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External shocks in a small open economy: an evaluation of monetary policy rules

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ABSTRACT

This paper evaluates several small open economy DSGE models and the impact of external shock spillovers on small open economies. We investigate five small economies (the UK, Australia, Canada, New Zealand and Taiwan) and find that the welfare consequences vary depending on key domestic economic variables, and the best interest-rate rule varies across models. Then we examine the performances of the four types of models, a preferred result has been found in a model which considers the country risk premium, as the best rule could be obtained as long as the selected parameters are calibrated for particular economies.

1. Introduction

The nominal interest rates have been reduced significantly in many economies simultaneously in response to the crisis during the global financial recession, which was initially started in the US. Similar situations were observed when the recent Covid-19 outbreaks, expansionary monetary policies have been adopted by many central banks, not only respond to the falling domestic demands, and the uncertain external economic environment as well. Motivated by these observations, in this paper, we are trying to answer several questions: (1) How does an external shock affect the domestic economy, especially when the region is considered as a small economy? (2) What characteristics of the domestic economy has, can magnify the impact of external shocks? (3) Can the small open economy model be a reliable tool for central banks when making policy decisions? (4) Which monetary policy should central banks employ when foreign shocks happen? To answer these questions, we employ a small open economy model and extend the model to several variations, discussing welfare consequences across different monetary policy rules.

The dynamic stochastic general equilibrium model is widely used as a benchmark tool for describing macroeconomic movements and policy analysis. However, a range of studies question some characteristics of this model and believe the standard DSGE

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model needs to be modified to fit a specific environment. One strand of literature argues the standard DSGE model cannot propose a proper international shock transmission effects (Buch et al., 2019; Croitorov et al., 2020; Ellen et al., 2020; Trung, 2019). Buch et al. (2019) find empirical evidence that heterogeneity exists in the cross-border transmission channel, the different country experiences different monetary transmission effect. The heterogeneous spillovers are also found in Trung (2019), who further points out that the magnitudes of exposure to external shocks would significantly depend on the receiving country's characteristics, such as development, financial and trade openness.

Aside from the above contributions, some studies believe a fixed, pre-determined model might not be able to produce robust results consistently, different model types employed under different circumstances (Blanchard, 2016; Fontana & Veronese Passarella, 2020). Fontana and Veronese Passarella (2020) state that the standard DSGE model fails to forecast the economy especially during the global financial crisis, and they modify the model by re-defining the natural output level which linked with the risk premium – the more financial asset collaterals, the less risk premium, the smaller output gaps.

Our paper extends the literature regarding the small open economy modelling (e.g., Alba et al., 2020; De Paoli, 2009; Galí, 2008) in several dimensions, investigating three variant versions of the standard small open economy model. First, we investigate a model variant which incorporates a country-specific factor that could allow external shock transmission affects differently to individual domestic countries. More specifically, we modify the standard small open economy model (Standard SOE) by introducing a country-specific coefficient to the external variables, and the value of the coefficient adopts the degree of openness of the small economy, following Trung (2019) and Croitorov et al. (2020). Second, we allow the natural output to vary depending on a country-specific risk premium in the second variant. Different from Fontana and Veronese Passarella (2020) who define the risk premium in financial asset markets, in our model, we focus on goods market, by assuming the natural output depends on the lagged output gap which is negatively related to the country-specific risk premium, the magnitude is decided by the substitutability in the domestic economy. The third variant combines the two variants mentioned above, considering both the country-specific coefficient and the country-specific risk premium.

In general, we assume the foreign country hit by a negative demand shock and investigate the responsiveness of the home economy which represents a small open economy in our model. In particular, five small open economies are examined, including the UK, Australia, Canada, New Zealand and Taiwan, as compared to the US economy, these economies could be considered as small open economies.

We first examine the impulse responses and model properties using the UK estimates, the results indicate that in the variants which taking country coefficient and risk premium into consideration, home variables show more plausible correlations with the foreign output comparing with those found under the Standard SOE. Then we apply sensitivity analysis to investigate the effects of changing key parameters. We find that the degree of openness has a significant effect on the magnitude which the receiving economy exposes to external shocks, but has a limited effect on the paths of

variable movements. The results also show that domestic variables experience higher deviations when the model takes risk premium into consideration. Then we evaluate the welfare consequences when the three selected variables vary. Several results were obtained: first, the more open the domestic economy is, the higher losses experiences; second, higher risk aversion agents adopted, lower welfare losses; last but not the least, we find that higher substitutability the home and foreign goods has, lower welfare losses. Comparing to the Standard SOE, the model which takes the risk premium into consideration tends to give a more plausible result as it seems to be consistent with the empirical evidence found in the literature.

Another contribution of this paper is that we not only investigate welfare consequences between different rules, we also examine the model performances regarding giving policy suggestions. We find that the best interest-rate rule changes with domestic economic conditions. Under Standard SOE and the first variant, the best rule significantly depends on the market exposures, managed floating regime is preferred when the domestic economy is relatively closed, while the floating regime targeting domestic inflation dominates when the degree of openness becomes higher. However, the results become more complicated when considering the second and third variants, the best rule depends on the openness and the substitutability as well.

Finally, in order to examine the performances of different models, we extend our analysis by investigating five small open economies. The results show that in the Standard SOE, the welfare performance of policy rules depends not only on the chosen key parameters but the other macroeconomic parameters. In the model with risk premiums, however, the best rules significantly depend on the selected parameters, other parameters do not have, or have very limited effect on the rule selections. That is, the model could give a robust policy suggestion with lower estimation errors as only a few variables are needed. The structure of the paper is organized as follows: Section 2 demonstrates the standard small open economy model and its variants, as well as the monetary policy rules and welfare. Section 3 shows the impulse responses and variances changes in domestic variables and Section 4 examines the performances of policy rules and models. Section 5 concludes.

2. Models

2.1. Standard small open economy model

The benchmark model we employed is the small open economy model developed by De Paoli (2009) and Galí (2008). The world comprises two economies, which is populated with a continuum of agents where an interval $(0, n]$ is located in Home country and the interval $(n, 1]$ lives in Foreign country. After solving for the standard two-country general equilibrium, Home economy is transformed into a" small open economy" by letting the size of Home country asymptotically approach zero, and the Foreign economy represents the rest of the world. Under this circumstance, in this paper, we treat the small open economy as an economy that is continually affected by the world economy, while the world economy behaves like a closed economy – changes in the Home country do not have an impact on the world. Variables with an asterisk superscript ($*$) represent the world economy.

In our model, representative households consume goods produced in both Home and Foreign countries and supply labour to monopolistically competitive firms. In addition, the model assumes trade imbalances and no trade or financial frictions exist, that is, the law of one price holds and asset markets are complete. Although the law of one price holds, purchasing power parity does not hold due to the home bias in consumption, the degree of openness and the relative size of the economy determines the level of home bias (De Paoli, 2009).

2.1.1. Households

The representative infinitely-lived household in Home country chooses consumption, C_t, and the level of labour supply, N_t, in order to maximise lifetime utility,

$$E_t \sum_{t=0}^{\infty} \beta^t U(C_t, N_t) \tag{1}$$

where $\beta \in (0,1)$ is discount factor. Assume a continuum of firms indexed by $j \in [0,1]$ and each firm produces a different variety of consumption goods using labour supplied by households as an input. In view of these assumptions, the consumption index and the labour index are respectively given by

$$C_t = \left[v^{\frac{1}{\eta}} C_{H,t}^{\frac{\eta-1}{\eta}} + (1-v)^{\frac{1}{\eta}} C_{F,t}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} \qquad N_t = \int_0^1 N_t(j) dj \tag{2}$$

where η is the elasticity of substitution between home and foreign goods, and v is home bias, representing each Home consumer has an asymmetric preference for Home and Foreign goods[1]. $(1-v)$ stands for Home consumers' preferences for Foreign goods, which is a function of the relative size of the Foreign country $(1-n)$ and the degree of openness λ, specifically, $(1-v) = (1-n)\lambda$. $N_t(j)$ is the amount of labour services supplied to the j firm. $C_{H,t}$ and $C_{F,t}$ represent consumption in the Home country which is produced in the Home and Foreign country respectively, and which are defined as $C_{H,t} = \left[\left(\frac{1}{n}\right)^{\frac{1}{\varepsilon}} \int_0^n C_{H,t}(j)^{\frac{\varepsilon-1}{\varepsilon}} dj \right]^{\frac{\varepsilon}{\varepsilon-1}}$ and $C_{F,t} = \left[\left(\frac{1}{1-n}\right)^{\frac{1}{\varepsilon}} \int_n^1 C_{F,t}(j)^{\frac{\varepsilon-1}{\varepsilon}} dj \right]^{\frac{\varepsilon}{\varepsilon-1}}$, where ε is elasticity of substitution across goods, and n is the size of Home economy. $C_{H,t}(j)$ is Home consumption for Home-produced good j and $C_{F,t}(j)$ is Home consumption for Foreign-produced good j. Similar preferences of consumption are defined for the Foreign country.

