Does wage-inflation targeting complement foreign exchange intervention? An evaluation of a multi-target, two-instrument monetary policy framework[☆]

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Abstract

We assess the inclusion of wage inflation as an intermediate target of an emerging central bank using a dynamic stochastic general equilibrium model with sticky wages and prices calibrated for the South Korean economy. The model includes wage inflation as an additional target jointly with domestic price inflation and the output gap in a Taylor- type interest rate rule operating with a sterilized foreign exchange (FX) intervention rule. Our results show a complementary relationship between wage inflation targeting and price inflation targeting. That is, by supplementing price inflation targeting with wage inflation targeting, welfare improves for cases with and without sterilized FX intervention. When intervention is in place, wage inflation targeting has the added advantage of reducing the volatilities of nominal exchange rate and foreign exchange reserves thereby promoting a more sustainable conduct of FX intervention.

Keywords: Emerging markets, foreign exchange interventions, sterilization, wage inflation targeting, Taylor rule, DSGE model
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1. Introduction

In the aftermath of the global financial crisis that began in 2008, central banks of major industrial and emerging-market economy (EME) countries have continued their accommodative policies despite historically low interest rates because of the sluggish economic recovery. However, early signs of declines in unemployment rates and/or of the rise in inflationary expectations in some countries have raised concerns that central banks will prematurely raise the interest rates and stall the fragile economic recovery. In fact, the European Central Bank (ECB) raised interest rates in July 2011 and the Federal Reserve Bank raised interest rates in December 2015 while the central banks of Brazil, Chile, Mexico and South Africa increased interest rates in early 2016.[1]

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[1]The European Central Bank raised interest rates in 2011 due to concerns on inflation despite the worsening GDP growth data in the EU (Atkins, 2011). The Federal Reserves raised the federal funds rates by 0.25 percentage points in December 2015 (http://www.bbc.com/news/business-35117405) with US unemployment rate at 4.9% (OECD, 2010). The Federal Reserve is also expected to increase interest rate in the last quarter of 2016 (Hilsenrath and Torry, 2016). As of July 2016, the central bank interest rates in Brazil, Chile, Mexico and South Africa are 14.25%, 3.5%, 4.25% and 7%, respectively (http//www.globalrates.com/interestrates/centralbanks.a.spx). The four emerging countries have adopted inflation targeting as monetary policies (Alba et al., 2015). Mallick and Sousa (2012) empirically investigate the monetary transmission mechanism in Brazil and South Africa.

The ECB decision in July 2011 is believed to have caused a double dip recession in the eurozone countries, so in November 2011; it reversed its decision and reduced interest rates.[2] Wren-Lewis (2014) argues that the ECB would not have raised interest rates had it used wage inflation as an intermediate target. He advocates wage inflation targeting (WIT) for the ECB since wage inflation changes infrequently and is less subject to inflation temporarily driven by increases of sales taxes and prices of commodities. Blanchflower and Posen (2014) also advocate wage inflation as an additional intermediate target of the Federal Reserve Bank. They show a significant negative relationship in the United States between wage rates and labor market slack - defined either as one minus the labor force participation rate or underemployment measured as part-time workers over total employment.[3] Therefore, a rise in labor market slack indicates a weak labor market and would be associated with lower wage growth and yet, unemployment rate would also be lower. Hence, Blanchflower and Posen argue that wage inflation would be a better intermediate target of monetary policy because, unlike the unemployment rate, it would be less distorted by labor market slack and would require less judgement.[4]

The rationale of Blanchflower and Posen (2014) and Wren-Lewis (2014) for central banks to target wage inflation could apply to inflation-targeting EME countries as well. For example, a cursory examination of South Korea's part-time employment rate (as percentage of total employment), unemployment rate and annual real wage growth from 2007 to 2013 may suggest that the rationale to target wage inflation could apply to South Korea. From 2007 to 2011, part-time employment rate rose steadily from 8.7% to 13.3% before dropping to 10% and 10.9% in 2012 and 2013, respectively. Part-time employment rate moved in the opposite direction to the annual real wage growth which was 3% in 2007 but became negative from 2008 through 2011 except for positive wage growth in 2010. As part-time employment rate dropped in 2012 and 2013, annual real wage growth became positive. In contrast, the unemployment rates were 3.2% in 2007 and 2008; it rose to 3.6% and 3.7% in 2009 and 2010, respectively, and then dropped to 3.45%, 3.2% and 3.1% from 2011 to 2013.[5] Hence, annual wage growth seems to be a better indicator of labor market slack than the unemployment rate.

Other than using inflation as a target, central banks of EME countries may also target the exchange rates and intervene in the foreign exchange (FX) markets.[6] For the case of South Korea, we examine possible indications of FX intervention by estimating a simple bivariate vector autoregressive (VAR) model that includes the log of the nominal effective exchange rate (NEER) and the FX reserve-to-GDP ratio using quarterly data from 1999Q1 to 2015Q4.[7] The bivariate VAR model's lag length is set at two periods and its variables are ordered assuming adjustments in reserves have no contemporary effects on the exchange rate. The impulse responses are shown in Figure 1. The lower left panel of Figure 1 shows that a rise in the NEER (appreciation) leads to a positive jump in the FX reserve-to-GDP ratio. This could indicate FX intervention of the Bank of Korea in which it purchases of foreign assets which temper the appreciation of the Korea's NEER. Furthermore, we interpret the top right panel of Figure 1, which shows the smooth rise in NEER (appreciation) in response to a rise in FX reserves-to-GDP ratio, as the tempering effect of the rise

[2]See Wall Street Journal (2015).

[3]Bell and Blanchflower (2016) also find that labor market slack is associated with lower wages in the United Kingdom during the global financial crisis.

[4]Sven Jari Stehn and Jan Hatzius, economists at Goldman Sachs, recommend a wage growth target for the Fed (Boesler, 2014). Marzo (2009) reviews the literature on wage inflation targeting. Canzoneri et al. (2005) note that wage inflation targeting would have been an obvious alternative to price inflation targeting but it has "received almost no attention" in the literature.

[5]Limited data on wages of EMEs prevent us from undertaking a more formal analysis of the relationship between labor market slack and wage growth. Data on part-time employment rate (percentage of employment) and the unemployment rate (percentage of labor force) of South Korea are from the World Development Indicators online (`http://data.worldbank.org/data-catalog/world-development-indicators`). Data on the annual real wage growth, defined as mean annual growth of real monthly earnings of employees, are available from 2006 to 2013 from the International Labor Organization, Global Wage Report Collection Dataset.

[6]Empirical evidence of such practice can be found in Suardi (2008) and Kasman and Ayhan (2008) among others.

[7]Data are retrieved from CEIC Macroeconomic Databases for Emerging and Developing Countries. The nominal effective exchange rate (NEER) is defined by the International Monetary Fund as the value of a currency versus the weighted average of several foreign currencies. A rise in NEER is an appreciation of the domestic currency against a basket of foreign currencies. South Korea's data series of FX reserve-to-GDP ratio is one of the longest among the 13 inflation-targeting EMEs.

of FX reserves (FX intervention) on the rise of NEER. Other than Korea, FX interventions are prevalent among EME and developing countries' central banks. Calvo and Reinhart (2002) examine 39 countries from January 1970 to November 1999 and find evidence of FX intervention in EME and developing countries. Aizenman et al. (2010) and Steiner (2015) examine 50 or more developed and developing countries from the 1970s to mid- to late- 2000 and find empirical evidence that EME countries' central banks, especially those with high-levels of FX reserves, not only intervened in the FX markets but also sterilized their interventions to pursue independent domestic monetary policies.[8]

There may be compelling reasons central banks of EMEs intervene in the FX markets. Among other reasons, Calvo and Reinhart (2000) find that compared to developed countries, in EMEs, large depreciations are contractionary, current account adjustments are sudden and severe, currency crisis often becomes credit crisis, exchange rate volatility have negative impact on trade, and pass-through is high from changes in exchange rates to inflation. Since low exchange rate volatility is positively related to trade, EMEs that are highly reliant on trade manage their exchange rates and intervene in the FX markets. These EMEs are usually faced with the trilemma constraint of being able to pursue independent monetary policy only by implementing capital controls.[9] However, Steiner (2015) finds that the trilemma constraints can be relaxed in EMEs with large FX reserves as changes in the FX reserves could substitute for capital controls. This implies the EMEs with high levels of FX reserves and small open economies have sets of policy options with price inflation targeting and wage inflation targeting through Taylor-type interest rate rule, and exchange rate stabilization through sterilized FX intervention. The wider sets of policy options come at the costs of highly volatile FX reserves and distortions in the financial markets when the exchange rate is rigidly fixed or revaluation losses and sterilization costs when the exchange rates are adjusted (Loeffler et al., 2012). Thus it would be interesting to study the interactions among these policy tools and evaluate their effects on welfare in a small open economy.

In this paper, we study optimal monetary policy rules in a simple dynamic stochastic general equilibrium (DSGE) model of a small open economy with wage and price rigidities. The model has two types of firms in the home economy: non-tradable goods producers and tradable (exportable) goods producers. Households provide labor services to firms in both sectors. In the benchmark setting, the central bank implements a Taylor-type interest rate rule together with a sterilized FX intervention rule. We augment the conventional Taylor-type interest rate rule such that it reacts not only to deviations of domestic price inflation from its target and to output gaps but also to wage inflation.[10] The sterilized FX intervention rule is as in Benes et al. (2015) in which the central bank purchases (sells) FX reserves in response to appreciation (depreciation) of the nominal exchange rate. Central bank purchases of FX reserves are funded by central bank securities sold to commercial banks. Benes et al. (2015) assume that commercial banks fund the purchases of central bank securities (and loans to households) with foreign borrowings. Hence, a rise in FX reserves increases the commercial banks' foreign-currency denominated liabilities and exposure to exchange rate risk, which in turn increases the risk premium of commercial-bank held domestic assets. The higher risk premium depreciates the nominal exchange rate since the interest rate, which is defined by the Taylor rule, does not respond to the higher risk premium. This setting allows the central bank to have a wider set of policy options with multiple instruments and transmission channels.

Specifically, we evaluate in a small open economy DSGE model, in which the central bank has multiple instruments and channels, the welfare effects of WIT with sterilized FX interventions. The goals here are to examine: 1) whether the inclusion of WIT is welfare-improving in a small open economy; 2) whether the improvement in welfare is sensitive to sterilized FX interventions of the central bank; and 3) whether WIT and sterilized FX interventions, as tools of price stabilization, complement each other. [11]

[8] Benes et al. (2015) review the literature on the effectiveness of sterilized FX interventions in EMEs

[9] Calvo and Reinhart (2000) list studies that find positive links between stable exchange rate and trade. Steiner (2015) reviews the literature on the trilemma constraints in EMEs.

[10] The conventional interest rate rule is of the type proposed by Taylor (1999) and Woodford (2003) among others.

