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RULES-BASED OPTIMAL MITIGATION OF ECONOMIC UNCERTAINTY

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ABSTRACT

A notable attribute of the empirical studies on monetary rules is that few published articles rely on the normative evaluation in eliminating unwanted economic uncertainty. To prevail over this shortcoming, this paper introduces the optimal mitigation of economic uncertainty and determines its applicability through a sample of 14 selected countries. Using the combination of the theoretically derived optimal mitigation of economic uncertainty with the empirical estimations leads to specific monetary rules. The findings of this paper provide some policy implications; the optimal mitigation of economic uncertainty can characterise the optimal use of the interest rate and exchange rate to eliminate economic uncertainty and serve as a monetary policy guide in the adjustment process to restore macroeconomic conditions of the equilibrium that eventually promote the best macroeconomic outcomes.

Keywords: Grid search algorithm, Optimal economic uncertainty, Monetary policy, Monetary rules, Sterilised intervention

INTRODUCTION

The monetary rule refers to a systematic rule whereby central banks determine policy using information about the macroeconomic performance of the economy

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relative to a target performance level (Black et al., 2017). The seminal work by Taylor (1993) best described the repercussions of his most well-known eponymous, systematic monetary rule. Since then, researchers have endeavoured to look into the vagueness of the stance of monetary policy through various monetary rules (Knotek et al., 2016). Greater emphasis is being placed on examining the effectiveness and robustness of rules-based policy to changes in economic conditions. Although researchers' rules-based policy design works well on average and serves as a summary reference tool of monetary policy stance (Taylor, 2012), they are not designed to work well in all situations of economic uncertainty (Yellen, 2015).[1] Thus, a potentially grave question remains as to whether further research in this field could enhance our knowledge of monetary rule in overcoming the economic uncertainty.

A notable attribute of the empirical studies on monetary rules is that few published articles rely on the normative evaluation in eliminating unwanted economic uncertainty.[2] For instance, Levin (2014) presents a set of fundamental principles concerning the effectiveness of central bank communications. He argues that a simple monetary rule can serve as a valuable benchmark in the central bank's decision-making process that promotes economic prosperity by reducing economic uncertainty. Evans et al. (2015) determine economic uncertainty on the reaction of monetary policy using the optimal Taylor rule in a standard new Keynesian model. They discover that the central bank tends to take a wait-and-see monetary strategy with unforeseeable economic outcomes. Aastveit et al. (2017) evaluate the influence of economic uncertainty on monetary policy using econometric techniques. They argue that high economic uncertainty tends to reduce the effectiveness of the monetary policy.

On the other hand, Caggiano et al. (2017) study the macroeconomic uncertainty to identify the stance of monetary policy. They discover that heightened uncertainty can induce a contraction in real activity in the presence of constrained monetary policy. Öge Güney (2018) examines the effects of growth and inflation uncertainty on the monetary policy reaction function using the asymmetries approach. He implies that the central bank responds aggressively to growth and inflation uncertainties during periods of economic expansion. Using impulse response function analysis, the results of the study by Leduc and Liu (2020) corroborate the findings of Thomas (2016). Leduc and Liu (2020) infer that adapting monetary policy to economic uncertainty arising from a pandemic disaster can help cushion the economy. In these studies, although efficacy measures of monetary rules are seldom disastrous, the existence of economic uncertainty can provide a valuable illustration for more aggressive policy actions to avoid economic disruption (Giannoni, 2002).

This paper is motivated by the fact that the recurrent episodes of economic uncertainty remain unavoidable for many years. From the subprime crisis in early 2007, the world witnessed the international financial crisis in September 2008, which triggered the worst ever global economic slowdown. Uncertainties persist, encompassing the fact that global economic recovery remains disappointingly feeble, fragile, and uneven. For example, in high-income economies, including Europe, Japan, and the United States (U.S.), economic recovery encompassing productivity and employment have remained below their pre-crisis level and, notably, below their potential (World Bank, 2014). In developing countries, the onerous risks comprise the marked slackening of growth, reflecting fundamental weaknesses, and the end of the U.S. Federal Reserve's quantitative easing (QE) 3 stimulus programme, reflecting a huge capital outflow. Although investment in the real economic activity remains fragile, strategies aimed at stimulating domestic consumption in combating slow and uneven growth are impeded by excessive debt overhang (World Bank, 2020). Furthermore, the emergence of the coronavirus pandemic in late 2019 has triggered an unprecedented global recession (International Monetary Fund [IMF], 2020). As stressed by the Bank for International Settlements (BIS, 2014), a new policy compass is needed to address economic uncertainty.

