by a negative foreign output shock. Specifically, we see that Israel has the highest welfare of 44.22 followed by South Korea.

Ideally, we would also like to consider the effect of a negative foreign output shock on non-oil producing economies that adopt other monetary regimes i.e., real output gap targeting, the Taylor rule and nominal output growth targeting. However, since none of our five non-oil producing economies actually pursue real output gap targeting, Taylor rule or nominal output growth targeting, we analyze them as hypothetical scenarios by setting $\varpi_\pi = 0$ and $\varpi_y = 1.5$ for real output gap targeting, $\varpi_\pi = 1.5$ and $\varpi_y = 0.5$ for Taylor rule, and $\varpi_\pi = \varpi_y = 1.5$ for nominal output growth targeting under the flexible exchange rate regime, $\varpi_e = 0.01$. We keep the share of oil import in world consumption, $\gamma^{ho} = 0.02$ and the elasticity of substitution of capital and oil, $\frac{1}{\upsilon} = 0.87$, since the baseline values as these are the average values computed from the five economies. Other parameter values are kept constant as shown in Table 2.

The simulated welfare results for various γ of the five exchange rate and monetary regimesare summarized in Table 4. It is important to take note that welfare is derived as a function of consumption (C_t) and labor supply (N_t). Figure 3 provides the impulse responses of overall consumption and labor supply of the five monetary regimes after a one-unit negative shock to foreign output. As discussed at length in the previous section, the changes in overall consumption and labor depend critically on the monetary policy regime. Among all the five monetary regimes, the largest increase in consumption occurs under real output gap targeting. This suggests that real output gap targeting is the most welfare-improving regime. Indeed, Table 4 shows that real output gap targeting delivers the highest welfare among the five monetary policy regimes. This finding remains robust when we vary the share of home goods in private consumption by setting the value of γ to be between 0.45 and 0.85, which is consistent with the value of γ for the five non-oil producing economies. When we vary the parameter of the share of home goods in private consumption, holding the other parameters of the model fixed at their baseline values, real output gap targeting always generates the highest welfare. Real output gap targeting is followed by either nominal output growth targeting or Taylor rule, and then CPI inflation targeting and the fixed exchange rate.

Since the fall in the global oil price due to the decline in foreign output has some positive supply side effect, it is reasonable to assume that an economy that has a relatively small share of domestic oil import in global oil import would benefit less from the positive supply side effect. Therefore, we attempt to account for this by varying the value of γ^{ho} so that it varies between 0.01 and 0.06 while holding the share of capital relative to oil in production (ι) to 0.85 as in the benchmark. Table 5 reports the simulated welfare for the four different monetary regimes with different values of γ^{ho}. Interestingly, we find that when γ^{ho} is very low, for instance when $\gamma^{ho} = 0.01$, nominal output growth targeting outperforms other monetary regimes. For any value of γ^{ho} that is more than or equal to 0.02, real output gap targeting becomes the regime that delivers the highest welfare. This finding is indeed intuitive. For non-oil producing economies, the positive supply side effect of a fall in oil price will become substantial only if an economy has a a relatively large share of oil imports in global oil.

4.3. The Best Monetary Policy

Since the fixed exchange rate regime generates the lowest welfare, to get a reasonable estimate of the policy parameters, we first kept ϖ_ϵ at 0.01 so we only consider flexible regimes. We then looped over both ϖ_π and ϖ_y from 0 to 2. As shown in Figure 3, the highest welfare obtained is 1.77×10^8 when $\varpi_\pi = 0.1$ and $\varpi_y = 1.1$. Although the results are not reported, we also considered values of ϖ_ϵ from 0.01 to 0.5 to see if welfare could increase further. It turns out that the parameter configuration of $\varpi_\epsilon = 0.01$ used in Figure 3 still delivers the highest welfare.[13] This finding further confirms that for a non-oil producing economy to experience a positive supply side effect from the fall in oil price, the central bank has to allow for an initial deflation, which implies a sufficiently small weight on inflation in the interest rate response function.