[11] Ghosh et al. (2016) also evaluate interest rate policy with inflation and output as targets when EMEs' central banks undertake FX intervention. In addition, they consider discretionary monetary policy vis-à-vis inflation targeting. However, they use a partial equilibrium model in which welfare is derived from the central bank's objective function.

Our study contributes to the existing literature in twofold. First, to the best of our knowledge, this is the first study formally designed to evaluate the role of WIT in an open-economy general equilibrium framework equipped with both the Taylor-type interest rate rule and the sterilized FX intervention rule. By putting together the two key features that are found in the real world to capture the characteristics of the EMEs and imposing simple enough assumptions, we are able to derive exact analytical solutions that allow us to obtain various optimal monetary stabilization rules and compare them. Second, with wage inflation added as a target to the interest rate rule along with domestic price inflation and the output gap, we document the complementary relationship between WIT and price-inflation targeting (PIT) under both foreign price shock and interest rate shock. In addition, we show that WIT reinforces sterilized FX intervention in stabilizing the exchange rate.

Our analytical results provide two insights in an open-economy general equilibrium setting. First, our finding reveals the importance for the central bank to care about wage inflation along with the policy goal of stabilizing domestic price inflation and the output gap. We show in the context of our model that together with PIT, an additional WIT in the Taylor-type interest rate rule is welfare improving. This finding is in line with that of Marzo (2009) for the closed economy. Second, unlike the previous literature which usually augment the Taylor rule with additional exchange rate terms, we follow Benes et al. (2015) in explicitly modelling sterilized FX intervention. This modification seems to be crucial since we find that WIT together with sterilized FX intervention not only performs equally well compared to the conventional Taylor-type rule in terms of stabilizing the domestic price inflation and the output gap but also provides an added advantage of smoother movements in exchange rate and FX reserves.

The rest of the paper is organized into five more sections. Section 2 presents our model. Section 3 describes the data source, parametrization and estimation results. Section 4 performs welfare analyses on different monetary regimes based on our model in Section 2. In Section 5, we examine the impulse responses and perform sensitivity analyses on the parameters. The last section concludes.

2. A small open economy model with sterilized FX interventions

Our model's underlying framework builds on the small open economy model developed by Gali and Monacelli (2016) to study welfare and optimal monetary policy. The model has non-tradable and tradable (exportable) sectors where labor is the only factor of production. Labor is assumed to be perfectly mobile between the two sectors and demonstrates decreasing returns to scale in production. A common wage-setting process with wage stickiness applies to the two sectors. The non-tradable sector produces differentiated goods which are sold in monopolistically competitive markets with staggered prices while the tradable sector produces goods that are sold in the globally competitive market at a given competitive price. Households consume domestically produced non-tradable goods and also foreign tradable (importable) goods. The prices of non-tradable goods are subject to nominal rigidities. We incorporate in the Gali and Monacelli (2016) model the sterilized FX intervention rule as in Benes et al. (2015). [12] The sterilized FX intervention rule aims to stabilize exchange rates in addition to the Taylor-type interest rate rule which aims to stabilize the domestic price inflation, the wage inflation and the output gap.

2.1. Central bank, commercial banks and households

We follow Benes et al. (2015) in linking the balance sheets of the central bank, the commercial banks and the households. The central bank holds stocks of foreign reserves, F_t, as assets and issues its own securities, O_t, as liabilities which are sold to the commercial banks. The commercial banks, besides holding the central bank's securities, also make loan, L_t, to the households and borrow, B_t, from abroad. Besides F_t and B_t which are expressed in terms of foreign currency, the other assets are expressed in terms of domestic currency.

The policy framework of the central bank with a dual instrument consists of a sterilized FX intervention rule and an interest rate rule which works as follows. In the sterilized FX intervention, the central bank

[12] Castillo (2014) specifies an alternative FX intervention mechanism and calibrates the model for Guatemala.

receives interest of r_t^* on its stock of reserves F_{t-1}, pays interest rate of r_t to commercial banks for holding its securities O_{t-1}, and makes transfers CF_t^{CB} to households:

$$CF_t^{CB} = E_t F_{t-1} \exp(r_t^*) - O_{t-1} \exp(r_t) - E_t F_t + O_t, \tag{1}$$

where E_t is defined as home currency per unit of foreign currency. The central bank determines the level of reserve holdings and the interest rate paid on its own securities. The stock of foreign reserves (expressed in terms of output) is expressed as:

$$\hat{f}_t^r = \rho_f \hat{f}_{t-1}^r - (1 - \rho_f) \left[\frac{\omega_e}{1 - \omega_e} e_t + \frac{\vartheta}{1 - \vartheta} \pi_{e,t} \right] + \epsilon_{f,t}; \ \epsilon_{f,t} \sim N\left(0, \sigma_f^2\right), \tag{2}$$

where f_t^r is the real foreign reserves ($F_t^r = F_t/P_t$) deflated by steady state output ($\bar{Y}$) or $f_t^r = F_t^r/\bar{Y}$. Hence, $\hat{f}_t^r$ is the log deviation of f_t^r from its steady sate value $\bar{f}^r$. e_t is the log nominal exchange rate and $\pi_{e,t} \equiv e_t - e_{t-1}$ is the depreciation of home currency. The coefficient ρ_f is the central bank's preference in smoothing the real reserves. The exchange rate movements are controlled by ω_e and ϑ. If $\omega_e \to 1$, the central bank aims to target the exchange rate at the desired level by adjusting the stock of FX reserves. The term $\vartheta / (1 - \vartheta) \pi_{e,t}$ is used to capture the exchange rate smoothing behavior. $\epsilon_{f,t}$ is independently and identically distributed (i.i.d) with a mean of zero and a variance of σ_f^2 and denotes the central bank's discretionary adjustment of the FX reserves.

We augment the interest rate rule to include a wage inflation target such that the nominal interest rate, r_t, follows the form:

$$r_t = \rho_r r_{t-1} + (1 - \rho_r) \left[\alpha_r \pi_{h,t} + \kappa \pi_{w,t} + \delta_r \hat{y}_t\right] + \epsilon_{r,t}; \ \epsilon_{r,t} \sim N\left(0, \sigma_r^2\right) \tag{3}$$

where in log terms, $\pi_{h,t}$ is the domestic inflation rate, $\pi_{w,t}$ is the wage inflation rate and $\hat{y}_t$ is the output gap. The coefficient ρ_r is the central bank's preference for interest rate smoothing. α_r, κ and δ_r are the responses of the interest rate to price inflation, wage inflation and output deviations from their targeted levels, respectively. $\epsilon_{r,t}$ is the central bank's discretionary adjustment of the interest rate. In this set-up, the central bank could simultaneously use the FX intervention rule as in Equation 2 to stabilize the exchange rate in the foreign exchange market and the interest rate rule as in Equation 3 to target the domestic inflation, wage inflation or the output gap or the combinations of the three.

Since the model allows for sterilization in the foreign exchange market, the central bank is able to create a wedge between the nominal interest rate and the exchange-rate adjusted foreign interest rate. Following Benes et al. (2015), a bank loan rate, r_t^l, is allowed to deviate from the policy interest rate, r_t. Such a deviation means that there is imperfect substitution between the central bank securities and bank loans. Therefore, in a perfectly competitive financial sector, the commercial banks behave according to:

$$\exp(r_t) = \exp(r_t^*) \mathbb{E}_t \{\exp(\pi_{e,t+1})\} \Omega_O(F_t^r) U_t^r \tag{4}$$

$$\exp(r_t^l) = \exp(r_t) \frac{\Omega_L}{\Omega_O(F_t^r)} \tag{5}$$

where $\Omega_O^{'}(F_t^r) > 0$. Equation 4 is the modified UIP condition where UIP is augmented with a spread, $\Omega_0(\cdot)$, which is increasing in the stock of real FX reserves, F_t^r. The equation pins down the exchange rate expectations for a given spread and the interest rate r_t is defined by the Taylor rule. U_t^r denotes an exogenous shock to the UIP condition which follows an autoregressive process:

$$\log U_t^r = \rho_{u^r} \log U_{t-1}^r + \epsilon_{u^r,t}; \ \epsilon_{u^r,t} \sim N\left(0, \sigma_{u^r}^2\right) \tag{6}$$

where $\epsilon_{u^r,t}$ is an i.i.d shock, normal, with zero mean and variance $\sigma_{u^r}^2$. Equation 5 introduces a spread between the bank loan rate and the interest rate. We henceforth address r_t as the policy rate and r_t^l as the lending rate.

The sterilized FX intervention may stationarize the nominal exchange rate via the following mechanism. In response to an initial appreciation in the exchange rate, the central bank purchases FX reserves to offset the appreciating pressure on domestic currency. The central bank funds the purchase of FX reserves by selling central bank securities to commercial banks, which in turn funds the purchase of central bank securities by borrowing abroad. This increases the commercial banks' foreign-currency denominated liabilities and exposure to exchange rate risk thereby increasing the risk premium of commercial-bank held domestic assets. The higher risk premium makes domestic assets less attractive since interest rate, which is defined by the Taylor rule, cannot rise in response to the higher risk premium. As a result, demand for domestic assets and domestic currency decrease, exerting a depreciating pressure on domestic currency. This will counter the initial appreciation hence stationarizing the nominal exchange rate.

2.2. Households and wage setting

We incorporate in the model of Benes et al. (2015) the specification of household behavior and wage rigidity as in Gali and Monacelli (2016).[13] The representative domestic household has expected lifetime utility given by:

$$E_0 \sum_{t=0}^{\infty} \beta^t U\left(C_t, N_t; Z_t\right) \tag{7}$$

where β is the discount factor; Z_t is an exogenous preference shifter; C_t is the household's consumption of the final goods; and N_t is the household's labor supply. We define the utility function by:

$$U\left(C_t, N_t\right) = Z_t \left[\log\left(C_t\right) - \Phi \frac{N_t^{1+\phi}}{1+\phi}\right] \tag{8}$$

In the above expression, $\Phi > 0$ is the degree of dissatisfaction from supplying N_t units of labor and ϕ denotes the Frisch elasticity of labor supply. Z_t follows an autoregressive process:

$$\log Z_t = \rho_z \log Z_{t-1} + \epsilon_{z,t};\ \epsilon_{z,t} \sim N\left(0, \sigma_z^2\right) \tag{9}$$

where $\epsilon_{z,t}$ is an i.i.d shock, normally distributed, with zero mean and variance σ_z^2.