Correspondingly, the Home price index is given by

$$P_t = \left[v P_{H,t}^{1-\eta} + (1-v) P_{F,t}^{1-\eta} \right]^{\frac{1}{1-\eta}} \tag{3}$$

where $P_{H,t}$ and $P_{F,t}$ are the price of Home-produced goods and the price for Foreign-produced good expressed in Home currency respectively, and which are defined as $P_{H,t} = \left[\left(\frac{1}{n}\right) \int_0^n P_{H,t}(j)^{1-\varepsilon} dj \right]^{\frac{1}{1-\varepsilon}}$ and $P_{F,t} = \left[\left(\frac{1}{n-1}\right) \int_n^1 P_{F,t}(j)^{1-\varepsilon} dj \right]^{\frac{1}{1-\varepsilon}}$.

Utility maximization is subject to the budget constraint, and assume the utility function takes the form $E_t[U] = \frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\varphi}}{1+\varphi}$, where σ is the inverse of the intertemporal elasticity of substitution and φ is the inverse Frisch elasticity of labour supply. Then solving the maximization problem, the optimal choice for the household is given by[2]

$$1 = \beta(1 + i_t)E_t\left[\frac{P_t}{P_{t+1}}\left(\frac{C_{t+1}}{C_t}\right)^{-\sigma}\right] \tag{4}$$

2.1.2. Firms

Each firm produces a differentiated good based on the production function

$$Y_t(j) = AN_t(j)^{1-\alpha} \tag{5}$$

where A stands for an exogenous measure of technology, assuming to be the same across firms. $1-\alpha$ represents the output elasticity of labor.

Following De Paoli (2009) and Chang and Liu (2018), price stickiness is modelled as in Calvo (1983) – in each period, only a fraction of $1-\theta$ of firms could receive price-changing information and are able to choose their prices optimally. The remaining fraction of firms, given by θ, do not receive the signal and keep the prices unchanged. Thus, the aggregate price dynamics can be written as

$$\Pi_{H,t}^{1-\varepsilon} = \theta + (1-\theta)\left(\frac{\tilde{P}_{H,t}}{P_{H,t-1}}\right)^{1-\varepsilon} \tag{6}$$

where $\Pi_{H,t} = \frac{P_{H,t}}{P_{H,t-1}}$ is the gross inflation rate, $\tilde{P}_{H,t}$ is the re-optimised price by firms which received price-change signal in period t.

In the Home country, firms choose prices to maximise their current profit each period. Due to the constraint of price stickiness, firms realise that the price they decide now will affect profits over the next k periods. Firms re-optimising the price in period t will choose $\tilde{P}_{H,t}$ so as to maximise the current market value of the profits for the next k periods given a probability" θ" that the chosen price indeed remains effective over that horizon. Formally, the firm's maximisation problem is

$$Max \sum_{k=0}^{\infty} \theta^k E_t\left[Q_{t,t+k}\left(\tilde{P}_{H,t}Y_{t+k|t}(j) - \Psi_{t+k}(Y_{t+k|t}(j))\right)\right] \tag{7}$$

subject to demand constraints $Y_{t+k|t}(j) = (\frac{\tilde{P}_{H,t}}{P_{H,t+k}})^{-\varepsilon}Y_{t+k}$, where $Q_{t,t+k} = \beta^k \frac{U_{c,t+k}}{U_{c,t}}\frac{P_{H,t}}{P_{H,t+k}}$, is a stochastic discount factor for nominal payoffs over the interval $[t, t+k]$, $Y_{t+k|t}(j)$ is output in period $t+k$ for a firm re-optimise price in period t, $\Psi_{t+k}(Y_{t+k|t}(j))$ is cost function.

2.1.3. Equilibrium

By solving the model, the equilibrium in a small open economy could be expressed as following equations:

$$\pi_{H,t} = \beta E_t \pi_{H,t+1} + \kappa_a \left[\left(\frac{\alpha + \varphi}{1 - \alpha} + \frac{\sigma}{1 - \lambda} \right) y_t - \sigma \frac{\lambda}{1 - \lambda} y^* - \sigma \gamma q_t \right] \tag{8}$$

$$y_t = E_t y_{t+1} - \frac{1 - \lambda}{\sigma} (i_t - E_t \pi_{t+1}) - \lambda \Delta E_t y^*_{t+1} - \gamma E_t \Delta q_{t+1} \tag{9}$$

$$s_t = (i^*_t - E_t \pi^*_{t+1}) - (i_t - E_t \pi_{H,t+1}) + E_t s_{t+1} \tag{10}$$

$$s_t = \frac{1}{1 - \lambda} q_t \tag{11}$$

$$\pi_t = \pi_{H,t} + \frac{\lambda}{1 - \lambda} (q_t - q_{t-1}) \tag{12}$$

where[3] $\kappa_a = \frac{(1-\theta)(1-\beta\theta)}{\theta} \frac{1-\alpha}{1-\alpha+\alpha\varepsilon}$, $\gamma = \frac{\eta\lambda(2-\lambda)}{1-\lambda}$. Equation (10) shows the international risk sharing condition and the terms of trade is shown in expression (11). q_t and s_t are the real exchange rate and the terms of trade, π_t and $\pi_{H,t}$ are CPI inflation and domestic inflation respectively, y_t is the output gap which is deviation of real output and the natural output level[4].

2.2. The foreign economy

The foreign economy is modelled as a closed economy which cannot be affected by a small open economy. Based on a closed-economy New Keynesian model, the foreign economy consists of households, firms and central banks. The equilibrium system of the foreign economy is shown as:

$$\pi^*_t = \beta E_t \pi^*_{t+1} + \kappa y^*_t \tag{13}$$

$$y^*_t = E_t y^*_{t+1} - \sigma^{-1} (i^*_t - E_t \pi^*_{t+1}) + g^*_t \tag{14}$$

$$i^*_t = h\pi^*_t + b(y^*_t - y^{*T}_t) \tag{15}$$

where $\kappa = \frac{(1-\theta)(1-\beta\theta)}{\theta} \frac{1-\alpha}{1-\alpha+\alpha\varepsilon} \left(\sigma + \frac{\varphi+\alpha}{1-\alpha} \right)$, π^*_t is Foreign CPI inflation, y^*_t is Foreign output gap, which is the deviation between output and its natural level. h and b are the weights the Foreign Central Bank assigned to stabilizing inflation and minimizing the output gap. $g^*_t = \rho_g g^*_{t-1} + \varepsilon^*_{gt}$ represents a demand shock, where ε^*_{gt} is a stochastic term with mean 0 and variance $\sigma^2_{\varepsilon_{gt}}$.

2.3. Model variants

Although the standard small open economy model has been widely used in the literature (e.g., De Paoli, 2009; Galí, 2008; Guerra-Salas et al., 2021), some characteristics have been questioned in recent studies regarding the responses to external shocks. In this paper, in addition to the standard small open economy model, three variants of the model have been discussed.

2.3.1. Small open economy model – variant 1

Some researchers argue that the standard DSGE model is not able to describe international shock transmission efficiently, as the model does not include a specific element describing the influences of international shock transmission to a particular economy (Georgiadis & Jančoková, 2020, Croitorov et al., 2020). Moreover, Trung (2019) finds that the spillover effects of foreign shocks appear to be heterogeneous across countries, and the degree of spillovers significantly depends on the receiving country's specific characteristics. Based on these observations, the first variant (Variant 1) relaxes the assumption of a complete financial market, the heterogeneous global spillover transmission is introduced through a country-specific factor. Under this model, the small open economy will be influenced by foreign external shocks heterogeneously, depending on the domestic region's economic condition.