4.4. Second Best Monetary Policy

Although real output gap targeting mostly delivers the highest welfare, Garín et al. (2016) argue that the output gap is difficult to measure since it is based on a hypothetical model construct which is unobservable. In contrast, nominal output is readily observed and available in real time. This may make it more practical for policy makers to implement nominal output growth targeting rather than real output gap targeting even though nominal output growth targeting is only the second-best monetary policy. Hence, we take a closer look at nominal output growth targeting by performing a grid search for our benchmark specifications in which we kept $\varpi_\epsilon = 0.01$ and looped over $\varpi_\pi = \varpi_y$ from 1 to 2. As shown in Figure 4, conditional welfare is at its peak of $2.x10^6$ at $\varpi_\pi = \varpi_y$ equal to 1.1. Hence, in our model, nominal output growth targeting delivers its highest welfare when interest responds by 1.1 units to a 1 unit negative foreign output shock.

[13] The welfare surface shows combinations of ϖ_π, ϖ_y and ϖ_e where the Blanchard and Kahn condition holds.

5. Conclusion

The global financial and economic crisis of 2008-2009 underlined the vulnerability of small open economies to adverse foreign output shocks. The simulations of the DSGE models used in this study suggest that a negative foreign output shock could affect a small open economy through various channels including the change in the oil price. First, a negative foreign output shock reduces foreign consumption of home produced goods (exports). As a result, domestic output, which consists of domestic consumption of home produced goods and foreign consumption of home produced goods, contracts. Second, a negative foreign output shock would reduce the global demand for oil, which reduces global oil price and thus domestic oil price. Since firms use oil as a factor of production besides capital and labor, the marginal costs of domestic firms decline. Third, since foreign prices are affected by the decrease in the global oil price, the terms-of-trade of the small open economy is also affected.

The fact that global oil price change due to foreign shocks reignites the debate about the appropriate monetary policy regime for a small open economy subject to negative foreign output shocks. The primary objective of our paper is to evaluate and compare the welfare impact of external output shocks under various monetary and exchange rate regimes. To do so, we use a simple DSGE with sticky prices and wages, imperfect competition in the goods market and incomplete pass through of exchange rate and foreign oil price. The monetary policy regimes considered are fixed or pegged exchange rate regime, CPI inflation targeting, real output gap targeting, the conventional Taylor-type interest rate rule and nominal output growth targeting. The simulations of the models used in this study suggest that for non-oil producing economies, real output gap targeting generates the highest welfare among the five monetary regimes for non-oil producing small open economies when share of oil import in world oil consumption γ^{ho} is relatively large ($\gamma^{ho} \geq 0.01$). These findings are consistent with Erceg et al. (2000) and Garín et al. (2016). However, nominal output targeting generates the highest welfare when γ^{ho} is relatively low.

At a broader level, our analysis can provide some guidance about monetary policy regimes for non-oil producing small open economies. For such economies, which depend heavily on exports and trade for growth, the capacity of monetary policy to cushion the impact of adverse foreign output shocks is one of the most important criteria for the appropriate policy regime. The pronounced impact of the recession in the advanced economies on the small open economies during the global crisis of 2008-2009 underlines the importance of mitigating foreign shocks. Our DSGE results suggest that real output gap targeting delivers the highest welfare for economies with relatively high share of global oil imports and the nominal output growth targeting for economies with relatively low share of global oil imports. We also show that maximum welfare for nominal output growth targeting is achieved when weights on inflation and real output gap growth is set around 1.1. Considering the practicality for policy makers of measuring nominal output growth targeting, we show that as a second best policy, nominal output growth targeting dominates the Taylor rule and CPI inflation targeting within the middle range of the openness (γ between 0.55 and 0.65) but outside of the range, Taylor rule dominates both nominal output growth targeting and CPI inflation targeting.

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Table 1: Selected Economic Indicators of Small Open Economies

Economy	Cumulative Change in Real GDP Growth (%)	Average Change in CPI Inflation (%)	Average Change in Exchange Rate (%)	Cumulative Change in Real Export Growth (%)	% of Export over GDP	% of Import over GDP	% of energy imports over energy use	Monetary Policy (2008)
Hong Kong	-13.08	0.38	-0.42	-18.13	158.60	172	99.54	Fixed exchange rate under the currency board
Singapore	-11.8	2.03	3.98	-10.47	215.05	191	98.25	Pegged to a basket of currencies
Korea	-7.65	1.32	27.16	-15.59	36.20	39	80.30	Inflation targeting
Taiwan	-12.04	0.14	-3.01	-23.00	53.46	40	98.13	Aims for stable prices and intervenes in the foreign exchange market
Israel	-6.41	2.64	4.25	-21.33	38.46	38.82	82.91	Inflation targeting