The consumption, C_t, is an aggregate of non-tradable goods, $C_{h,t}$ and tradable (importable) goods, $C_{m,t}$:

$$C_t \equiv A C_{h,t}^{1-\omega_m} C_{m,t}^{\omega_m} \tag{10}$$

where $\omega_m \in (0,1)$ is the share of consumption of tradable goods and $A \equiv (1-\omega_m)^{-(1-\omega_m)} \omega_m^{-\omega_m}$. The demand functions for the non-tradable and importable goods are $P_{h,t}C_{h,t} = (1-\omega_m) P_t C_t$ and $P_{m,t}C_{m,t} = \omega_m P_t C_t$, respectively. $P_{h,t}$ denotes the aggregate prices for non-tradable goods while $P_{m,t}$ is the aggregate prices for importable goods. The consumer price index is $P_t = P_{h,t}^{1-\omega_m} P_{m,t}^{\omega_m}$. Consequently, the CPI inflation is given by $\Pi_t = \Pi_{h,t}^{1-\omega_m} \Pi_{m,t}^{\omega_m}$ where $\Pi_{h,t} \equiv P_{h,t}/P_{h,t-1}$ and $\Pi_{m,t} \equiv P_{m,t}/P_{m,t-1}$. The price of importable goods is the product of nominal exchange rate and autoregressive exogenous world price:

$$P_{m,t} = E_t P_t^* \tag{11}$$

$$\log P_t^* = \rho_p^* \log P_{t-1}^* + \epsilon_{p,t}^*;\ \epsilon_{p,t}^* \sim N\left(0, \sigma_p^{*2}\right) \tag{12}$$

Each household maximizes its utility in Equation 7 subject to the following budget constraint:

$$P_t C_t - L_t = -\exp\left(r_{t-1}^l\right) L_{t-1} + W_t N_t + CF_t^{CB} + \Delta_t - P_t \Psi\left(\frac{L_t}{P_t}\right) \tag{13}$$

where $\Psi\left(L_t/P_t\right)$ captures the loan adjustment costs with $\Psi'\left(L_t/P_t\right) > 0$ and $\Psi''\left(L_t/P_t\right) > 0$. These conditions prevent excessive loans. Δ_t is the total amount of profits households received from firms, the

[13] The details of the Gali and Monacelli model deriving wage rigidity and extending the model to include tradable and non-tradable sectors are in their online appendix (http://www.nber.org/data-appendix/w22489/OnlineAppendix_final.pdf).

commercial banks and the central bank, which are treated as exogenous by the household. Maximizing the utility subject to the budget constraint gives the following first order conditions:

$$-\lambda_t\left[1-\Psi'\left(\frac{L_t}{P_t}\right)\right]+\beta\mathbb{E}_t\{\lambda_{t+1}\}\exp\left(r_t^l\right)=0 \tag{14}$$

$$\frac{Z_t}{C_t}-\lambda_t P_t=0 \tag{15}$$

$$\Phi Z_t N_t^{\phi}-\lambda_t W_t=0 \tag{16}$$

The first equation can be manipulated so as to obtain:

$$\frac{\lambda_t}{\mathbb{E}_t\lambda_{t+1}}\left[1-\varrho\left(L_t^r\right)\right]=\beta\exp\left(r_t^l\right), \tag{17}$$

where $L_t^r \equiv L_t/P_t$ is the real level of loans and $\varrho\left(L_t^r\right) \equiv \Psi'\left(L_t^r\right)$ is the credit-sensitive wedge between the interest rate and the discount factor. The household's outstanding stock of loans which represents the country's net foreign liabilities is given by:

$$L_t=L_{t-1}\exp\left(r_{t-1}^*+\log\Pi_{e,t}\right)+\left(C_{m,t}Y_{m,t}-P_{x,t}Y_{x,t}\right). \tag{18}$$

As in Gali and Monacelli (2016), we assume a continuum of monopolistically competitive households (indexed from zero to one). Each household supplies a unit of differentiated labor to both the non-tradable goods producers and the tradable goods producers. Labor is perfectly mobile between the sectors and hence equalizes wages for the same type of labor across sectors.

We assume non-tradable goods producers reside in $[0,b]$ and the tradable goods producers reside in $[b,1]$. Each firm in each of the sectors employs all differentiated labor types indexed by j. Hence, total labor demand by firm i in non-tradable goods sector is $N_{h,t}^d(i)=\left(\int_0^1 N_{h,t}^d(i,j)^{(\theta_w-1)/\theta_w}dj\right)^{\theta_w/(\theta_w-1)}$ and its counterpart in tradable goods sector is $N_{x,t}^d(i)=\left(\int_0^1 N_{x,t}^d(i,j)^{(\theta_w-1)/\theta_w}dj\right)^{\theta_w/(\theta_w-1)}$. As such, the optimal type-j-labor demand for both the non-tradable goods sector and the tradable goods sector are $N_{h,t}^d(j)=\left[W_t(j)/W_t\right]^{-\theta_w}N_{h,t}^d$ and $N_{x,t}^d(j)=\left[W_t(j)/W_t\right]^{-\theta_w}N_{x,t}^d$. Wage index is given by $W_t=\left[\int_0^1 W_t(j)^{1-\theta_w}dj\right]^{1/(1-\theta_w)}$.

At each period only a fraction of $(1-\xi_w)$ of households are randomly drawn from the population to reset their nominal wages. Consider the optimal wage setting problem for household j:

$$\max\mathbb{E}_t\sum_{k=0}^{\infty}(\beta\xi_w)^k U\left[C_{t+k|t}(j),N_{t+k|t}(j);Z_{t+k|t}\right], \tag{19}$$

where $N_{t+k|t}(j)$ is time $t+k$ labor supply by household providing labor service of type j who last reset her wage in time t. At the chosen wage $\bar{W}_t(j)$, the household is assumed to supply enough labor to satisfy demand. The constraint reads:

$$N_{t+k|t}(j)=N_{t+k|t}^d(j)=\left(\frac{\bar{W}_t(j)}{W_{t+k}}\right)^{-\theta_w}N_{t+k}^d \tag{20}$$

Here, N_{t+k}^d represents the aggregate labor demand during the period. In addition, the household faces the following budget constraint:

$$P_{t+k}C_{t+k|t}-L_{t+k|t}=-\exp(r_{t+k-1|t}^l)L_{t+k-1|t}+\bar{W}_t(j)N_{t+k|t}(j)+CF_{t+k|t}^{CB}+\Delta_{t+k|t}-P_t\Psi\left(\frac{L_{t+k|t}}{P_{t+k}}\right) \tag{21}$$

As each household j re-optimizing the wage at a given time t chooses the same optimal wage, we leave out the index j. Solving the optimal wage-setting problem gives the following first order condition:

$$\sum_{k=0}^{\infty} (\beta\xi_w)^k \mathbb{E}_t \left\{ U_{c,t+k|t} \left[\frac{\bar{W}_t}{P_{t+k}} - M_w MRS_{t+k|t} \right] \right\} = 0, \tag{22}$$

where $M_w \equiv \theta_w / (\theta_w - 1)$ and $MRS_{t+k|t} \equiv \Phi C_{t+k|t} N^{\phi}_{t+k|t}$. Together with the log-linearised equations for conditional marginal rate of substitution and labor demand, the wage-setting rule can be written as:

$$\bar{w}_t = \beta\xi_w \mathbb{E}_t\{\bar{w}_{t+1}\} + (1 - \beta\xi_w) \left(w_t - (1 + \theta_w\phi)^{-1} \hat{\mu}^w_t \right), \tag{23}$$

where $\hat{\mu}^w_t = \mu^w_t - \mu^w$ denotes the deviations of the economy's log average wage mark-up $\mu^w_t = w^r_t - mrs_t$ from its steady state level μ^w where $w^r_t = w_t - p_t$ is the real wage. Defining $\Pi_{w,t} \equiv W_t / W_{t-1}$. From now on, a lower case variable denotes the percentage deviation of the variable from its steady state. We have a log-linearised equation for the evolution of nominal wage which can be written as:

$$\pi_{w,t} = \beta \mathbb{E}_t \{\pi_{w,t+1}\} - \lambda_w \hat{\mu}^w_t + u^w_t, \tag{24}$$

where $\lambda_w \equiv (1 - \xi_w)(1 - \beta\xi_w) / [\xi_w (1 + \theta_w \phi)]$ and u^w_t denotes wage inflation shock that follows a normal distribution: $u^w_t \sim N\left(0, \sigma^2_{u^w}\right)$.

2.3. Non-tradable goods producers

Production in the non-tradable and tradable sectors is from Gali and Monacelli (2016). The production function of a domestic firm in non-tradable goods sector is given by:

$$Y_{h,t}(i) = A_{h,t} N_{h,t}(i)^{1-\alpha} \tag{25}$$

where $Y_{h,t}(i)$ denotes the output of non-tradable good i, and $N_{h,t}(i)$ is the total labor demand by firm i in the non-tradable goods sector as previously defined. $(1 - \alpha) \in (0, 1)$ is the output elasticity of labor. The source of exogenous shock is the productivity shock with $A_{h,t}$ following an autoregressive process:

$$\log A_{h,t} = \rho_h \log A_{h,t-1} + \epsilon_{h,t};\ \epsilon_{h,t} \sim N\left(0, \sigma^2_h\right) \tag{26}$$

where $\epsilon_{h,t}$ is an i.i.d shock, normal, with zero mean and variance σ^2_h. The nominal marginal cost would be common across domestic firms and given by:

$$\Psi_{h,t} \frac{\partial Y_{h,t}}{\partial N_{h,t}} = W_t \tag{27}$$

where $\Psi_{h,t}$ denotes nominal marginal cost, $\partial Y_{h,t} / \partial N_{h,t} = (1 - \alpha) Y_{h,t} / N_{h,t}$, and the index i is omitted.

Following Calvo (1983), each period, a firm in the non-tradable goods sector is allowed to reset its price with a probability of $(1 - \xi_p)$ and must keep the price unchanged with a probability of ξ_p. Inspecting this reveals that ξ_p is a crucial parameter reflecting the degree of nominal rigidities in prices. When ξ_p approaches 0, we get to a perfectly flexible price economy. Likewise, when ξ_p approaches 1, prices are completely fixed.