The objective of this study is to determine the applicability of the optimal mitigation of economic uncertainty in a simple open economy model, such that:

1. The optimal mitigation can serve as a good prescription tool to characterise the optimal use of policy rates—the interest rate and the exchange rate—to eliminate economic uncertainty, and
2. The optimal mitigation can serve as a monetary policy guide in the adjustment process to restore macroeconomic conditions of the equilibrium.

In doing so, the optimal mitigation of economic uncertainty should help promote the best macroeconomic outcomes. The present study uses a sample comprising 14 selected countries (see Data Description section for details on selected countries). The present study's main innovative feature is adopting the optimal mitigation of economic uncertainty, which has arisen from the link between the policy of interest rate stability and the policy of exchange rate stability and is the combination of two monetary rules – the target interest rate and the target exchange rate.

THEORETICAL MODEL

The optimal mitigation of economic uncertainty is a rules-based mechanism of economic uncertainty avoidance, which has arisen from the link between the policy of interest rate stability (through open market operations)[3] and the policy of exchange rate stability (through sterilised intervention operations)[4] and is the combination of two monetary rules – the target interest rate and the target exchange rate. This viable form is based on the managed float exchange rate theory, presented by Bofinger and Wollmershauser (2001) in explaining the new global monetary arrangements. The theory implies that an intervention strategy in the foreign exchange market can be regarded as a managed floating exchange rate regime. To evade a monotonous interpretation of the managed float exchange rate theory, a policy of exchange rate stability (through sterilised intervention operations by fine-tuning exchange rate levels) may not lead to a deficiency of policy of interest rate stability (through open market operations by fine-tuning interest rate levels). Thus, in the context of optimal mitigation of economic uncertainty, the exchange rate and the interest rate are mutually compatible for eliminating unwanted economic uncertainty.

In accordance with the convention on the monetary policy strategy, the theory of managed float can help ensure the simultaneous achievement of internal and external equilibrium in an open economy. Internal equilibrium signifies that the open market operations and the sterilised intervention operations are two independent instruments that minimise the central bank's loss function. External equilibrium signifies that the path of the exchange rate is driven consistently by the uncovered interest parity (henceforth, UIP) to keep the foreign capital market stable. Because the bulk of the evidence reveals that UIP usually does not hold (Engel, 2014), the central bank can constantly employ sterilised intervention operations to fulfil UIP (Burger & Knedlik, 2004). Gan (2014a) argues that the sterilised intervention operations on exchange rate misalignments can combat disturbances in the foreign capital market. However, one may adopt the use of the open market operations, rather than the sterilised intervention operations, to influence the exchange rate if UIP holds in practice (Gan, 2018).

The theoretical modelling of the optimal mitigation of economic uncertainty commences with the derivation of the economic uncertainty index model (see the subsection of The Economic Uncertainty Index Model). The subsection of The Monetary Rules for Economic Uncertainty Elimination augments the derived economic uncertainty index model to yield monetary rules to eliminate unwanted economic uncertainty and ensure internal and external equilibrium.

The Economic Uncertainty Index Model

This section derives the economic uncertainty index model within a system of equations. The model-building process begins with the simple open economy model, an extension of the simple New Keynesian model that has firmly established micro-foundations based on price rigidity (Evans et al., 2015). This model is a commonly used structural model in the literature on monetary rules (e.g., Ball, 1999; Gan, 2014b; Roste, 2017). The following simple structural model gives the inputs to the constructions for the economic uncertainty index model.

$$y_{g_t} = \alpha_1 y_{g_{t-1}} - \lambda_1 r_{g_{t-1}} - \delta_1 e_{g_{t-1}} + \varepsilon_t \tag{1}$$

$$\pi_{g_t} = \alpha_2 y_{g_{t-1}} + \beta_{\pi_1} \pi_{g_{t-1}} - \delta_2 e_{g_{t-1}} + \eta_t \tag{2}$$

$$e_{g_t} = \lambda_2 r_{g_t} + \upsilon_t \tag{3}$$

$$r_{g_t} = \alpha_4 y_{g_{t-1}} + \beta_{\pi_3} \pi_{g_{t-1}} - \delta_4 e_{g_{t-1}} + \zeta_t \tag{4}$$

where Equations 1, 2, 3 and 4 represent the investment-saving curve, the Phillips curve, an exchange rate model in reduced form, and the central bank's reaction function, respectively. y_g, π_g, e_g and r_g denote the real output, inflation, real exchange rate and real interest rate, respectively; each variable is expressed in the gap form, representing the deviation between the actual and potential levels.[5] ε, η, υ, and ζ are the demand shock, the supply shock, the shock to the exchange rate, and the monetary policy shock, respectively. Regarding the link between the independent variable and dependent variable in each equation of the structural model, positive and negative signs describe, respectively, positive and negative relationships. Additionally, the structural relationships indicated above are in the same vein as Ball (1999) and Gan (2014b) in their simple open economy model.[6]