Notes: We consider 2008 Q1 as the benchmark date of the 2008 financial crisis. We follow Blanchard and Gali (2007) in calculating the cumulative change in real GDP gain or loss over eight quarters following benchmark date relative to the trend given by the cumulative real GDP growth rate over the preceding eight quarters. The change in CPI inflation (exchange rate) is the average rate of inflation (depreciation or appreciation) in eight quarters following each of the benchmark date minus the average inflation (depreciation or appreciation) rate over the eight quarters immediately following the benchmark date. Exchange rate is defined as national currency per US dollar. A positive (negative) sign in the fourth column indicates the depreciation (appreciation) of the national currency against the US dollar. All quarterly data are from CEIC Data on Emerging Markets except for export and import as a percentage of GDP which are from the World Development Indicator online, and the real export of Israel is from OECD.Stat. When available, seasonally adjusted real GDP are used. Information on countries that target inflation are from Truman (2003). Information on the monetary policies of Singapore, Hong Kong, Taiwan, China, and Israel are from websites of the Monetary Authority of Singapore, the Hong Kong Monetary Authority, the Economic Intelligent Unit (2008 Country Reports) and Bank of Israel, respectively. Percentage of energy imports over energy use are from the World Economic Indicators except for Taiwan, China which are from the "Energy Indicators of Taiwan" at the Bureau of Energy, Ministry of Economic Affair website.

Table 2: Calibration

Param.	Value	Description	Source
β	0.99	Discount rate	Xie et al. (2017)
σ	0.5	Preference parameter	Alba et al. (2013)
δ	0.025	Depreciation rate	Schmitt-Grohé and Uribe (2004)
η	3	Parameter governing investment adjustment costs	Authors' choice [a]
ρ	1.01	Substitutability between domestic and foreign goods	Alba et al. (2013)
γ	0.63	Share of foreign goods in total consumption	Authors' estimate [b]
γ^*	0.7	Share of domestic goods in total foreign consumption	Authors' choice
α	0.7	Share of labor in output	Alba et al. (2013)
ι	0.85	Share of capital relative to oil in production	Alba et al. (2013) [c]
υ	1.14	Inverse of the elasticity of substitution of capital and oil	Authors' estimate [d]
θ	0.75	Probability of price nonadjustment	Common in Calvo pricing literature
θ_w	0.75	Probability of wage nonadjustment	Author's choice [e]
ϑ	6	Elasticity of substitution between varieties of goods	Common in Calvo pricing literature
ϑ_w	6	Elasticity of substitution between types of labor	Xie et al. (2017)
γ_o	0.02	Impact of oil price on the foreign price level	Authors' choice [f]
γ_{ho}	0.02	Share of oil import in world oil consumption	Authors' estimate [g]
ψ	3	Marginal disutility of work effort	Monacelli (2004)
$\rho_{od*}^{y^*}$	0.55	Foreign income elasticity of demand for oil	Alba et al. (2013)
$\rho^{p_o^*}$	0.4	Short run foreign price elasticity of demand for oil	Authors' choice [h]
γ_{op}	0.45	Pass-through of foreign oil price to domestic oil price	Authors' choice
γ_{ep}	0.4	Exchange rate pass-through	Authors' choice

Notes: (1) Calculated using 0.1 to be the share of oil relative to capital stock in production, following Alba et al. (2013). (2) All smoothing parameters such as, ρ_{y*}, ρ_{os*}, ρ_a and ρ_{r*} are set at 0.9 and their parameter scaling the standard deviations of exogenous shocks such as, σ_{y*}, σ_{os*}, σ_a and σ_{r*} are set at 0.0001.

[a]In past literature, the choices of η roughly ranged from 2 to 6. In Schmitt-Grohé and Uribe (2004) they adopted 2.48, in Schmitt-Grohe and Uribe (2005) they used 2.79. In Galí and Monacelli (2016), they used 5.169.

[b]:γ is set to be the average of the γ values of the countries under investigation here. γ value of the respective countries are listed in Table 3.