The firm's objective is to maximize the expected present value of its profits. Therefore, the firm will adjust its price in period t to solve the following problem[14]:

$$\max \sum_{k=0}^{\infty} \xi^k_p \mathbb{E}_t \left\{ \Lambda_{t,t+k} \left(\frac{1}{P_{h,t+k}} \left[\bar{P}_{h,t} Y_{h,t+k|t} - C_{t+k}\left(Y_{h,t+k|t}\right) \right] \right) \right\} \tag{28}$$

[14] See Gali (2015, Chapter 3).

subject to a sequence of demand constraints:

$$Y_{h,t+k|t} = \left(\frac{\bar{P}_{h,t}}{P_{h,t+k}}\right)^{-\theta_p} C_{t+k} \tag{29}$$

for $k = 0, 1, 2, \ldots$ where $\Lambda_{t,t+k} \equiv \beta^k U_{c,t+k}/U_{c,t}$ is the stochastic discount factor, $\mathcal{C}_t(\cdot)$ is the nominal cost function, and $Y_{n,t+k|t}$ 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:

$$\sum_{k=0}^{\infty} \xi_p^k \mathbb{E}_t \left\{ \Lambda_{t,t+k} Y_{h,t+k|t} \left(\frac{1}{P_{h,t+k}}\right) \left(\bar{P}_{h,t} - \mathcal{M}\Psi_{h,t+k|t}\right) \right\} = 0 \tag{30}$$

where $\Psi_{t+k|t} \equiv \mathcal{C}'_{t+k}\left(Y_{h,t+k|t}\right)$ denotes the nominal marginal cost in period $t+k$ for a firm which last reset its price in period t and $\mathcal{M} \equiv \theta_p / (\theta_p - 1)$. Log-linearizing the above optimality condition around the perfect foresight zero inflation steady state where $\Lambda_{t,t+k} = \beta^k$, gives:

$$\bar{p}_{h,t} = \mu^p + (1 - \beta\xi_p) \sum_{k=0}^{\infty} (\beta\xi_p)^k \mathbb{E}_t\{\psi_{t+k|t}\}, \tag{31}$$

where $\psi_{t+k|t} \equiv \log \Psi_{t+k|t}$ is the log marginal cost and $\mu^p \equiv \log \mathcal{M}$ is the log of the desired gross mark-up.

As in wage inflation, domestic price inflation can be derived as:

$$\pi_{h,t} = \beta \mathbb{E}_t\{\pi_{h,t+1}\} - \lambda_p \hat{\mu}_t^p + u_t^p, \tag{32}$$

where $\lambda_p \equiv \left[(1-\xi_p)(1-\beta\xi_p)/\xi_p\right]\Theta$, and $\Theta \equiv (1-\alpha)/(1-\alpha+\alpha\theta_p) \in (0,1]$. The average price markup is given by $\mu_t^p = p_{h,t} - w_t^\tau - p_t + a_{h,t} - \alpha n_{h,t}$ and $\hat{\mu}_t^p = \mu_t^p - \mu^p$. u_t^p is the cost-push shock that follows a normal distribution: $u_t^p \sim N\left(0, \sigma_{u^p}^2\right)$.

2.4. Tradable goods producers

The production function of a domestic firm in tradable goods (exportable) sector is given by:

$$Y_{x,t}(i) = A_x N_{x,t}(i)^{1-\alpha}, \tag{33}$$

where $Y_{x,t}(i)$ denotes the output of tradable good i and $N_{x,t}(i)$ is the total labor demand by firm i as previously defined. The productivity in the tradable goods sector is assumed to be fixed at A_x. The nominal marginal cost would be common across the domestic firms and given by:

$$\Psi_{x,t} \frac{\partial Y_{x,t}}{\partial N_{x,t}} = W_t \tag{34}$$

where $\Psi_{x,t}$ denotes the nominal marginal cost. Since the producer is a price-taker in the world market, the marginal cost equals the price of exports, $P_{x,t}$, which is a product of the exchange rate, E_t, and the autoregressive exogenous world export price, $P_{x,t}^*$, such that:

$$P_{x,t} = E_t P_{x,t}^* \tag{35}$$

$P_{x,t}^*$ follows an auto-regressive process

$$\log P_{x,t}^* = \rho_{p_x}^* \log P_{x,t-1}^* + \epsilon_{p_x,t}^*;\ \epsilon_{p_x,t}^* \sim N\left(0, \sigma_{p_x}^{*2}\right) \tag{36}$$

2.5. Equilibria in the labor and goods markets

The labor market clears when the demand for labor from the non-tradable and tradable (exportable) sectors equals the total supply:

$$N_t = N_{h,t} + N_{x,t} \tag{37}$$

For the non-tradable goods market to clear, it requires that the supply of the non-tradable goods meets the demand for non-tradable goods consumption:

$$Y_{h,t} = C_{h,t} \tag{38}$$

Supply of the exportable goods, on the other hand, should meet the exogenous world demand:

$$Y_{x,t} = \left(\frac{P_{x,t}}{P_t^* E_t}\right)^{-1} Y_t^* \tag{39}$$

$$\log Y_t^* = \rho_y^* \log Y_{t-1}^* + \epsilon_{y,t}^*;\ \epsilon_{y,t}^* \sim N\left(0, \sigma_y^{*2}\right) \tag{40}$$

$$\tag{41}$$

where the world demand, Y_t^*, is assumed to follow an autoregressive processes.[15] The aggregate output equals the total production from both the non-tradable and tradable sectors:

$$Y_t = Y_{h,t} + Y_{x,t}. \tag{42}$$

2.6. Balance of payments and the rest of the world

Deflating Equation 18 by the consumer price index and steady state output gives a real measure of the balance of payments:

$$l_t^r = l_{t-1}^r \exp\left(r_{t-1}^* + \log \Pi_{e,t} - \log \Pi_t\right) + \bar{Y}^{-1}\left(Q_t C_{m,t} - P_{x,t}^r Y_{x,t}\right) \tag{43}$$

As $L_t^r = L_t/P_t$ is the real measure of loans, we have $l_t^r = L_t^r/\bar{Y}$. $P_{x,t}^r \equiv P_{x,t}/P_t$ which is the relative price of exportable goods. The country's terms of trade is given by $S_t \equiv P_{x,t}/P_{m,t}$. The real exchange rate is defined as $Q_t \equiv E_t P_t^*/P_t$ where an increase in Q_t is a real depreciation of the home currency. The foreign interest rate is assumed to follow an autoregressive process:

$$r_t^* = \rho_r^* r_{t-1}^* + \epsilon_{r,t}^*;\ \epsilon_{r,t}^* \sim N\left(0, \sigma_r^{*2}\right). \tag{44}$$

where $\epsilon_{r,t}^*$ is an i.i.d. shock, normal, with zero mean and variance, σ_r^{*2}.

2.7. Steady states and the log-linearised model

Following standard steps, we first specify the functional forms of Ω_O and Ψ. As $\Psi = (1/2)\,\varrho^*\left(L_t^r - \bar{L}^r\right)^2$, we have the following form of $\varrho\left(L_t^r\right)$:

$$\varrho\left(L_t^r\right) = \varrho^*\left(L_t^r - \bar{L}^r\right) = \varrho^* \bar{Y}\left(l_t^r - \bar{l}^r\right) \tag{45}$$

where L_t^r denotes real value of loans relative to steady state output. Ω_O is defined as:

$$\log\left[\Omega_O\left(F_t^r\right)\right] = \Omega_O^*\left(F_t^r - \bar{F}^r\right) = \Omega_O^* \bar{Y}\left(f_t^r - \bar{f}^r\right) \tag{46}$$

[15]In our model, we do not assume correlated foreign shocks as in Justiniano and Preston (2010). This is because, first, in the post-crisis period, interest rates in the advanced economies have remained low and many central banks resorted to unconventional monetary policies, and second, we calculated the correlations among these variables and found insignificant pair-wise correlation among them in the post-crisis period.

where F_t^r denotes the real value of FX reserves relative to the steady state output. At steady state, $\log\left[\Omega_O\left(\bar{F}^r\right)\right] = \Psi = \varrho = 0$, and $\bar{P}_m = \bar{P}_n = \bar{P}_x^* = \bar{P}_x = \bar{Q} = \bar{P} = \bar{C} = 1$. Thus, $\bar{C}_n = 1 - \omega_m$, and $\bar{C}_m = \omega_m$.

From the balance of payments, we have $\bar{Y}_x = \omega_m + \bar{l}^r\left(\beta^{-1} - 1\right)\bar{Y} = \omega_m + \zeta$, implying that $\bar{Y} = 1 + \zeta$. Thus $\bar{Y}_h/\bar{Y} = (1 - \omega_m)/(1 + \zeta)$ and that $\bar{Y}_x/\bar{Y} = (\omega_m + \zeta)/(1 + \zeta)$. Trade balance is given by $tb = \zeta$. The steady state employment is given by $\bar{N}_h = 1 - \omega_m$, $\bar{N}_x = \omega_m + \zeta$ and $\bar{N} = 1 + \zeta$, rendered by setting the following parameters to be: $\Phi = (1 - \alpha)(1 + \zeta)^{-\phi}$, $A_h = \omega_n^{\alpha}$ and $A_x = (1 - \omega_n + \zeta)^{\alpha}$. Both the inflation targets $\pi_{h,t}^T$ and $\pi_{w,t}^T$ are set to zero, implying $\bar{i} = \bar{r}^l = \bar{i}^* = -\log(\beta)$. The starting value for nominal exchange rate is $E^T = 1$.

We log-linearise the equations around the steady states and use lower cases to represent percentage deviations from the steady states. The key equations are summarized in Table 1.

2.8. *The welfare loss function*

We approximate the welfare loss function and show it to be in second-order terms of wage inflation, domestic price inflation and output gap:

$$\mathbb{L} = -\mathbb{E}_t \sum_{t=0}^{\infty} \beta^t \bar{N} \left\{ \frac{\Upsilon}{2\left(1 + \theta_w \phi\right)\lambda_w} \pi_{w,t}^2 + \frac{\theta_p}{2\lambda_p} \Gamma_h \pi_{h,t}^2 + \iota \Gamma_h^2 \hat{y}_{h,t}^2 + \iota \Gamma_x^2 \hat{y}_{x,t}^2 + 2\iota \Gamma_h \Gamma_x \hat{y}_{h,t} \hat{y}_{x,t} + t.i.p + o\left(\|a\|^3\right) \right\} \tag{47}$$

where $\hat{y}_{h,t} = y_{h,t} - y_{h,t}^n$, $\Upsilon = \theta_w(1 - \alpha)\left(\theta_w(1 + \phi) + 1\right)$, $\Gamma_h = \bar{N}_h/\bar{N}$, $\Gamma_x = \bar{N}_x/\bar{N}$ and $\iota = (1 + \phi)/\left[2(1 - \alpha)\right]$. In the special case where $\alpha = 0$, the welfare loss function can be further simplified into:

$$\mathbb{L} = -\mathbb{E}_t \sum_{t=0}^{\infty} \beta^t \bar{N} \left[\frac{\Upsilon}{2\left(1 + \theta_w \phi\right)\lambda_w} \pi_{w,t}^2 + \frac{\theta_p}{2\lambda_p} \Gamma_h \pi_{h,t}^2 + \frac{1 + \phi}{2}\left(\hat{y}_t - y^n\right)^2 \right] + t.i.p + o\left(\|a\|^3\right) \tag{48}$$

Inspecting Equation 48 immediately reveals that the benevolent central bank should care about not only fluctuations in domestic price inflation and output gap but also the variations of wage inflation. In this model, the central bank faces trade-off in stabilizing both types of inflation, from the goods and the labor markets, and the output gap.[16]

3. Data, parametrization and estimation

We obtain the parameter values through calibration and Bayesian estimation. The reason for this approach is that we calibrate the parameters that are associated with the steady states so that the steady states of the model are the same as that of the actual economy, and we let the data speak for themselves on the parameters that shape the economic dynamics. For the parameters that are difficult to identify, we also calibrate them. Data used for both calibration and estimation spans from 1999Q1 (the first year that Korea adopted inflation targeting) to 2016Q1.