Therefore, the global variables (π_t^*, y_t^* and i_t^*) in the standard small open economy are re-presents as:

$$x_{i,t}^* = \tau_{St} x_{i,t}^* \tag{16}$$

where $x_{i,t}^* \in (\pi_t^*, y_t^*, i_t^*)$ and τ_{St} is the country-specific coefficient, measuring the connections between home and foreign countries. We assume the coefficient takes the value of the degree of openness in the small open economy:

$$\tau_{St} = \lambda_{St} \tag{17}$$

where λ_{St} is the openness of the individual economy. More precisely, the magnitude of foreign shocks depends on the receiving country's degree of market openness, that is, the home bias of the small open economy could help the region to be more defendable to external shocks. If the domestic economy is completely open, then Variant 1 collapses to the Standard SOE.

2.3.2. Small open economy model – variant 2

The second strand of literature questions the forecasting ability of DSGE models. Fontana and Veronese Passarella (2020) point out that the standard DSGE models fail to forecast the global financial crisis in 2008, in order to improve the model performance, they modify the model by considering a risk premium that re-defines the natural output. In their model, the natural output is affected by the lagged output level, and the degree of adjustment depends on a pre-determined parameter. Taking the idea of the Fontana and Veronese Passarella (2020), in the second variant, we introduce the risk premium through natural output level, but instead of using a pre-

determined statistical value to set the degree of adjustment, we let the adjustment varying across countries based on their economic conditions. The natural output level is defined as:

$$y_t^N - y_{t-1}^N = \varphi_1 \rho_t, \varphi_1 \in (-1, 0) \tag{18}$$

where y_t^N and ρ_t are the natural output and the country-specific risk premium respectively. φ_1 represents the negative relationship between the natural output and country risk premium. Here, we assume φ_1 is measured by σ, as the higher risk aversion that domestic consumers adopt, the higher risk premiums requested, so the lower natural output produced. In terms of country-specific risk premium, agents would usually face a lower risk premium when the economy has a sufficient growth rate. Therefore, the risk premium could be expressed as a function of the output gap:

$$\rho_t = \varphi_2(y_{t-1} - y_{t-1}^N), \varphi_2 \in (-1, 0) \tag{19}$$

So a high risk premium is associated with a negative output gap, while a lower risk premium is required by agents when a positive output gap appears. φ_2 measures influences of output gaps on current risk premium, in this paper, we assume φ_2 takes the value of η. The reason behind this is when the intratemporal elasticity of substitution is getting higher, the effects of terms of trade increase, the marginal utility of consuming foreign goods rises, which in turn causes firms to reduce domestic productions, so the probability of negative output gaps increases and domestic risk premium rises.

Combining the preview two equations with their assigned parameters, the natural output is defined as the following expression:

$$y_t^N = y_{t-1}^N + \sigma\eta(y_{t-1} - y_{t-1}^N) \tag{20}$$

The natural output level would be adjusted based on the natural output inertia and the variances of the lagged output gap. If the home and foreign goods are substitutes ($\sigma\eta > 1$), the higher substitutability between goods, the more marginal utility of consuming foreign goods rises, the larger domestic consumption falls lead to a larger fall in the natural output, which enlarges the output gap. Therefore, the lagged output gaps affect the natural output by a degree which is more than unity. On the contrary, if goods are complements ($0 < \sigma\eta < 1$), the rising domestic consumption increases home production, which leads to the output gap shrinking. As a result, the output gaps have a reduced effect on the natural output level, which is less than unity. When goods are perfect substitutes ($\sigma\eta = 1$), the natural output is the output level with a lag; if no substitutability ($\sigma\eta = 0$), the output gap has no effect on the natural output level, the model is identical with the standard small open economy model.

Now we replace the natural output level in the Standard SOE, which is assumed fixed and kept at 0, with the natural output level which is linked with the country-specific risk premium we derived above, then the IS and Phillips curve becomes:

$$\pi_{H,t} = \beta E_t \pi_{H,t+1} + \kappa_a \left[\left(\frac{\alpha + \varphi}{1 - \alpha} + \frac{\sigma}{1 - \lambda} \right) (y_t - y_t^N) - \sigma \frac{\lambda}{1 - \lambda} y^* - \sigma \gamma q_t \right] \qquad (21)$$

$$y_t - y_t^N = (E_t y_{t+1} - E_t y_{t+1}^N) - \frac{1 - \lambda}{\sigma} (i_t - E_t \pi_{t+1}) - \lambda \Delta E_t y_{t+1}^* - \gamma E_t \Delta q_{t+1} \qquad (22)$$

2.3.3. Small open economy model – variant 3

The third alternative (Variant 3) to the standard small open economy combines the previous 2 variances – considering both the country-specific factor and the country-specific risk premium in the model.

2.4. Monetary Policy rules

In the paper, we investigate the performances of different monetary policy rules in the small open economy (Table 1). Generally, the monetary policy rules take similar forms of the Taylor-type rule, as Berger (2008) believes simple policy could be considered as it could provide a guideline to policymakers to assess and prepare policy decisions.

2.4.1. Floating regime – domestic inflation targeting

Under floating monetary policy regime, the exchange rate is not a policy target, central banks would let it be completely flexible. The first interest-rate rule we considered is a floating regime which policymakers targets domestic inflation. The rule could be expressed as follows:

$$i_t = h_{St}(\pi_{H,t} - \pi_{H,t}^T) + b_{St}(y_t - y_t^T) \qquad (23)$$

where h_{St} and b_{St} are the weights assigned to inflation and output gap which are chosen by central banks.

2.4.2. Floating regime – CPI inflation targeting

The second interest rate we considered in this paper is still a floating regime, but CPI inflation becomes the policy target instead of domestic inflation. The rule is similar to the previous regime:

$$i_t = h_{St}(\pi_t - \pi_t^T) + b_{St}(y_t - y_t^T) \qquad (24)$$

Table 1. Simple policy rules.

	Target inflation	Monetary rules
Floating regime – targeting CPI	$\pi_{H,t}$	$i_t = h_{St}(\pi_{H,t} - \pi_{H,t}^T) + b_{St}(y_t - y_t^T)$
Floating regime – targeting PPI	π_t	$i_t = h_{St}(\pi_t - \pi_t^T) + b_{St}(y_t - y_t^T)$
Managed floating regime	π_t and q_t	$i_t = h_{St}(\pi_t - \pi_t^T) + b_{St}(y_t - y_t^T) + c(q_t - q_t^T)$

Source: Authors.

2.4.3. Managed floating regime

Coric et al. (2015) point out that the Croatian central bank should pay more atten-
tion to exchange rate fluctuations management, although coordinated monetary and
fiscal policies seem to be able to stimulate growth without having a large variance in
the exchange rate. It might be sensible to consider the exchange rate as one of the
policy targets when designing monetary rules. A managed floating regime allows cen-
tral banks to respond to the movement of the exchange rate in addition to CPI infla-
tion and output targeting (Sangare, 2016). Under this rule, the exchange rate becomes
one of the policy targets. Then the policy rule becomes:

$$i_t = h_{St}(\pi_t - \pi_t^T) + b_{St}(y_t - y_t^T) + c(q_t - q_t^T) \tag{25}$$

where c is the policy coefficient that the central banks choose to stabilising
exchange rate.

2.5. Welfare

Following Woodford (2003) and De Paoli (2009), the welfare function can be derived
by solving a second-order approximation of the household utility function. Appendix
A presents the detailed calculation is shown to derive a welfare function using a
second-order Taylor approximation. The welfare function for a small open economy[5]
can be written as a quadratic function of the output gap, domestic inflation and the
real exchange rate,

$$L = \frac{1}{2}\Phi_\pi \pi_{H,t}^2 + \frac{1}{2}\Phi_y(y_t - y_t^T)^2 + \frac{1}{2}\Phi_q(q_t - q_t^T)^2 \tag{26}$$

where $\Phi_\pi = \frac{1}{(1-\lambda+\sigma\gamma)}\frac{\varepsilon}{\kappa_a}$, $\Phi_y = \frac{1}{(1-\lambda+\sigma\gamma)}(\frac{\alpha+\varphi}{1-\alpha} + \frac{\sigma}{(1-\lambda)(1-\lambda+\sigma\gamma)})$ and
$\Phi_q = \frac{1-\lambda+\sigma\gamma}{\sigma^2}(1 + \frac{(\lambda-\lambda\sigma-1)}{(1-\lambda)(1-\lambda+\sigma\gamma)})$, and y_t^T and q_t^T are policy targets.