[c]Our choice of ι, 0.85 closely follows the 0.90 reported in Alba et al. (2013).

[d]υ is set to be the average of υ values of the respective countries, reported in Table 3.

[e]In Galí and Monacelli (2016), both θ and θ_w are set to be 0.8, which are close to ours.

[f]In Alba et al. (2013) it was set to be 0.01.

[g]It is taken to be the average of γ_{ho} of the countries under investigation, reported in Table 3.

[h]This corresponds to the largest price elasticity of oil demand we could find in Caldara et al. (2016).

Table 3: Simulated Welfare of Different Countries

Economy	υ	γ	γ_{ho}	**Simulated Welfare**	**Policy Parameters**
Hong Kong, China	0.95	0.6	0.005	-4.13	$\varpi_\pi = 0, \varpi_y = 0, \varpi_e = 0.99$
Singapore	1.1	0.5	0.02	-4.72	
Korea, Rep. of	1.34	0.6	0.06	2.79	$\varpi_\pi = 1.5, \varpi_y = 0, \varpi_e = 0.01$
Taiwan, China	1.1	0.8	0.02	-1.57	
Israel	1.15	0.7	0.005	44.22	

Notes: (1) We use capital stock data from Penn World Table and energy use data from World Bank to compute the average oil-to-capital ratios from 1975 - 2008 for different countries, which we further use to compute υ. For Taiwan, the energy use data for Taiwan is found from *taiwan.gov.tw*. For Hong Kong, the energy use data is found from energy use data from EIA. (3) γ^{ho} values are calculated based on oil import data from CIA The World Factbook, except for Israel. γ^{ho} value of Israel is calculated based on 2008 oil import data from U.S. Energy Information Administration (EIA), retrieved from IndexMundi. (4) Simulated welfare is reported as value of 10^4. (5) γ (share of home goods in overall consumption) for Hong Kong is from Cheng and Ho (2009), for Singapore from Chow-Tan et al. (2014), for South Korea from Alp et al. (2012), for Taiwan, China from Teo (2009) and for Israel from Ilek and Rozenshtrom (2017).

Table 4: Simulated Welfare with Different Values of γ

γ	Fixed exchange rate	CPI inflation targeting	Real output gap targeting	Taylor rule	Nominal output growth targeting
0.45	-4.76	150.67	2412.93	468.94	-64335.87
0.55	-4.46	16.78	1058.32	48.68	373.53
0.65	-4.24	0.093	305.03	4.39	10.57
0.75	-4.08	-1.68	64.77	-0.66	-1.24
0.85	-3.95	-1.36	2.01	-1.01	-1.46

Notes: (1) γ^{ho} is kept at 0.02, the average value for the sample countries and υ is 1.14, also the average value for the sample countries. (2) Simulated welfare is reported as value of 10^4.

Table 5: Simulated Welfare with Different Values of γ^{ho}

γ^{ho}	Fixed exchange rate	CPI inflation targeting	Real output gap targeting	Taylor rule	Nominal output growth targeting
0.01	-3.91	7.71	-706.26	52.35	53.31
0.02	-4.28	1.34	400.33	7.51	20.68
0.03	-4.55	-0.61	63.99	2.00	12.83
0.04	-4.76	-1.60	28.10	-0.07	9.29
0.05	-4.94	-2.22	16.34	-1.18	7.25
0.06	-5.09	-2.66	10.71	-1.89	5.93

Notes: (1) γ is kept at 0.63 and υ is 1.14. (2) Simulated welfare is reported as value of 10^4.