The values of the calibrated parameters are obtained either from the existing literature or from our calculations based on the data. These values are summarised in Table 2. For ω_m, we calibrate it to be the average imports to consumption ratio in the sample period. The trade balance, ζ, is calculated as the trade balance as a percentage of GDP. To obtain the smoothing parameters for the Taylor and the FX intervention rules, we run first order uni-variate auto-regressions for the Korean money market rate and reserves-to-GDP ratio to obtain the coefficients of their respective lags. The parameters for price and wage rigidities are chosen according to the assumption that producers and households get to optimise prices and wages semi-annually.[17]

[16] Exact derivation of the welfare loss function is available from the authors upon request.

[17] We attempted to estimate all the coefficients including price rigidities and persistence of the preference shock, but the estimation returns values that are too far from reasonable ranges for some parameters. We thus decided to fix these coefficients. The impulse responses and the conclusions from our welfare analyses did not show obvious change as we fixed the coefficients.

The other parameters are estimated via the Bayesian method described in An and Schorfheide (2007). These parameters include the responses of policy interest rate to inflation and output gap, the responses of FX reserves to exchange rates, the auto-regressive coefficients and standard deviations of exogenous shocks. They are associated with the state variables that drive the model economy. The parameters describing the responses of policy interest rate to inflation and output gap are assumed to follow gamma distributions. For the responses of FX reserves to exchange rates and the auto-regressive coefficients we assume that they follow beta distributions with mean 0.5 so as to restrict the posterior estimates within the range of $[0, 1]$. The standard deviations of exogenous shocks are assumed to follow inverse-gamma distributions. The prior mean for standard deviation of preference shock (σ_z) follows Chung et al. (2007), and the prior mean for standard deviation of UIP shock (σ_{u^r}) follows Piao and Joo (2011). Prior means for standard deviations of the other shock variables are chosen so as to match the theoretical moments derived from simulation with the empirical moments of key model variables as described later. The posterior means are used as estimates for the parameter values and both the prior and posterior estimates are tabulated in Table 3.

We specify 11 variables to be the observables for Bayesian estimation. They are foreign price p^*, export price p^*_x, foreign interest rate r^*, output gap g, foreign output y^*, CPI inflation π, consumption c, foreign reserves to steady state GDP ratio $\hat{f}$, domestic interest rate r, wage inflation π_w and nominal exchange rate depreciation π_e. The corresponding data and their sources are summarised in Appendix Appendix A. We apply Hodrick and Prescott (1997) filter with $\lambda = 1600$ on the data and use their cyclical components for the estimation in Dynare.

The non-stationary variables in our model, specifically the nominal exchange rate and the price indices, may complicate the search for the posterior modes. As such, we employ Monte Carlo optimization method specified in Adjemian et al. (2011). This routine enables us to begin from a point in parameters space with a high- posterior-density value and to utilize an appropriate covariance matrix for the jumping distribution.[18] Subsequently, we use Metropolis Hastings with 200,000 replications to compute the posterior mode. The average acceptance ratio per chain is 35.92%.

Our estimation produces sound convergence diagnostics. The univariate convergence diagnostics generated after the estimation show that the 80% interval/quantile range based on the pooled draws from all sequences converge to the mean interval range based on the draws of the individual sequences for all parameters. The second and the third central moments of the pooled and the within-sample mean converge as well. Convergence also shows in the multivariate convergence diagnostic plot.

The theoretical moments of some model variables are able to match their empirical counterparts. The ratio between the theoretical standard deviations of wage inflation and output gap is 1.0678, within the 99% confidence interval calculated from the data (0.8616, 1.8883). The ratio between the theoretical standard deviations of nominal exchange rate depreciation and output gap is 3.4271, also within the 99% confidence interval calculated from the data (1.9756, 4.8201). Moreover, the theoretical standard deviation of reserves-to-GDP ratio is also not far from its confidence interval. Although the moments of a few other variables do not seem to match, one should be aware of the following. First, our model is based on Gali and Monacelli (2016), which describes a stylised economy. Without capturing more complicated interactions or production processes in the economy, it is not easy to match the moments of most of the variables. Second, knowing the constraint of the model in matching the moments, we prioritise our target to a formula for the FX intervention rule that reproduces movements in reserves reasonably well.

The posterior estimates reported in Table 3 show that all the estimated parameters are identified. While the response of the policy interest rate to domestic inflation is of a reasonable magnitude at 1.734, its response to output gap is slightly larger than usual at 1.878. In later part of the paper, we will show that a lower value results in better welfare. In the FX intervention rule, the reserves are found to respond more actively to nominal exchange rate depreciation ($\vartheta = 0.685$) than to deviations of the nominal exchange rate from its fix target ($\omega_e = 0.230$). This implies that the central bank emphasises more on exchange rate smoothing. Among the shocks, some are more persistent such as the productivity and foreign output shocks while the

[18]This process is triggered by the option of `mode_compute` $= 6$ in Dynare estimation.

others die out faster such as the foreign price shock.

We examine how the exogenous shocks shape the dynamics of the key macroeconomic variables via variance decompositions. Table 4 reports the forecast error variance decomposition of output gap, domestic inflation, wage inflation and nominal exchange rate to the twelve shocks in the model. In the model, the contributions of foreign price shock and domestic interest rate shock are quite substantial. For instance, it is noted that while domestic interest rate shock explain close to 45% of the volatilities in output gap, the contribution of foreign price shock on the fluctuation in output gap is more than 22%. Both shocks together explain more than 67% of the volatilities in output gap, which suggests that it is important to consider these two shocks in the studies as these are central to the determination of both the interest rate policy and sterilized FX intervention.

4. Welfare analysis

In this section, we examine the welfare implications of PIT, WIT and sterilized FX intervention. The evaluation is carried out in three steps. In the first step, we look at the welfare implications of WIT in a Taylor rule framework without sterilized FX intervention (Taylor rule alone). This is done by comparing the welfare losses at different combinations of PIT and WIT represented by the values of coefficients α_r and κ. In the second step, we consider the Taylor rule with the FX intervention rule with sterilization (referred to simply as sterilized FX intervention) and repeat the experiment in the first step. This is done to examine the welfare implications of WIT when the central bank adopts a dual-instrument framework. In the last step, we analyse the welfare implications of the sterilized FX intervention by finding the differences in welfare losses calculated in the previous two steps. A positive value implies a lower welfare loss (an hence a welfare improvement) under FX intervention rule with sterilization as compared to the Taylor rule alone.

As our interest here is on how the interactions between PIT, WIT and sterilized FX intervention change the welfare of the economy, before our experiments, it is reasonable to fix δ_r, the coefficient of output gap in the Taylor rule, at a value that minimises welfare loss. A grid search for the minimum welfare loss, for α_r between 1 and 5 and δ_r between 0 and 3, reveals that δ_r revolves between 1.2 and 1.3. At the estimated value of $\alpha_r = 1.734$, we find that $\delta_r = 1.2$ produces the minimum welfare loss. As such, we fix δ_r at 1.2 for the welfare and counter-factual analyses in the remaining part of the paper.

We first calculate the welfare loss defined in Equation 47 for each pair of α_r and κ between 1 and 5 with the Taylor rule alone (without sterilized FX intervention) so that $\omega_e = \vartheta = 0$. A larger value of α_r implies stricter PIT. Likewise, a larger value of κ means stricter WIT. This range of α_r and κ corresponds to a relatively active Taylor rule as the policy interest rate is found to be more responsive to price and wage inflation.[19] The welfare losses are shown in the upper left panel of Figure 2.

First, we find that stricter PIT or WIT, and hence correspondingly larger values of α_r and κ, leads to smaller welfare loss in the Taylor-rule alone framework. Stricter PIT and WIT are expected to reduce the volatility in both price and wage inflation. However, besides price and wage inflation, in our derivation of welfare loss as in Equation 47, volatility in output gap also matters. As a result, despite stability in price and wage inflation, welfare loss also varies with the change in output gap. Our simulations reveal that the improvement in welfare is less obvious at larger values of α_r which implies that in reaction to a more stable price inflation, output volatility increases suggesting a clear trade-off between stabilizing price and output.[20] Second, we find that at any value of α_r, WIT always results in an improvement in the welfare. Since wage is an important component in the overall production costs, limiting the volatility in wages can reduce the need for producers to adjust prices, thus stabilizing price inflation. Consistent with this line of argument, our simulations further suggest that a combined PIT and WIT can lead to lower welfare loss as compared to that which relies only on PIT.

[19] We have also experimented for α_r and κ between 0 and 1 but the welfare losses obtained are not well-behaved and hence not reported. Results can be made available upon request from the authors.

[20] We find a turning point of the welfare loss at $\alpha_r = 7$. Since this is a value that is too far from a reasonable range, we do not discuss it in the paper.

In the second step, we augment the monetary policy framework with the FX intervention rule with sterilization and repeat the simulations in the first step. The inclusion of the FX intervention rule is achieved by setting the relevant parameters to their estimated values, in other words, $\omega_e = 0.2301$ and $\vartheta = 0.6864$. The welfare losses are shown in the upper right panel of Figure 2. The findings in these simulations are relatively similar to that of Taylor rule alone where we also find that PIT and WIT together improve welfare. This further leads us to conclude that there are some complementarity between WIT and PIT. Putting these together suggests that PIT and WIT improve welfare regardless of the types of monetary policy regimes.

We complete the welfare analysis with a comparison between the single-instrument framework (Taylor rule alone) and the dual-instrument framework (Taylor rule with sterilized FX intervention or simply sterilized FX intervention). To enable such comparison, we subtract the welfare losses calculated in the dual-instrument framework in the second step from that calculated in the Taylor rule alone framework in the first step at each coordinate of (α_r, κ). The differences in welfare are then interpreted as the welfare improvements and we show them in the lower panel of Figure 2. First, the surface plot remains positive for all combinations of α_r (PIT) and κ (WIT), implying higher welfare in a dual-instrument framework. This could be due to more stable exchange rate movements as a result of sterilized FX intervention. In a small open economy, the volatility in price inflation attributes greatly to the combined effects of import prices and exchange rates. Stabilizing exchange rate via sterilized FX intervention thus helps to stabilize price inflation and hence improves welfare in the economy. Second, the complementary role of sterilized FX intervention to PIT and WIT is more prominent when PIT and WIT are less aggressive. Specifically we see that when α_r and κ are between 1 and 2, the dual-instrument framework exhibits an obvious advantage over the Taylor rule alone framework as welfare improvements at these values are found to be significantly larger. However, as PIT and WIT become stricter, that is when α_r and κ are larger, the magnitude of welfare improvements diminishes.