Like in the closed economy, welfare loss in a small open economy is affected by
two economic distortions, price stickiness and monopolistic competition in domestic
production. In addition to these two factors, terms of trade externality arise when
Home and Foreign goods are not perfect substitutes. As imported goods are not per-
fect substitutes for domestic goods, welfare could be improved through firms' monop-
olistic power. Firms in the Home economy could gain from improving terms of trade
by adjusting the real exchange rate. When goods are substitutes between countries, an
appreciating real exchange rate could increase welfare, while a depreciating real
exchange rate could be welfare improving when domestic and foreign goods are
complements.

3. Simulation results

3.1. Benchmark calibration

In our setup, when a demand shock hits the foreign economy, the effect spills over to
small open economies. First, the foreign country is calibrated to represent the external

Table 2. Benchmark calibrations.

		Value & Sources			
		US		UK	
Discount factor	β	0.99	Assumption	0.99	Assumption
Inverse intertemporal elasticity of substitution	σ	1.18	Aguirre and Vazquez (2020)	0.87	Bhattarai and Trzeciakiewicz (2017)
Inverse Frisch elasticity of labour supply	φ	1.45	Aguirre and Vazquez (2020)	1.38	Bhattarai and Trzeciakiewicz (2017)
Elasticity of labour	α	0.82	Aguirre and Vazquez (2020)	0.3	Bhattarai and Trzeciakiewicz (2017)
Elasticity of substitution	ε	6	Assumption	6	Assumption
Index of price stickiness	θ	0.77	Aguirre and Vazquez (2020)	0.78	Bhattarai and Trzeciakiewicz (2017)
Degree of openness	λ	–	–	0.3	World Bank
Intratemporal elasticity of substitution	η	–	–	1.77	Mumtaz and Theodoridis (2015)
Weight put on inflation	h_{St}	1.9	Aguirre and Vazquez (2020)	1.61	Bhattarai and Trzeciakiewicz (2017)
Weight put on output gap	b_{St}	0.05	Aguirre and Vazquez (2020)	0.09	Bhattarai and Trzeciakiewicz (2017)
Weight put on exchange rate	c	–	–	0.5	Sangare (2016)

Source: Authors.

economy, adopting the US estimates made by Aguirre and Vazquez (2020). And regarding the home economy, this paper investigates five small open economies (The UK, Australia, Canada, New Zealand and Taiwan[6]). In the benchmark, in line with R. Zhang et al. (2021) and S. Kim and Lim (2018), we treat the UK as an example of the small open economy, which is calibrated based on the estimations for the UK (Bhattarai & Trzeciakiewicz, 2017). The calibrations are summarised in Table 2.

For both home and foreign economies, the discount factor β is set to 0.99, which implies that the annual real interest rate is 4%, and the elasticity between differential goods is assumed to be 6, in line with Galí (2008). Following estimations obtained by Aguirre and Vazquez (2020) and Bhattarai and Trzeciakiewicz (2017) for the US and the UK economy, we let the inverse intertemporal elasticity of substitution in home and foreign economy is set to 1.18 and 0.87 respectively. The elasticity of labor α is 0.82 for the foreign country and 0.3 for the home economy. The Calvo parameter on prices θ is set to 0.77 for the foreign economy, representing the average price duration is approximately nine month in the US from 1961 to 2016; while according to Bhattarai and Trzeciakiewicz (2017), θ is assumed to be 0.78, indicating the UK experiences a roughly similar price duration with the US. φ is the inverse Frisch elasticity of labor supply which is assumed to be 1.45 and 1.38 for foreign and home economy respectively. The elasticity of substitution between home and foreign goods, which is 1.77, is taken from Harrison and Oomen (2010) and Mumtaz and Theodoridis (2015). The openness of degree, λ, is assumed to be 0.3, implying an average 30% import share of the GDP in the UK in recent years.

The policy coefficients in monetary policy rules are set following the estimates of Bhattarai and Trzeciakiewicz (2017) and Aguirre and Vazquez (2020). In the foreign economy, the weights assigned to inflation and output gap are 1.9 and 0.05 respectively, while the policy coefficients on inflation and output gap are 1.61 and 0.09 for the domestic economy. For the managed floating regime, the weight attached to the exchange rate is set as 0.5, in line with Sangare (2016).

3.2. Impulse responses

Before analyzing the impulse responses under the standard small open economy and its variants, we first describe how the external shock transmissions work in our model. In our two-country model, the size of Home country is asymptotically approaching zero, so the economic movement in Foreign economy could be solved independently as the impact that domestic variables could have on foreign countries is negligible (Auer et al., 2019). In order to examine the dynamics of macroeconomics in the small open economy when an external shock hits, we let a negative demand shock hits the foreign economy, then spillovers to small open economies.

Figure 1 shows the impulse responses of domestic and CPI inflation, exchange rate, nominal output and the output gap, and interest rate when a foreign demand shock hits[7], under four types of models. In general, the paths of variables are similar under Standard SOE and Variant 1 except for the magnitude. Similar paths also

(a) Standard SOE. (b) Variant 1. (c) Variant 2. (d) Variant 3.
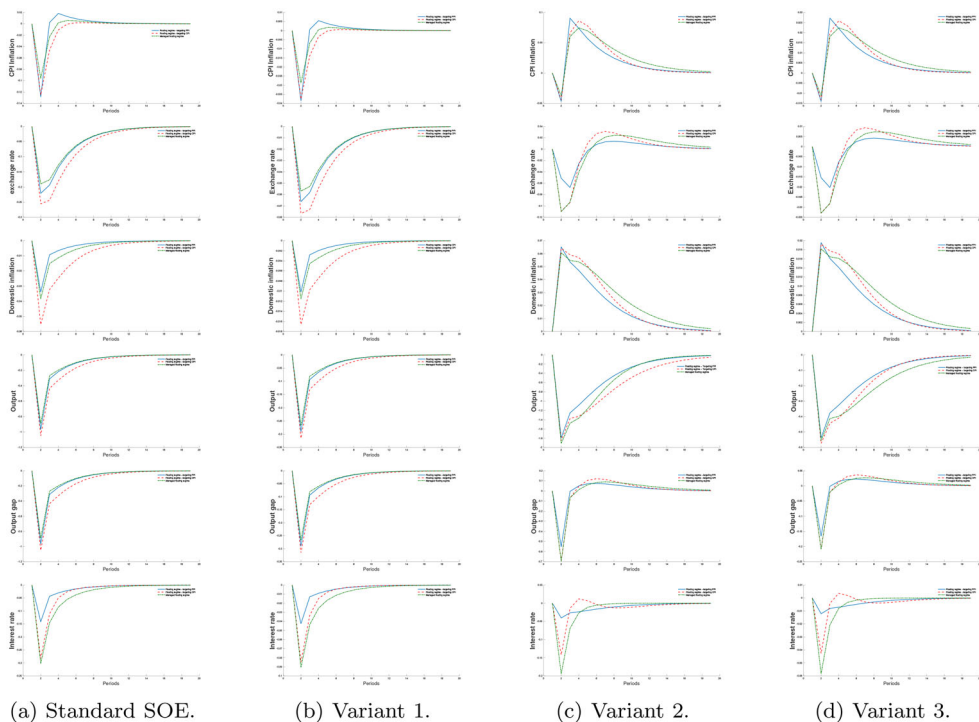
Figure 1. Impulse responses when an external demand shock hits. Notes: Column (a) to column (d) shows the impulse responses under Standard SOE, Variant 1, Variant 2 and Variant 3 respectively. Source: Authors.

appear on Variant 2 and Variant 3. This might be explained that the country-specific factor has been considered in Variant 1 (and Variant 3), which means the external shock affects the home country proportionally by the degree of the home country's market exposure. Under the calibration of the benchmark, the UK has an average 30% import share of the GDP, the home country, therefore, only experiences 30% of the effect of the foreign shock, compared to the Standard SOE.