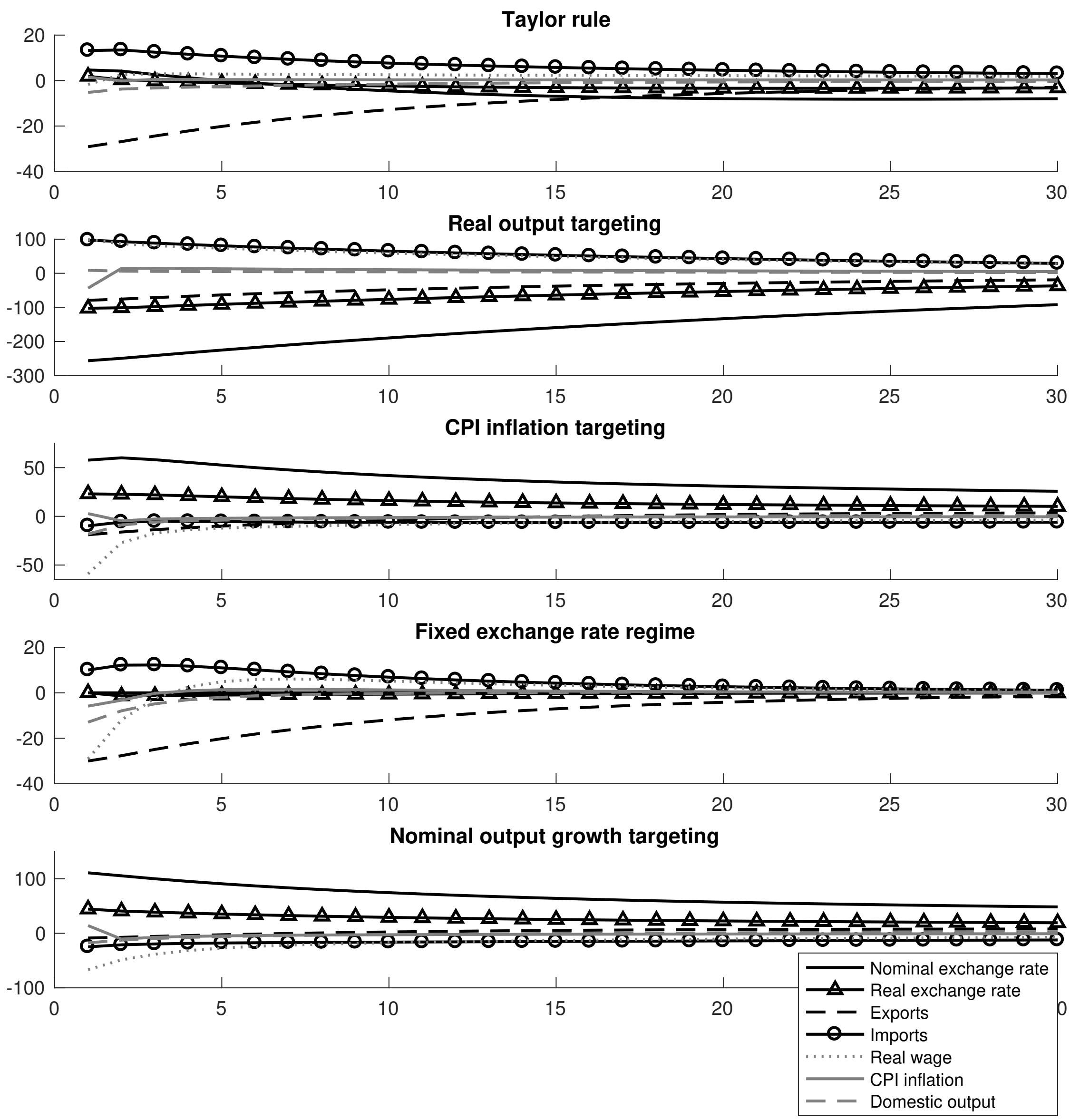

Figure 1: Impulse Response Plots After a 1 Unit Negative Shock to Foreign Output