5. Counter-factual simulations

5.1. Impulse responses

In our impulse responses, we examine four monetary policy regimes: Taylor rule alone with and without WIT; and sterilized FX intervention with and without WIT. Since the welfare loss is found to be monotonously decreasing in the coefficient of price inflation in the Taylor rule, instead of using an optimal value, we use the estimated value $\alpha_r = 1.734$ for the simulations in this section. As for the coefficient of output gap, we use the optimal value found in Section 4 where δ_r is set at 1.2. To simulate the Taylor rule with WIT, we set the coefficient of wage inflation to be equal to that of price inflation such that $\kappa = 1.734$. For the second pair of policy regimes with sterilized FX intervention, we set the coefficients of exchange rates in the FX intervention rule to their estimated values with $\omega_e = 0.2301$ and $\vartheta = 0.6846$.

With this set-up, we can trace through the responses of various macroeconomic variables to different shocks under alternative monetary policy regimes. Specifically, we concentrate our analysis on the foreign price shock and policy interest rate shock. We choose these two shocks as they turn out to be important in shaping the dynamics of a few macroeconomic variables such as output gap, domestic price and wage inflation and nominal exchange rate from the variance decompositions shown in Table 4. For ease of explanation, we plot the impulse responses of sterilized FX intervention using black lines and that of Taylor rule alone (without FX intervention) using grey lines. We also use solid lines to represent regimes without WIT and dashed lines to represent regimes with WIT.

5.1.1. Foreign price shock

We begin by considering the impact of a positive one percent foreign price shock which occurs in period 1 and dies out gradually over time. Figure 3 plots the responses of some key macroeconomic variables including output gap, domestic inflation, wage inflation, nominal exchange rate, policy interest rate and FX reserves under four different regimes. The x-axis is time reported in quarters and the y-axis represents the deviations from steady state.

The impulse response functions of the economy to an increase in foreign price produce some very similar results among the four regimes. A positive foreign price shock can be interpreted as a worsening of terms-of-trade. With higher foreign price, exports produced by the small open economy become relatively competitive and hence demand for exports increases which further leads to a positive output gap. As the increase in output gap is larger and hence dominates the responses of both price and wage inflation, policy interest rate responds with a higher rate. Further investigations into the household consumption suggest that household consumption declines as a result of higher interest rate which further imposes downward pressure on price and wage inflation. With higher interest rate, home currency appreciates against the foreign currency.

The most striking difference between Taylor rule alone (grey lines) and sterilized FX intervention (black lines) lies in the responses of nominal exchange rate. The magnitude of the appreciation is relatively lower under sterilized FX intervention than under the Taylor rule alone. As explained in Section 2.1, sterilized FX intervention tempers the appreciation of the nominal exchange rate since it increases central bank FX reserves and commercial banks' holdings of central bank securities, which in turn increase the commercial banks' foreign-currency denominated liabilities – as commercial banks' assets are assumed to be funded with foreign borrowings – and exposure to exchange rate risk. Hence the risk premium on domestic assets increases reducing the demand for domestic assets and domestic currency since the interest rate does not respond to risk. As such, sterilized FX intervention helps to relieve partially the appreciating pressure on the domestic currency and consequently, import price in home currency are less volatile. The same is seen on domestic price inflation. This in turn leads to smaller changes in price and wage inflation of the economy.

A comparison between the regimes with WIT (dashed lines) and the ones without (solid lines) proves the advantage of WIT in stabilizing the nominal variables. Domestic inflation, nominal wage inflation and nominal exchange rate are more stable when WIT is introduced to the policy framework. The policy interest rate under sterilized FX intervention with WIT has a smaller response compared to that of the sterilized FX intervention without WIT. This is favourable because, with WIT, it imposes less appreciating pressure on the nominal exchange rate and the central bank need to intervene less in the foreign exchange market. Hence, the movements in reserves are smoother with WIT making the intervention more sustainable.

5.1.2. Interest rate shock

Figure 4 shows the responses of the key macroeconomic variables to a 25-basis-point increase in the policy interest rate. In this case, while regimes with WIT show smaller responses than their counterparts, the differences between Taylor rule alone and sterilized FX intervention are small. An increase in the policy interest rate reduces household consumption which results in lower production and price. Households would allow nominal wage to decrease so as to match real wage with the marginal rate of substitution. The increase in policy interest rate causes domestic currency to appreciate.

With sterilized FX intervention, the central bank accumulates more reserves from the foreign exchange market in order to stabilize the currency. As such, the most prominent differences between Taylor rule alone and sterilized FX intervention lie in the change in FX reserves as well as the fluctuation in the nominal exchange rate. While the resulting differences in the responses of domestic price inflation and nominal wage inflation are not as obvious as in the case of foreign price shock, variables under sterilized FX intervention are slightly less volatile.

The difference between the regimes with and without WIT is more striking. In general, we find more stabilizing effects in all the impulse responses as shown in Figure 4. Similar to the case of foreign price shock, we see that WIT leads to smaller response in policy interest rate, lesser appreciating pressure on domestic currency, and hence smoother responses in reserves.

5.2. Coordination among PIT, WIT and sterilized FX intervention

Our earlier discussions have shown that combinations of PIT, WIT and sterilized FX intervention deliver the best outcomes both in terms of the welfare and the impulse responses. From the welfare analysis, we find the improvements in welfare are obvious when PIT and WIT are less strict. Our impulse responses further show that sterilized FX intervention with WIT produces the least volatilities at least for the nominal variables. Another finding that is not found in the welfare analysis is that WIT helps reduce the volatility in FX reserves should the central bank need to apply sterilized FX intervention to stabilize the nominal exchange rate. This finding may be of interest to central banks adopting sterilized FX intervention as they may only possess limited amounts of reserves, and persistently large volatilities in reserves may risk making sterilized FX intervention unsustainable in the long run. In this section, we conduct sensitivity analyses to discover how the macroeconomic volatilities change under the foreign price and interest rate shocks at different combinations of PIT and WIT.

We loop the values of α_p and κ between 1 and 5 and calculate the second moments of output gap, domestic inflation and reserves. While output gap and domestic inflation are the key variables that determine the welfare losses, volatility in reserves could also have implications for the conduct of sterilized FX intervention. Volatilities of the variables, calculated as the square roots of the second moments, are shown in Figure 5.

The volatilities show similar patterns except for that of the output gap under the foreign price shock. We observe a trade-off between output gap and domestic inflation volatilities in the case of the foreign price shock. As the central bank adopts stricter PIT and WIT, the volatility in output gap increases while that of domestic price inflation decreases. Whereas, under an interest rate shock, both output gap and domestic price inflation show decreasing volatility as PIT and WIT get stricter. As for the reserves, we find consistent results as in our impulse response analysis: stricter PIT or WIT leads to more stable reserves under both the foreign price and interest rate shocks. This is an added advantage of the coordination among PIT, WIT and sterilized FX intervention that is not captured by the welfare loss function.

5.3. Coordination between WIT and wage policy

Wage stickiness is an important motivating factor for the inclusion of WIT in central bank's policy framework. A crucial question that follows is how WIT and policies guiding wage flexibility should coordinate to improve welfare. We therefore conduct a sensitivity analysis of welfare loss to changes in the WIT coefficient, κ, and the degree of wage flexibility in the labor market, ξ_w.

Figure 6 shows the relationship between κ and ξ_w against the welfare loss for the dual-instrument framework when all shocks in our model are present. Note that in our wage setting, at each period, only $(1 - \xi_w)$ fraction of households can change wage. This means that ξ_w can have value between the range of 0 and 1, with the degree of nominal wage rigidity increasing with ξ_w. We restrict our discussion to middle to moderate degrees of wage rigidity/flexibility as at the extreme values of ξ_w near 0 and 1, the welfare losses are either too large or too small to distinguish their changes with the WIT coefficient.

Our findings from this sensitivity analysis is consistent with the literature such as Erceg et al. (2000). First, wage rigidity causes welfare loss. This is seen from the increasing surface as ξ_w increases in its value. As wage becomes more rigid, firms and households are not able to adapt to changing economic conditions and have to deviate their production and consumption from the natural levels. Second, WIT reduces welfare loss caused by wage rigidity. This is seen from the decreasing surface as WIT gets stricter. When the central bank adopts WIT in the presence of wage rigidity, the interest rate responds to changes in nominal wages, helping firms and households adjust their production and consumption behavior if they are unable to adjust wages in time. Our findings thus suggest that WIT could pair with a more flexible wage policy to achieve better welfare for the economy.

6. Conclusion

The sluggish recovery from the global financial crisis motivated policy makers to look for new measures of resource slack, and recent studies have found a good measure in nominal wage inflation. As such, wage inflation should be a target of monetary policy. In addition, the rapid accumulation of FX reserves in the EMEs has prompted the re-thinking of the macroeconomic trilemma as well as the role of macroeconomic policies in advanced and emerging market economies. With substantial amount of reserves, the central bank is able to moderate the exchange rate in the FX markets without changing the domestic monetary base. In this paper, we examine the interactions among the conventional price inflation targeting, wage inflation targeting and sterilized FX interventions. We look for conditions under which an additional nominal target, the wage inflation, is preferable to the conventional set-up with only output gap and price inflation targets. We also look at situations in which the central bank carries out sterilized FX interventions while conducting independent monetary policies at home.

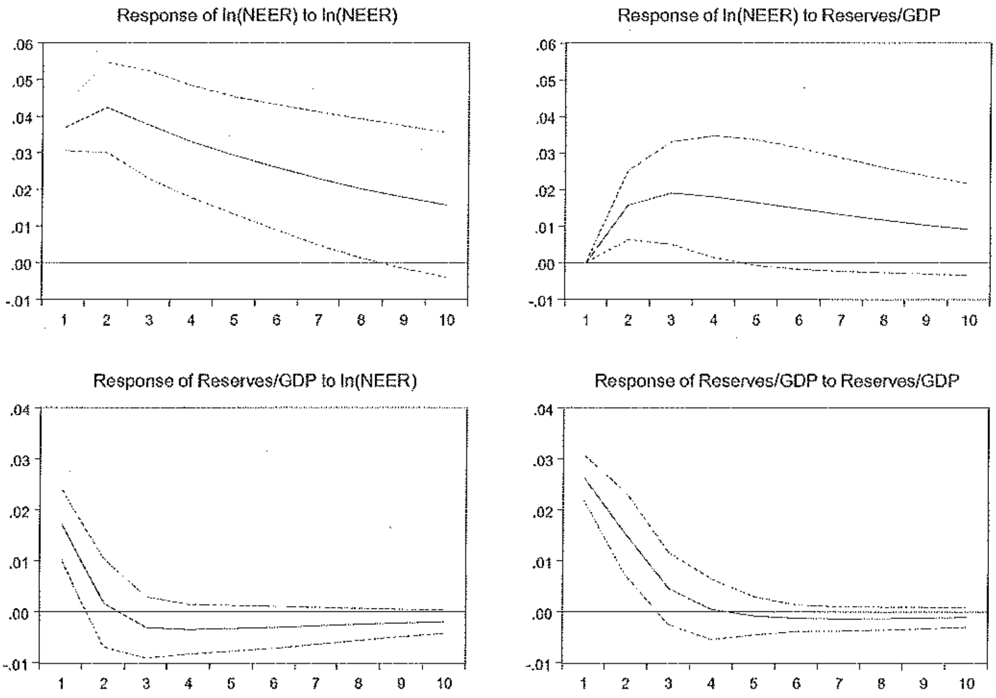

Figure 1: Impulse responses with 95% confidence intervals.