Now we take a closer look at the impulse responses under the Standard SOE and its Variant 1. When a negative foreign demand shock hits, exports drop leading to a falling in home output. To stimulate the economy, the central bank reduces the interest rate, leading to the exchange rate decreases, the depreciated home currency causing the imports to become more expensive, imports consumptions tend to fall. However, in our case, the elasticity of intratemporal substitution is low ($\eta = 1.77$), the effect of terms of trade is limited, it is hard to translate the consumption towards foreign-produced goods. Therefore, the effect of lower consumption on imports due to the depreciation in the exchange rate is dominated by the rising in consumption of home-produced goods caused by the lower interest rate, so output starts to rises and goes back to its equilibrium. Comparing the three interest-rate rules, the floating regime which targets CPI inflation experiences the largest depreciation in the exchange rate which enlarges the output gap, in contrast, the lowest output gap is associated with the managed floating regime, in which central banks pay attention to stabilizing the exchange rate. Interest rates fall in all cases, but the lowest deviation appears in the floating regime which targets domestic inflation, as it targets exchange rates in neither direct nor indirect ways.

Next, we turn to analyze the dynamics of key variables under Variant 2 and Variant 3. In these two models, a country-specific risk premium is considered. When a negative foreign demand shock hits, the exports fall due to falling demand of foreign consumptions, domestic output decreases by a larger level comparing to the Standard SOE. The reason behind this is that if demand falls, higher risk premiums will be requested by agents which further enlarges the magnitude of the falling output. On the other hand, the output gap experiences a less deviation comparing to the Standard SOE, as output gaps in Variant 2 and 3 are defined as the deviation of output and the natural output level which is a function of lagged output – it smooths and shrinks the output gaps in general. Therefore, in Variant 2 and Variant 3, interest rates decrease but with lower deviations comparing to their corresponding model (Standard SOE and Variant 1) respectively.

After analyzing the dynamics of the standard small open economy model and its variants, in order to further investigate the properties of those models, we calculate the correlations between key variables in the home country and the foreign output, comparing to the real data found in the UK. Table 3 calculates the correlations between the home variable and the foreign output using the simulated results, comparing to the first column which is the correlation between the UK variables and the US output from 1992 to 2013. Before we compare the simulation performances, it is reasonable that the correlations derived from models are much higher than we found in the data, as the real data are influenced by a much more complicated economic condition, whereas consumptions are the only factor that affects the economy in our

Table 3. Correlations between home variables and the foreign output.

| | | Standard SOE | | | | Variant 1 | | | | Variant 2 | | | | Variant 3 | |
	Data	Floating 1	Floating 2	Floating 3	Floating 1	Floating 2	Floating 3	Floating 1	Floating 2	Floating 3	Floating 1	Floating 2	Floating 3
CPI inflation	−0.5533	0.8910	0.9764	0.9557	0.8919	0.9764	0.9557	0.1862	0.1804	0.2305	0.1862	0.1804	0.2305
Output gap	0.6079	0.9992	0.9868	0.9996	0.9992	0.9868	0.9996	0.8619	0.8081	0.7788	0.8619	0.8081	0.7788
Interest rate	0.8659	0.9998	0.9916	0.9832	0.9998	0.9916	0.9832	0.8719	0.9138	0.9897	0.8719	0.9138	0.9897
Exchange rate	0.3964	0.8540	0.8161	0.8307	0.8540	0.8161	0.8307	0.7423	0.8181	0.8353	0.7423	0.8181	0.8535

Notes: Data are detrended with the Hodrick-Prescott filter.
Source: Authors.

models. However, it is still worth mentioning here, as correlations could reveal the properties of models, at least the effect of external factors on domestic variables.

From the results, Variant 2 and Variant 3 simulate closer correlations as we found in the empirical results except for CPI inflation, which might be due to the very simple price structure we considered in the model. A nearly collinearity has been found for standard SOE and Variant 1. Another interesting thing we found is that correlations are the same in the standard SOE and Variant 1, and in Variant 2 and Variant 3, which further indicates that the external shock spillover affects the domestic economy heterogeneously through the magnitude, not the paths.

3.3. Model variances in different scenarios

The previous section shows the impulse responses and properties of the standard small open economy model and its three variants under benchmark calibration. To further investigate spillovers of external shocks, we examine the effect of home responses by changing the key parameter values in the benchmark calibration to represent different domestic economic characteristics. There are three variables we are particularly interested in: the degree of openness λ (determines the level of exposures to foreign shocks), the risk aversion σ (determines the degree of risk premium a home country would experience) and the intratemporal elasticity of substitution η (affects the relationship between risk premium and output gap).

Figures 2–4 illustrate how does values of the selected parameters affect the results. Figure 2 allows the degree of openness to vary ($\lambda \in (0, 1)$) while keep other parameters are fixed as the initial calibration. Almost all home variables show increasing trends as λ goes up regardless of the model types, indicating that the more open the

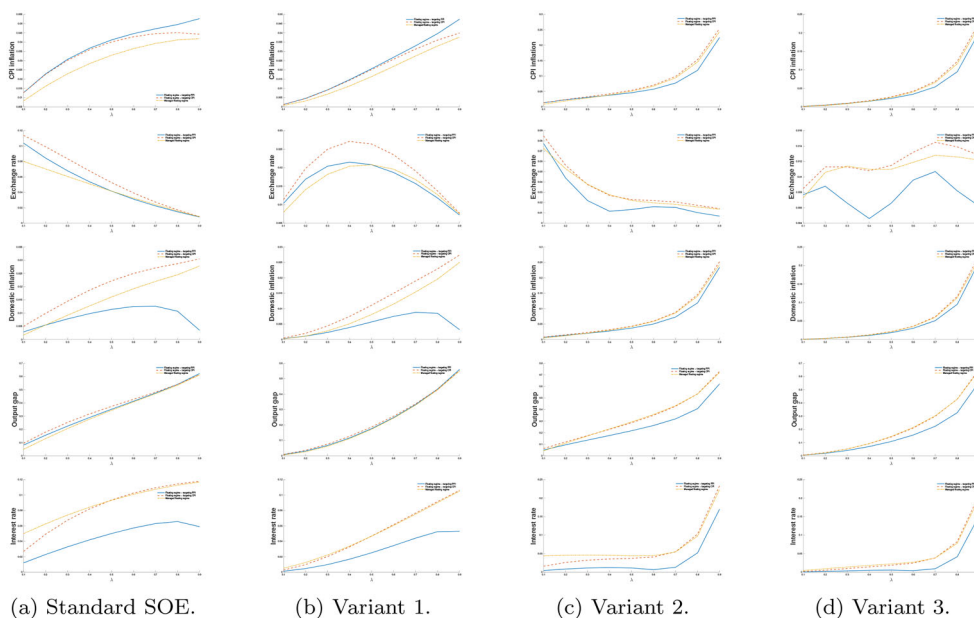(a) Standard SOE.   (b) Variant 1.   (c) Variant 2.   (d) Variant 3.

Figure 2. Deviations of home variables varying the degree of openness.
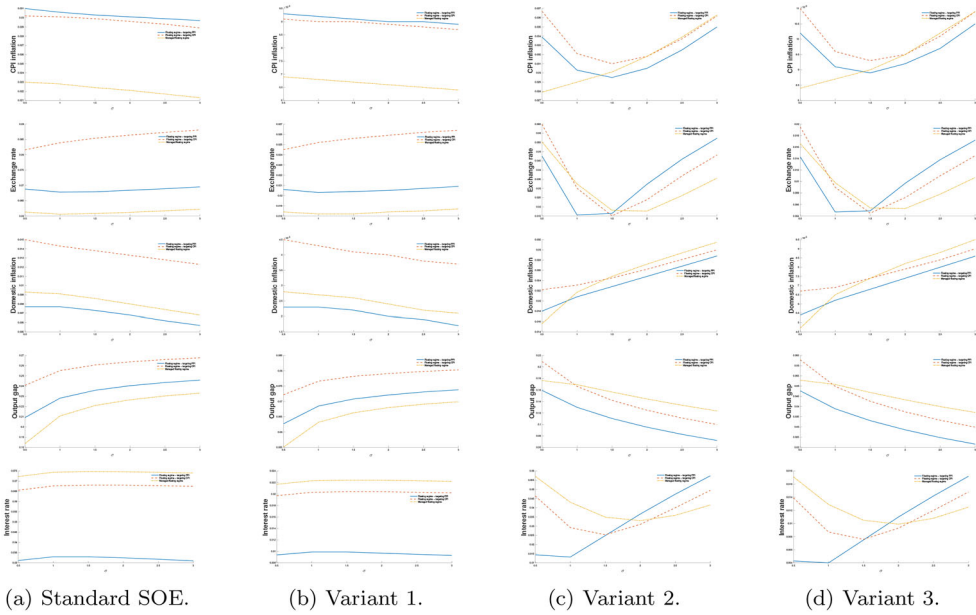Source: Authors.