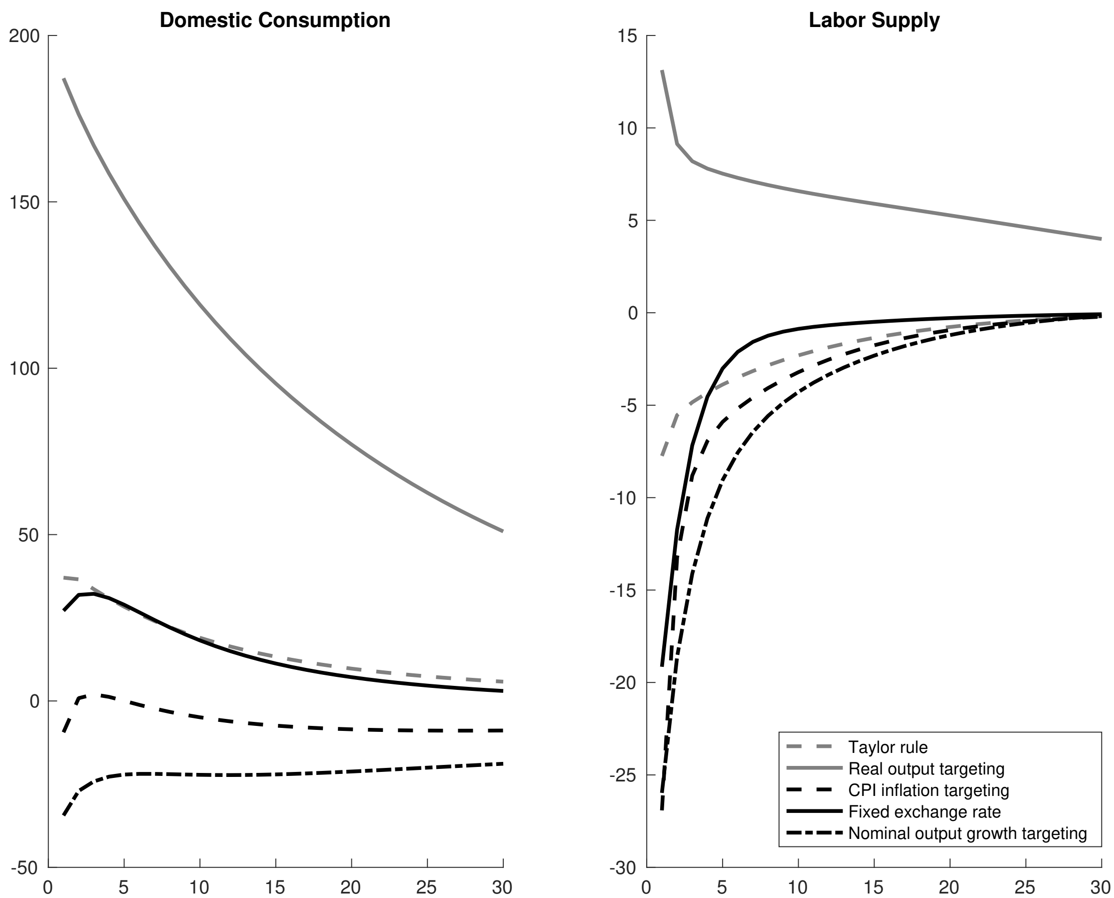

Figure 2: Impulse Response of Total Consumption and Labor Supply After a 1 Unit Negative Shock to Foreign Output