To conduct independent monetary policies at home, the interest rate needs to respond promptly to varying real and nominal volatility. In a small open economy, the consequence of varying interest rate is an appreciating or a depreciating pressure on the nominal exchange rate. Sterilized FX interventions come into play when the central bank prefers stable exchange rate movements. To reduce the volatility of exchange rates, the central bank responds to any changes in exchange rates with changing stocks of reserves. However, sterilized FX intervention is not without costs. It is only feasible until the central bank runs out of its reserves. Thus, the first question is whether there exists an independent monetary policy that could improve welfare. The second question is whether such a policy could also promote a more sustainable sterilized FX interventions. While the former question applies generally to small open economies, the latter is of much interest to the EMEs. Our answers to these questions involve the inclusion of WIT in the interest rate rule. First, our welfare analyses show that a combination of PIT and WIT improves welfare of the economy. Welfare improves regardless whether the central bank implements the Taylor rule with or without sterilized FX interventions. Second, our counter-factual analyses and sensitivity analyses show that, under the foreign price and interest rate shocks, incorporating WIT has an obvious effect of reducing volatility in reserves. This is primarily due to the smaller changes in price and wage inflation that lead to smaller-than-usual change in the interest rate and hence smaller appreciating or depreciating pressure on the exchange rate. As such, our conclusion is that WIT is welfare improving in small open economies, and if the central bank adopts sterilized FX interventions, WIT promotes more sustainable sterilized FX interventions. Interest rate rule with WIT and sterilized FX interventions should be used in tandem to achieve stabilities at home and in the FX market.

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Table 1: Key equations.

$c_t = c_{t+1} + z_t - z_{t+1} - \left(r_t^l - \pi_{t+1}\right) - \varrho^* \bar{Y} \hat{l}_t^r$	Euler equation
$\pi_{h,t} = \beta \mathbb{E}_t\{\pi_{h,t+1}\} - \lambda_p \left(\mu_t^p - \mu^p\right) + u_t^p$	Domestic price-setting
$\pi_{w,t} = \beta \mathbb{E}_t\{\pi_{w,t+1}\} - \lambda_w \left(\mu_t^w - \mu^w\right) + u_t^w$	Wage-setting
$\hat{l}_t^r = \frac{\hat{l}_{t-1}^r}{\beta} + \frac{\bar{l}^r}{\beta}\left(r_{t-1}^* + q_t - q_{t-1}\right) + \frac{1}{\bar{Y}}\left[\omega_m \left(q_t + c_{m,t}\right) - \bar{Y}_x \left(p_{x,t}^r + y_{x,t}\right)\right]$	Balance of payments
$r_t = r_t^* + q_{t+1} - q_t + \pi_{t+1} - \pi_{t+1}^* + \Omega_O \bar{Y} \hat{f}_t^r + u_t^r$	UIP
$r_t^l = r_t - \Omega_O \bar{Y} \hat{f}_t^r$	Lending rate
$r_t = \rho_r r_{t-1} + (1-\rho_r)\left(\alpha_r \pi_{h,t} + \kappa \pi_{w,t} + \delta_r \hat{y}_t\right) + \epsilon_{r,t}$	Interest rate rule
$\hat{f}_t^r = \rho_f \hat{f}_{t-1}^r - (1-\rho_f)\left(\frac{\omega_e}{1-\omega_e} e_t + \frac{\vartheta}{1-\vartheta}\pi_{c,t}\right) + \epsilon_{f,t}$	FX intervention rule

Notes: Variables in lower cases represent log-deviations from the steady states except for balance of payment $\hat{l}_t^r$ and reserves $\hat{f}_t^r$ which are level deviations from their steady states expressed as percentages of the steady state output: $\hat{l}_t^r = \left(L_t^r - \bar{L}^r\right)/\bar{Y}$ and $\hat{f}_t^r = \left(F_t^r - \bar{F}^r\right)/\bar{Y}$.

Table 2: Calibrated parameters.

Parameter	Definition	Value	Source
ω_m	Imports in consumption	0.642	CEIC and authors' calculations
ζ	Trade balance	0.022	CEIC and authors' calculations
β	Discount factor	0.99	Gali and Monacelli (2005)
α	Output elasticity of labour	0.5	Benes et al. (2015)
ϕ	Frisch elasticity of labour supply	4	Authors' choice
Ω_O^*	Risk premium	0.1	Benes et al. (2015)
θ_p, θ_w	Elasticity of substitution between goods (labour)	6	Gali and Monacelli (2005)
ρ_z	Smoothing parameter for preference evolution	0.019	Chung et al. (2007)
ρ_r	Smoothing parameter for interest rate rule	0.791	CEIC and authors' calculations
ρ_f	Smoothing parameter for FXI rule	0.768	CEIC and authors' calculations
ξ_p, ξ_w	Price (wage) rigidity	0.5	Authors' choice
ϱ^*	Wedge between lending rate and discount factor	0.01	Benes et al. (2015)

Table 3: Prior and posterior estimates.

	Prior mean	Post. mean	90% HPD interval		Prior distr.	Prior s.d.
Parameters						
α_r	3.0000	1.7339	(1.6725,	1.8118)	Gamma	0.2500
δ_r	0.2500	1.8777	(1.6339,	2.0922)	Gamma	0.1300
ω_e	0.5000	0.2301	(0.0890,	0.3764)	Beta	0.2000
ϑ	0.5000	0.6846	(0.6282,	0.7421)	Beta	0.2000
ρ_p^*	0.5000	0.6570	(0.5746,	0.7376)	Beta	0.2000
$\rho_{p_x}^*$	0.5000	0.7999	(0.7564,	0.8452)	Beta	0.2000
ρ_r^*	0.5000	0.8497	(0.7798,	0.9230)	Beta	0.2000
ρ_h	0.5000	0.9428	(0.9234,	0.9606)	Beta	0.2000
ρ_y^*	0.5000	0.9118	(0.8593,	0.9678)	Beta	0.2000
ρ_{u^r}	0.5000	0.7416	(0.6521,	0.8278)	Beta	0.2000
Standard deviations of shocks						
	Prior mean	Post. mean	90% HPD interval		Prior distr.	Prior s.d.
σ_h	0.0050	0.0324	(0.0323,	0.0324)	Inv. Gamma	0.0010
σ_r^*	0.0020	0.0009	(0.0008,	0.0010)	Inv. Gamma	0.0010
σ_p^*	0.0040	0.0350	(0.0303,	0.0399)	Inv. Gamma	0.0010
$\sigma_{p_x}^*$	0.0040	0.0287	(0.0252,	0.0325)	Inv. Gamma	0.0010
σ_y^*	0.0200	0.0055	(0.0047,	0.0063)	Inv. Gamma	0.5000
σ_r	0.0020	0.0376	(0.0321,	0.0431)	Inv. Gamma	0.0010
σ_f	0.0100	0.0253	(0.0216,	0.0288)	Inv. Gamma	0.0100
σ_{u^p}	0.0040	0.0485	(0.0482,	0.0487)	Inv. Gamma	0.0010
σ_{u^w}	0.0220	0.0270	(0.0233,	0.0304)	Inv. Gamma	0.0040
σ_{u^r}	0.0100	0.0153	(0.0101,	0.0201)	Inv. Gamma	0.0200
σ_z	0.0360	0.0308	(0.0263,	0.0350)	Inv. Gamma	0.0070

Notes: α_r and δ_r are the responses of domestic policy interest rate to domestic price inflation and output gap, respectively. ω_e and ϑ, when transformed to $\omega_e/(1-\omega_e)$ and $\vartheta/(1-\vartheta)$, are the responses of FX reserves to deviations from fixed exchange rate target and nominal depreciation, respectively. ρ_p^*, $\rho_{p_x}^*$, ρ_r^*, ρ_h, ρ_y^* and ρ_{u^r} are autoregressive coefficients of foreign price, export price, foreign interest rate, domestic productivity, foreign output and UIP condition shocks. σ_h, σ_r^*, σ_p^*, σ_y^*, σ_r, σ_f, σ_{u^p}, σ_{u^w}, σ_{u^r} and σ_z are the standard deviations of domestic productivity, foreign interest rate, foreign price, foreign output, policy interest rate, reserves, domestic inflation, wage inflation, UIP condition and preference shocks.

Table 4: Variance decompositions.

	σ_i^*	σ_p^*	$\sigma_{p_x}^*$	σ_h	σ_{u^p}	σ_{u^w}	σ_{u^r}	σ_z	σ_y^*	σ_i	σ_f
Output gap	0	22.16	13.59	0.45	11.92	0.15	0.12	6.27	0.57	44.56	0.2
Domestic inflation	0.01	3.68	8.04	2.05	79.38	0.61	0.16	0.07	0.78	5.2	0.02
Wage inflation	0.04	7.96	19.89	2.11	2.27	47.79	1.8	0.09	1.61	16.38	0.07
Nominal exchange rate	0.24	18.38	19.45	7.25	4.78	0.25	16.82	0.27	2.3	30.13	0.13
Policy interest rate	0	3.86	0.37	3.29	10.78	0.26	0.12	1.59	0.15	79.34	0.26
FX reserves	0.2	15.41	15.17	5.98	3.64	0.16	15.08	0.26	1.68	28.16	14.26

Notes: σ_i^* refers the foreign interest rate shock, σ_p^* is the foreign price shock, $\sigma_{p_x}^*$ is the world export price shock, σ_h is the domestic productivity shock, σ_{u^p} and σ_{u^w} are the cost-push shocks to inflation of domestic price and nominal wage, σ_{u^r} is the shock to the UIP condition, σ_z is the preference shock, σ_y^* is the foreign output shock, σ_i is the domestic interest shock and σ_f is the FX reserves shock.