Figure 3. Deviations of home variables varying the risk aversion.
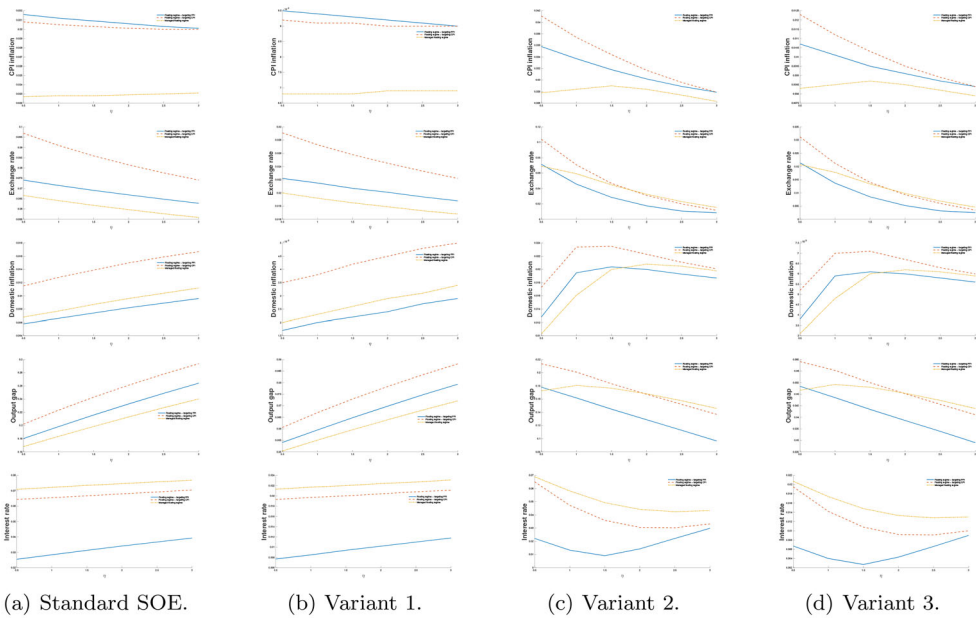Source: Authors.

Figure 4. Deviations of home variables varying the intratemporal elasticity of substitution.
Source: Authors.

economy is, the more exposure to external shocks, the higher deviations experienced in home variables. The only exception is the standard deviations of exchange rates, showing different trends across the four types of models. Under Standard SOE, the

exchange rate is decreasing with the increasing λ, this could be explained that the higher degree of openness, the foreign-produced goods become more preferred as home bias reduced, leading to a rising in the price of imports, which partially offsets the falling imports prices induced by the negative demand shock. Therefore, the deviation of the exchange rate is falling when the openness goes up. However, when the market exposure is considered a factor affecting external shock transmission (Variant 1), the deviation of exchange rate experiences an upward-shifting when λ increases to the intermediate level, then decreases afterwards, the highest deviation appears when consumers have symmetric preferences across home and foreign goods. Under Variant 2, the deviation of the exchange rate is decreasing with the rising degree of openness, but with more fluctuations comparing to the standard SOE, and the movement becomes more complicated under Variant 3.

Instead of varying λ, Figure 3 varies the risk aversion of home agents. Under the standard SOE and Variant 1, the higher risk aversion the agents have, the larger output gap deviation experienced in the home economy, the lower domestic inflation deviates. In addition, there is no significant effect on CPI inflation, exchange rate and interest rate when the risk aversion varies. However, the effects of risk aversion on the home economy become significant when risk premiums are considered (Variant 2 and Variant 3). On the one hand, the output gap deviation is decreasing when agents are getting more averse to risk, this could be explained by that the natural output is defined as a function of natural output inertia and lagged output gap. When risk aversion is increasing, the risk premium becomes higher, the natural output is affected more by the path of output with a lag, so the output gap shrinks. On the other hand, the deviation of domestic inflation goes up with the rising risk aversion, and exchange rate variance is decreasing at the beginning but increasing at a higher level of risk aversion.

Figure 4 shows the effects of home variables when varying the elasticity of substitution of home and foreign goods. The deviations of exchange rate are falling across all models, as the higher intratemporal elasticity, the more consumptions lead towards imports, larger rises in imports prices which offsetting the falling imports prices induced by external shocks, so the less deviates experienced in exchange rates, however, the deviations in Variant 2 and 3 are much larger than Standard SOE and Variant 1. The deviations of domestic prices and output gaps under Standard SOE and Variant 1 show upward-shifting trends with an increasing η, however, reversed responses have been found under Variant 2 and 3.

4. Welfare and best rules

4.1. Welfare losses in standard small open economy model and its variants

In this section, we investigate how parameters affect domestic welfare and which interest-rate rule could produce better welfare under different economic conditions. Following the previous analysis, we first examine domestic welfare consequences by varying one of the selected parameters in the initial calibration. Figure 5 shows welfare losses when varying λ, σ and η respectively. The first column shows the welfares across the degree of openness – Standard SOE and Variant 1 show welfare losses are
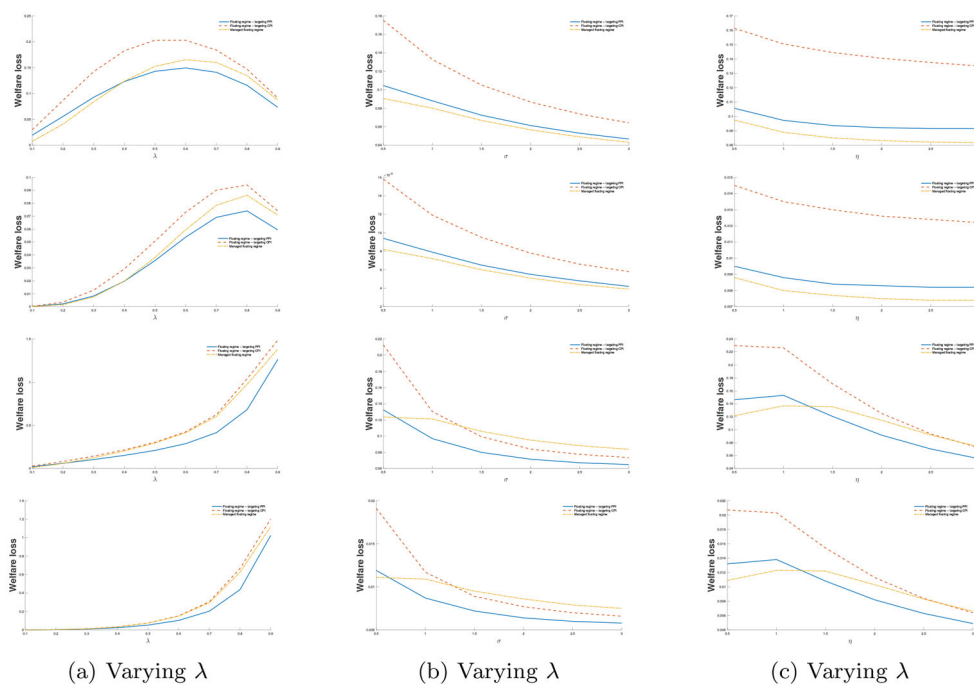
Figure 5. Domestic welfare losses under different models.
Notes: The welfare consequences simulated from the Standard SOE, Variant 1, Variant 2 and Variant 3 are shown in the top panel, the second, the third and the bottom panel respectively. While the first column shows the welfare losses when varying the degree of openness, the second column displays the welfare losses when varying risk aversion, and the last column illustrates the corresponding welfare loss if intratemporal elasticity of substitution varies.
Source: Authors.

increasing with the rising λ, but downward trends turn out when λ is getting higher; while the results from Variant 2 and Variant 3 indicate that the more open the region is, the more welfare loss it experiences, and moreover, the marginal effect is getting larger when λ rises to a very high level. The results found in Variant 2 and Variant 3 are consistent with several empirical findings which point out the effect of external shocks could be exacerbated by domestic trade openness (Georgiadis, 2016; Trung, 2019).

The second column shows the welfare losses when the intertemporal elasticity of substitution varies. The more risk aversion in the economy implies a lower elasticity of intertemporal substitution, agents could increase their current consumptions which leads to the output goes up, the output gap shrinks eventually. Therefore, regardless of which model we use, a decreasing trend is obtained under each model: the more risk aversion the agents adopt, the fewer welfare losses experienced in the society.