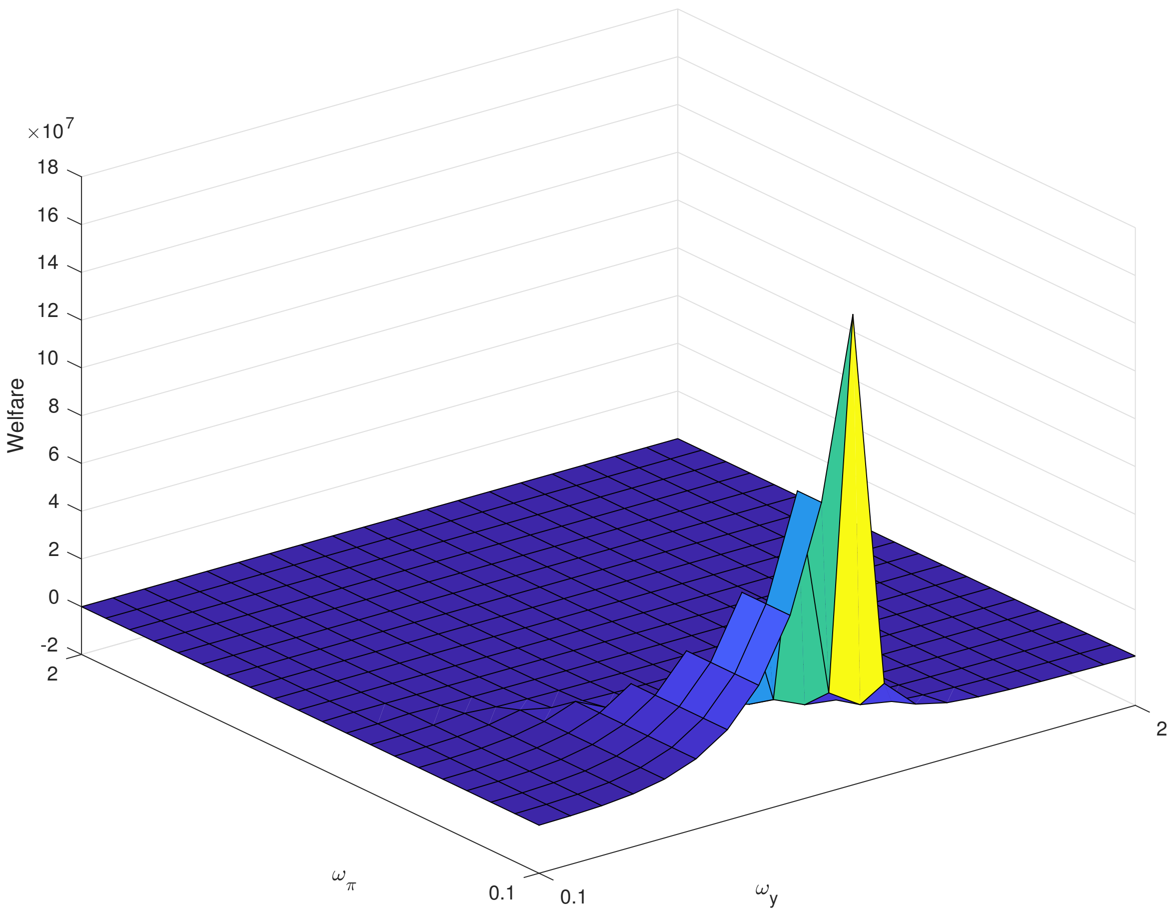

Figure 3: Coordination between Inflation Targeting and Output Targeting

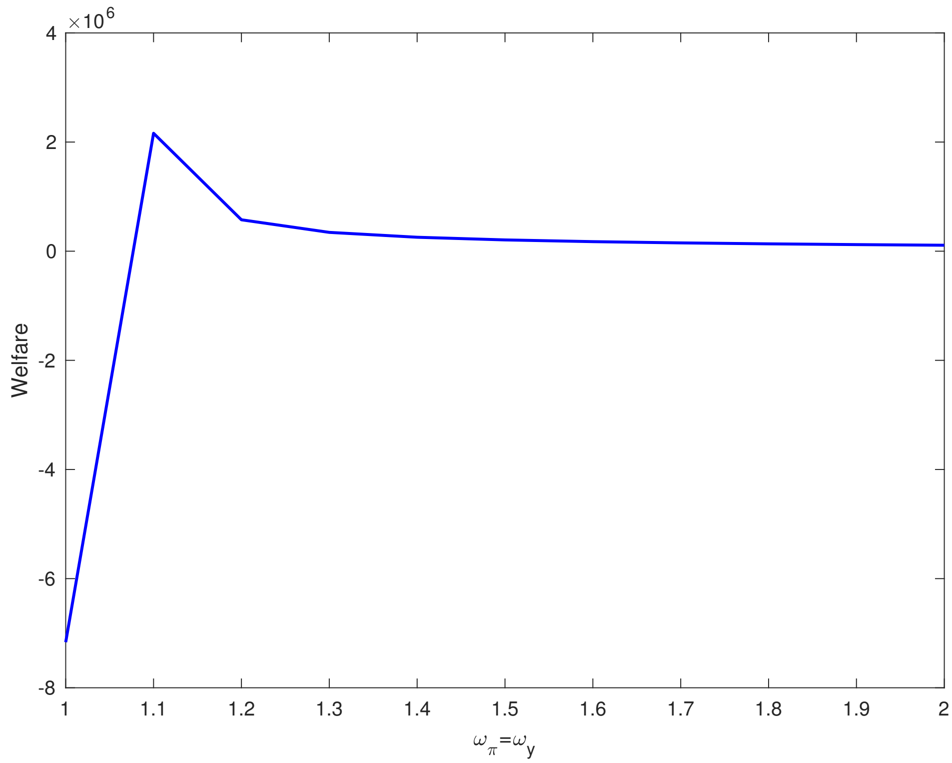

Figure 4: Welfare at Different Levels of Nominal Output Growth Targeting