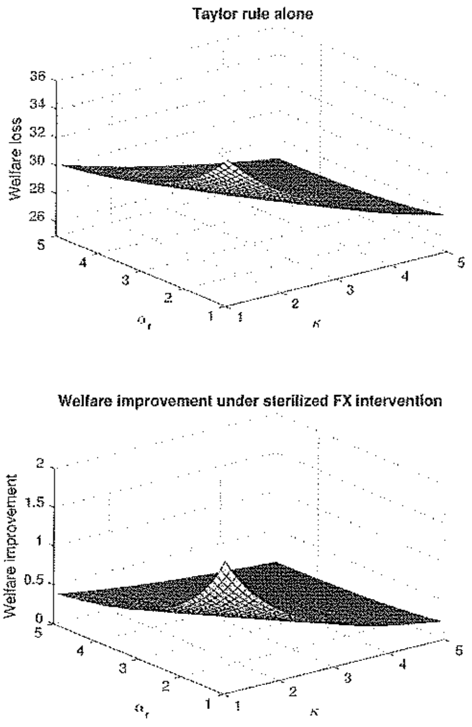

Figure 2: Welfare comparison between Taylor rule and FX intervention.

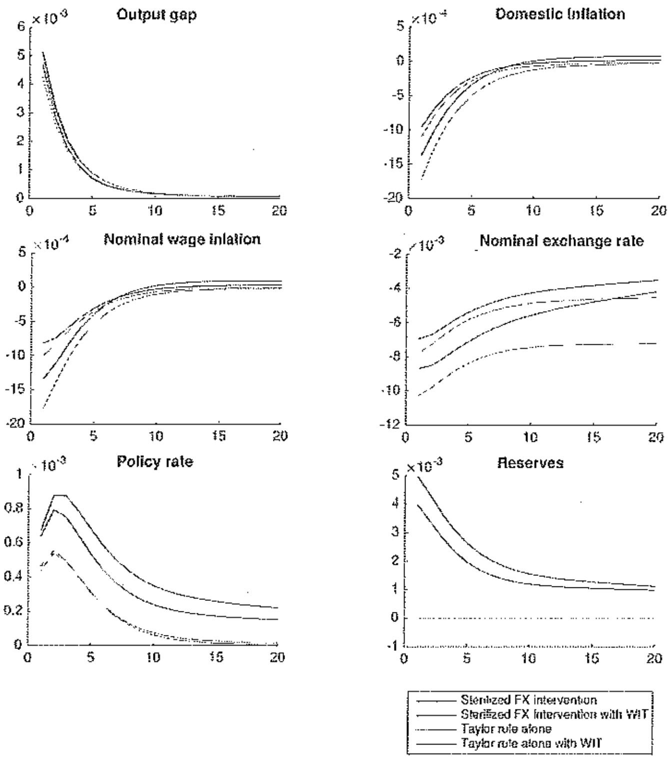

Figure 3: Impulse responses to a 1% foreign price shock.

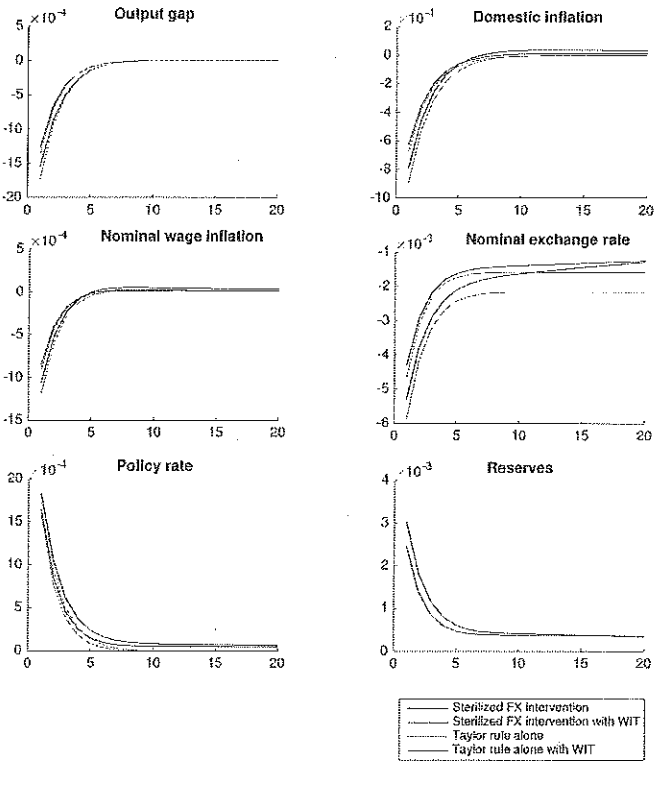

Figure 4: Impulse responses to a 25-basis-point interest rate shock.

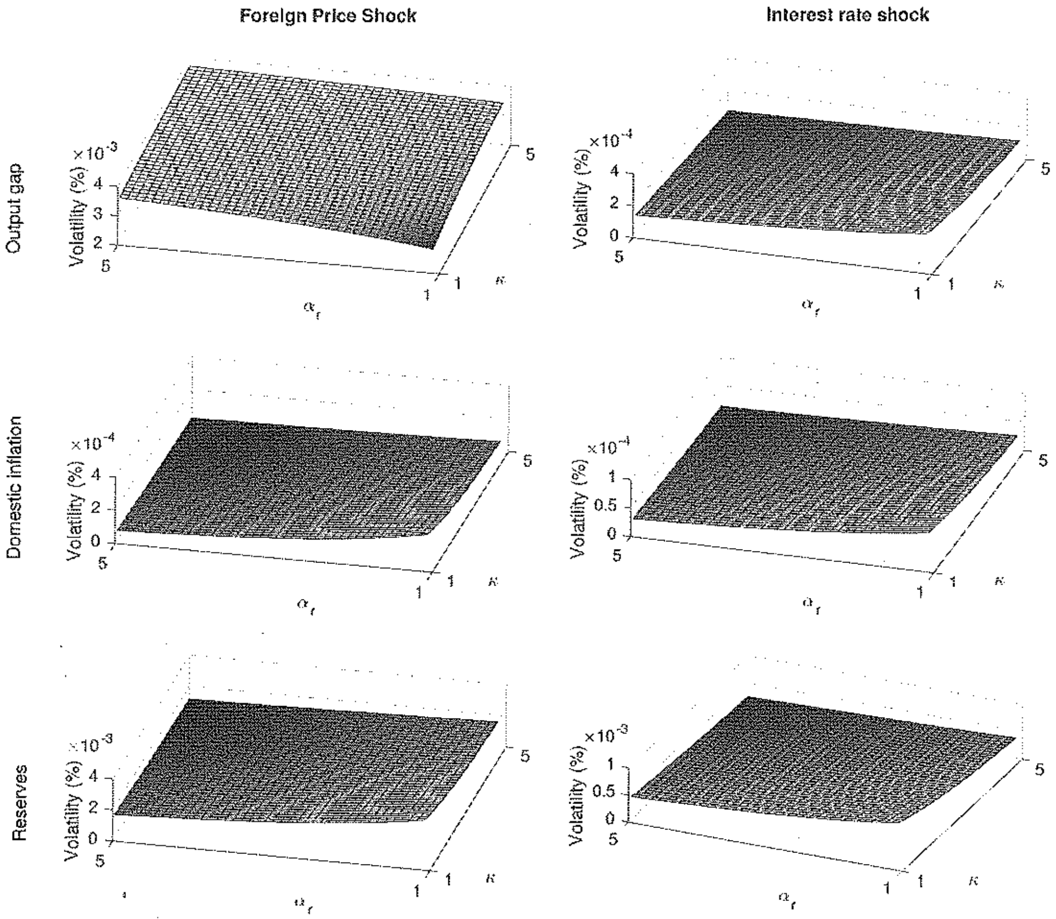

Figure 5: Volatilities of output gap, domestic inflation and reserves under foreign price and interest rate shocks.

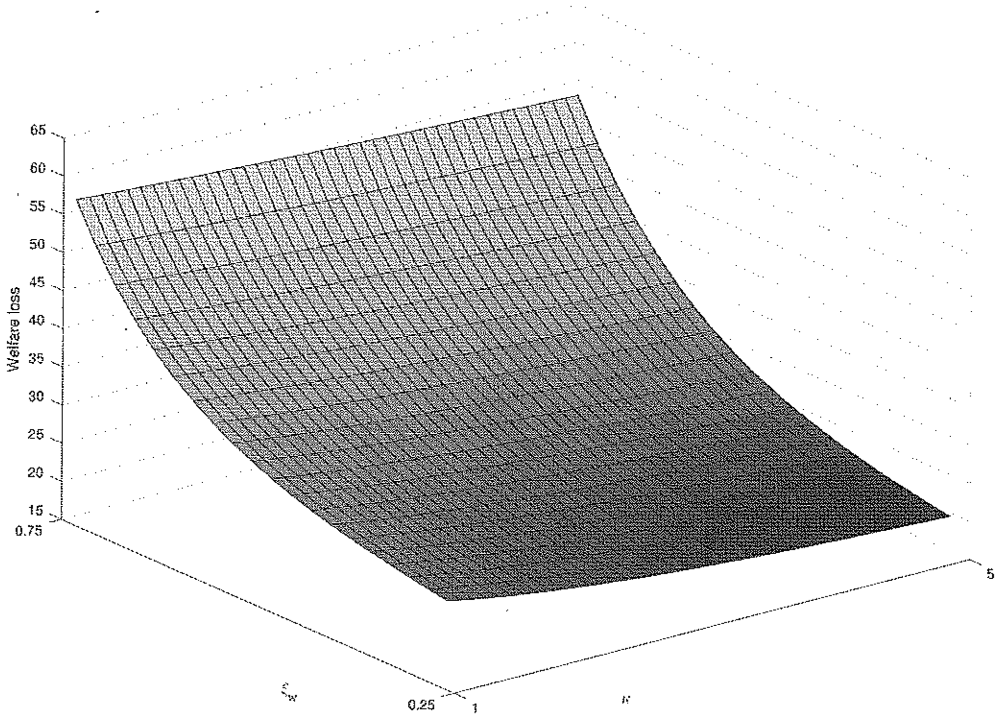

Figure 6: Coordination between wage-inflation targeting and wage policy.

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Appendix A. Observables and data sources

p^*: Log of import price index (2010=100)
Source: CEIC

p_x^*: Log of export price index (2010=100)
Source: CEIC

r^*: G7 GDP-weighted money market rate
Source for G7 money market rates: OECD Statistics
Source for G7 real GDP: CEIC

g: Log of real GDP
Source: OECD Statistics

y^*: Log of G7 real output Source: CEIC

π: First difference of logged consumer price index
Source: CEIC

c: Log of consumption (2010=100, seasonally adjusted)
Source: OECD Statistics

f: Reserves to trend GDP ratio
Source for reserves in USD: Bank of Korea
Source for nominal GDP and exchange rate: CEIC

r: Interest rate
Source: OECD Statistics

ω: First difference of logged manufacturing wage index
Source: International Financial Statistics

π_e: Nominal exchange depreciation
Source: CEIC