The welfare performances with varying η are shown in the last column in Figure 5. Under the standard SOE and Variant 1, a decreasing trend has been observed in welfare losses when the intratemporal elasticity of substitution is getting larger, however, this trend is associated with quite flatter curves, therefore, it might indicate that the elasticity between home and foreign goods does not have a solid effect on domestic welfare. However, this effect becomes significant when we model the home economy using Variant 2 and Variant 3. A clearly falling trend on welfare losses has been

observed when home and foreign goods are substitutes, and an opposite case (a slightly increasing trend) has been found when goods are complements (although the effect is quite small). The higher substitutability between home and foreign goods, the larger effect of terms of trade which could redirect the consumptions towards foreign goods, the rising consumptions would eventually increase welfare. However, complements indicate a positive correlation between the marginal utility of home-produced consumption and the marginal utility of consuming imports, the effect of terms of trade reduced, in this case, the welfare losses appear to be flat curves but with a slightly increasing shift.

After evaluating the welfare losses by changing the selected variables, it seems that both the variant models with country-specific risk premium and the model with country-specific coefficient outperform the standard small open economy model, as the simulated results are more plausible and matched the empirical finding in the literature.

4.2. Welfare performances under different interest-rate rules

After examining the welfare consequences induced by different economic conditions, we now turn to evaluate welfare performances under different interest-rate rules. In order to cover as many scenarios as possible, we vary the three variables (λ, σ and η) simultaneously, instead of varying one of which. Table 4 shows the best rule which produces the lowest welfare loss in a specific environment. First, results are identical between Standard SOE and Variant 1, similar results are also found in Variant 2 and Variant 3. This gives further evidence that although the degree of openness affects the explosion of the domestic region to external shocks, the momentous difference is the size of changes in domestic variables, consequently, there is no impact on the performances of interest-rate rules.

Under Standard SOE and Variant 1, when the domestic country is relatively closed, the effect of home bias increases, home-produced goods are more preferred relative to imports, domestic prices go up which enlarge the gap between prices of home goods and foreign-produced goods, the exchange rate deviations rises, so a managed floating exchange rate regime outperforms other rules. On the other hand, the degree of openness increases, the floating regime which targets domestic inflation becomes the preferred rule, as imports prices fall after the shock, but recovers afterwards as more imports are consumed, as a result, controlling domestic prices could increase welfare. However, there is no significant effect on welfare when varying the intertemporal and intratemporal elasticity of substitutions.

The welfare performances become complicate when we produce the simulations using Variant 2 and Variant 3. Like the Standard SOE and Variant 1, the managed floating regime is preferred when λ is low, while the floating regime which targets domestic inflation outperforms when λ is getting higher. However, under Variant 2 and Variant 3 models, the effect of intratemporal elasticity of substitution becomes more complex and depends on the degree of openness and risk aversion. On the one hand, when home and foreign goods are compliments, foreign-goods consumption

Table 4. Best rule suggested by different models.

λ	η \ σ	Standard SOE			Variant 1			Variant 2			Variant 3		
		0.5	3	5.5	0.5	3	5.5	0.5	3	5.5	0.5	3	5.5
λ=0.1	0.5	Floating 1	Floating 3	Floating 3	Floating 3	Floating 3	Floating 3	Floating 3	Floating 3	Floating 3	Floating 3	Floating 3	Floating 3
	3	Floating 1	Floating 3	Floating 3	Floating 3	Floating 3	Floating 3	Floating 3	Floating 1	Floating 1	Floating 3	Floating 1	Floating 1
	5.5	Floating 1	Floating 3	Floating 3	Floating 3	Floating 3	Floating 3	Floating 3	Floating 3	Floating 3	Floating 3	Floating 3	Floating 3
λ=0.3	0.5	Floating 1	Floating 3	Floating 3	Floating 3	Floating 3	Floating 3	Floating 3	Floating 3	Floating 3	Floating 3	Floating 3	Floating 1
	3	Floating 1	Floating 3	Floating 3	Floating 3	Floating 3	Floating 3	Floating 1	Floating 1	Floating 2	Floating 1	Floating 1	Floating 2
	5.5	Floating 1	Floating 3	Floating 3	Floating 3	Floating 3	Floating 3	Floating 1	Floating 3	Floating 1	Floating 1	Floating 3	Floating 1
λ=0.5	0.5	Floating 1	Floating 3	Floating 3	Floating 1	Floating 3	Floating 3	Floating 1	Floating 3	Floating 1	Floating 1	Floating 3	Floating 1
	3	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1	Floating 2	Floating 1	Floating 1	Floating 2
	5.5	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1	Floating 3	Floating 2	Floating 1	Floating 3	Floating 1
λ=0.7	0.5	Floating 1	Floating 3	Floating 3	Floating 1	Floating 3	Floating 3	Floating 1	Floating 3	Floating 1	Floating 1	Floating 3	Floating 1
	3	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1
	5.5	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1	Floating 3	Floating 2	Floating 1	Floating 3	Floating 1
λ=0.9	0.5	Floating 1	Floating 3	Floating 3	Floating 1	Floating 3	Floating 3	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1
	3	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1
	5.5	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1	Floating 2	Floating 3	Floating 1	Floating 2	Floating 3

Source: Authors.

transmission is difficult as the marginal utility of consuming domestic goods is increasing with the marginal utility of foreign consumption, and a relatively closed domestic economy would enlarge this effect. As a consequence, a managed exchange rate regime is preferred. However, when the openness is high, the consumption redirects to imports, the deviation of exchange rate shrinks, a floating regime targeting domestic inflation outperforms other rules, especially when domestic agents are highly risk-adverse. On the other hand, if the home and foreign goods are substitutes and the degree of risk aversion is low, the managed floating regime outperforms when the domestic country is relatively closed, while the floating regime targets PPI starts to dominate when openness is high. One exception is that when the substitutability is exceptionally high, the managed exchange rate regime turns out to be the best rule with the home economy is extremely open, this could be explained that in a nearly completely open economy, consumptions mainly rely on imports, a relatively stable exchange rate would improve welfare, therefore, a managed floating regime becomes the best rule.

The above results are obtained by changing the value of selected parameters (the domestic openness, intertemporal and intratemporal elasticity of substitution) while keeping other parameters as fixed as shown in the benchmark calibration (shown in Table 2). Do other macroeconomic parameters affect the welfare consequences? Can the models give a robust performance that could give a suggestion that central banks could rely on? To answer these questions, we extend our analysis by investigating four more small open economies, compute welfare losses, and then find the best rule which gives the lowest welfare loss for individual countries.

In order to investigate both advanced and emerging small open economies, we select five regions: Australia, Canada, New Zealand, Taiwan and the UK, following literature which investigating economic issues by taking these economies to represent small open economies (Alba et al., 2020; Georgiadis & Zhu, 2021; Kim et al., 2020; Kim & Lim, 2018; Zhang et al., 2021).

Moreover, the small open economies we selected not only cover a wide range of intertemporal and intratemporal elasticity of substitution and the domestic openness differs across economies, but also experience different macroeconomic conditions, such as different price durations, labor elasticity and the policy coefficients in the interest-rate rules (calibrations[8] are shown in Table 5). Table 6 shows the best rules found in the Standard SOE and its variant models. The" Model simulated" column shows the best rule when all parameters are calibrated using country-specific values for the individual regions, while the" Benchmark suggested" shows the best rule suggested by the model in which only openness and substitutability suits the economy characteristics while keeping other parameters fixed.

Table 5. Calibrations for five different economies.

	λ	η	σ	θ	φ	h_{St}	b_{St}	Sources
New Zealand	0.5	2	0.12	0.75	1.9	1.89	0.03	Funke et al. (2018)
Australia	0.24	1	0.27	0.09	1	2.47	0.15	Zhang and Dai (2020)
Canada	0.4	1	8	0.65	1	1.8	0.65	Delpachitra et al. (2020)
UK	0.3	1.77	0.87	0.78	1.38	1.61	0.09	Bhattarai and Trzeciakiewicz (2017)
Taiwan	0.56	2.5	1	0.75	0.65	0.77	1.13	Chu (2018)

Source: Authors.

Table 6. Comparisons of best rules under different calibrations – a robust test.

	Standard SOE		Variant 1		Variant 2		Variant 3	
	Model simulated	Benchmark suggested	Model simulated	Benchmark suggested	Model simulated	Benchmark suggested	Model simulated	Benchmark suggested
New Zealand	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1
Australia	Floating 3	Floating 3	Floating 3	Floating 3	Floating 3	Floating 3	Floating 3	Floating 3
Canada	Floating 2	Floating 3	Floating 2	Floating 3	Floating 1	Floating 1	Floating 1	Floating 1
UK	Floating 3	Floating 3	Floating 3	Floating 3	Floating 1	Floating 1	Floating 1	Floating 1
Taiwan	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1	Floating 1

Source: Authors.

The results in the Variant 2 and Variant 3 appears to be consistent between the benchmark suggested the best rule and the model simulated the best rule across the five regions, suggesting that the effect of parameters we selected dominates the other parameters – the welfare performances of interest-rate rules mainly depend on the three selected variables, other macro parameters do not, or at least have very limited effects on the welfare consequences. This might suggest that policymakers could make a decision based only on the value of openness and substitutability between goods. However, parameters do have effects on the welfare performances in different rules when we considering Standard SOE and Variant 1, as the best rule changes in Canada. Consequently, in the Standard SOE and Variant 1, all macroeconomic parameters should be taken into consideration when making a policy suggestion. In this case, we might conclude that when making a policy decision, Variant 2 and Variant 3 outperform the Standard SOE and Variant 1, because in these models, fewer variables are required to have a robust result, which might reduce estimation errors.

5. Conclusion

The interconnection between small open economies and the foreign country has been widely discussed since the financial crisis in 2008. However, researchers argue that global shock transmission cannot be fully described in the standard DSGE model. In our paper, we extend the standard small open economy model in several ways: (1) adding a country-specific factor which allows heterogeneous foreign shock transmission; (2) relating the domestic natural output to a country risk premium; (3) combining the two cases.

We first investigate impulse responses and welfare consequences in the standard SOE and its three variants under the benchmark calibration, then we extend our analysis by varying three selected variables. The results vary across models, but in general, showing that the openness has a significant effect on the external shock transmission, a higher degree of openness induces larger vulnerability to external shocks, which in turn leads to larger welfare losses. And the welfare losses are decreasing with domestic substitutability. By comparing results across models, the results obtained from the models which take country-specific risk premium into consideration, seem to be more plausible and consistent with empirical findings in the literature.

Furthermore, we evaluate the best interest-rate rule in different models and then examine the model performances. We find that the rule which gives the lowest welfare loss differs across models, given the same economic conditions. Then we

calculate the best rules for five economies using their specific calibrations, comparing to the best rules we found when using benchmark calibration which only adjust the selected parameter values. We find that the results are consistent when using Variant 2 and Variant 3 models, indicating that other than the three key variables, other macroeconomic parameters do not or at least have little effect on deciding the best rule. As a consequence, we might conclude that a model considering a country-specific risk premium outperforms the standard DSGE model if the model is used to give policy suggestions, because fewer parameters considered, fewer estimation errors lead to more robust results consequently. Finally, we would like to mention that this paper is trying to give some policy suggestions for central banks such as which model can be relied on, or which monetary policy rules should be used under various economic conditions, however, we should also be aware that there might exist some bias as the real economic situations are much more complicated than the simplistic models we considered in this paper.

One of the limitations of this paper is that we do not consider some special cases, such as zero lower bound (ZLB). When nominal interest rates fall to ZLB, the policy rate cannot be further reduced, and the effectiveness of monetary policy is significantly limited. One fruitful extension of this analysis would be to take the ZLB into consideration and accommodate the unconventional monetary policy in the small open economy modeling. It would be interesting to see that whether the coordination of both conventional monetary policy (like we discussed in the paper) and the unconventional monetary policy (e.g., Quantitative Easing), could improve social welfare more effectively.

Notes

1. For $v = \frac{1}{2}$, the model assumes symmetric preferences across countries.
2. The Foreign economy's Euler equation is given in a similar form.
3. Note that when the model is assumed to be a closed economy ($\lambda = 0$), the model collapse to the standard New Keynesian Phillips curve and the IS curve which are identical to the ones commonly used in the closed economy.
4. the natural output level in the standard small open economy model is assumed fixed and kept at 0
5. In the welfare function, the relative weight of inflation with respect to the output gap is determined by the structural parameters in the model. When the Home economy becomes closed ($\lambda = 0$), the welfare function collapses to the standard welfare in a closed economy.
6. In this paper, we investigate five small open economies to cover both advanced and emerging small open economies, the UK estimates are shown in the benchmark calibration Table 2, while the rest four economies calibration are shown in Table 5.
7. We assume the foreign economy hit by a negative, one standard deviation demand shock.
8. Calibrations for New Zealand, Australia, Canada, the UK and Taiwan are taken the estimates found by Funke et al. (2018), B. Zhang and Dai (2020), Delpachitra et al. (2020), Bhattarai and Trzeciakiewicz (2017) and Chu (2018) respectively.
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Appendix A. Welfare approximation in a small open economy

In this appendix, we derive a second-order Taylor approximation of utility function, to obtain a welfare loss function in a small open economy.

Take a second order approximation of utility,

$$\frac{u_t - u}{u_c C} = \hat{c}_t + \frac{1-\sigma}{2}\hat{c}_t^2 + \frac{u_n N}{u_c C}\left(\hat{n}_t + \frac{1+\varphi}{2}\hat{n}_t^2\right) \tag{A1}$$

In order to obtain a expression for aggregate demand in the Home country c_t, combine the international risk sharing ($c_t = c_t^* + \frac{1}{\sigma}q_t$) and the relationship between home and foreign output ($y_t = y_t^* + \left(\frac{1-\lambda}{\sigma} + \gamma\right)q_t$),

$$c_t = \frac{1}{1 - \lambda + \sigma\gamma}y_t + \left(1 - \frac{1}{1 - \lambda + \sigma\gamma}\right)y_t^* \tag{A2}$$

Similar with the closed economy, the linearised labour index could be written as

$$\hat{n}_t = \frac{1}{1-\alpha}\left[\hat{y}_t - a_t + \frac{\varepsilon}{2}\frac{1-\alpha+\alpha\varepsilon}{1-\alpha}varp_{H,t}(i)\right] \tag{A3}$$

According to the labour index (5), the marginal product of labour in a small open economy could be derived as:

$$-\frac{U_n}{U_c} = \frac{1-\alpha}{1 - \lambda + \sigma\gamma}\frac{C}{N} \tag{A4}$$

Now substitute the previous results into Equation (A1),

$$\frac{u_t - u}{u_c C} = -\frac{1}{2(1 - \lambda + \sigma\gamma)}\left[\left(\frac{1+\varphi}{1-\alpha} - \frac{(1-\sigma)(1+\lambda-\sigma\gamma)}{1 - \lambda + \sigma\gamma}\right)y_t^2 - 2\frac{1+\varphi}{1-\alpha}a_t y_t\right.$$
$$\left. + \frac{(1-\sigma)(\lambda-\sigma\gamma)}{1 - \lambda + \sigma\gamma}(y_t - y_t^*)^2 + \varepsilon\frac{1-\alpha+\alpha\varepsilon}{1-\alpha}varp_{H,t}(i)\right] + t.i.p. \tag{A5}$$

where $t.i.p.$ stands for terms of independent of policy.

Log-linearise the marginal cost in the Home economy,

$$mc_t = \left(\frac{\alpha+\varphi}{1-\alpha} + \frac{\sigma(1-\lambda)+\lambda\sigma}{(1-\lambda)(1 - \lambda + \sigma\gamma)}\right)y_t - \frac{1+\varphi}{1-\alpha} \tag{A6}$$

Therefore,

$$a_t = \frac{1-\alpha}{1+\varphi}\left[\frac{\alpha+\varphi}{1-\alpha} + \frac{\sigma}{(1-\lambda)(1 - \lambda + \sigma\gamma)}\right]y_t \tag{A7}$$

Insert a_t into Equation (A5), and using the discounted value of price index, $\sum_{t=0}^{\infty}\beta^t varp_{H,t}(i) = \frac{\theta}{(1-\theta)(1-\beta\theta)}\sum_{t=0}^{\infty}\beta^t\pi_{H,t}^2$, then welfare loss function, Equation (26) could be obtained

$$L = \frac{1}{2}\Phi_\pi\pi_{H,t}^2 + \frac{1}{2}\Phi_y\left(y_t - y_t^T\right)^2 + \frac{1}{2}\Phi_q\left(q_t - q_t^T\right)^2$$