Consider the derived simple rules for the operating targets can provide a premise for the economic uncertainty model's constructions. One can define the operating targets by two policy variables: the exchange rate (e_g) and the interest rate (r_g). To derive the simple rule for e_g, this study shifts the time one period forwards in both Equations 1 and 2 to show the effects of exchange rate on the output gap (y_g) and inflation gap (π_g). This yields:

$$y_{g_{t+1}} = \alpha_1 y_{g_t} - \lambda_1 r_{g_t} - \delta_1 e_{g_t} \tag{5}$$

$$\pi_{g_{t+1}} = \alpha_2 y_{g_t} + \beta_{\pi_1} \pi_{g_t} - \delta_2 e_{g_t} \tag{6}$$

To eliminate interest rate from Equation 5, substituting Equation 3 into Equation 5 gives:[7]

$$y_{g_{t+1}} = \alpha_1 y_{g_t} + \left(\frac{\lambda_1}{\lambda_2}\right)\upsilon_t - \left(\frac{\lambda_1}{\lambda_2}\right)e_{g_t} - \delta_1 e_{g_t} \tag{5.1}$$

The simple exchange rate rule can then be derived from a linear combination of the state variables corresponding to terms on the right-hand sides of Equations 5.1 and 6; this linear combination is given by equation:

$$\alpha_1 y_{g_t} + \left(\frac{\lambda_1}{\lambda_2}\right)\upsilon_t - \left(\frac{\lambda_1}{\lambda_2}\right)e_{g_t} - \delta_1 e_{g_t} + \alpha_2 y_{g_t} + \beta_{\pi_1}\pi_{g_t} - \delta_2 e_{g_t} = 0\,.$$

This yields:

$$e_{g_t} = \left(\frac{1}{\frac{\lambda_1}{\lambda_2} + \delta_1 + \delta_2}\right)\left(\left(\alpha_1 + \alpha_2\right)y_{g_t} + \beta_{\pi_1}\pi_{g_t} + \left(\frac{\lambda_1}{\lambda_2}\right)\upsilon_t\right) \tag{7}$$

where e_{g_t} depends on the shock to the exchange rate and related observable variables. By Equation 3, υ_t can be replaced by $e_{g_t} - \lambda_2 r_{g_t}$. Thereby, Equation 7 can also be expressed as:

$$e_{g_t} = \left(\frac{1}{\delta_1 + \delta_2}\right)\left(\left(\alpha_1 + \alpha_2\right)y_{g_t} + \beta_{\pi_1}\pi_{g_t} - \lambda_1 r_{g_t}\right) \tag{8}$$

Ball (1999) argues that the monetary authority can set the rule(s) of monetary policy in terms of either a combination of the exchange rate and interest rate, or exchange rate alone, or interest rate alone. Thus, one can derive the simple interest rate rule by rearranging Equation 8. This yields:

$$r_{g_t} = \left(\frac{\alpha_1 + \alpha_2}{\lambda_1}\right)y_{g_t} + \left(\frac{\beta_{\pi_1}}{\lambda_1}\right)\pi_{g_t} - \left(\frac{\delta_1 + \delta_2}{\lambda_1}\right)e_{g_t} \tag{9}$$

Equation 9 is also known as a hybrid Taylor-type rule, and is a generalised monetary policy reaction function with coefficient of $y_{gt} > 0$ coefficient of $\pi_{gt} > 0$, and coefficient of $e_{gt} < 0$ (Hammermann, 2005); that is, the central bank can stabilise y_{gt} and π_{gt} by increasing r_{gt}, and can also stabilise e_{gt} by reducing r_{gt}. This equation can be written as the backward-looking model, which is given by

$r_{g_t} = \dot{\alpha} y_{g_{t-1}} + \dot{\beta}_{\pi} \pi_{g_{t-1}} - \dot{\delta} e_{g_{t-1}}$. Here, $\dot{\alpha}$ represents $(\alpha_1 + \alpha_2)/\lambda_1$, $\dot{\beta}_{\pi}$ represents $\beta_{\pi 1}/\lambda_1$, and $\dot{\delta}$ represents $(\delta_1 + \delta_2)/\lambda_1$. This backward-looking model has a similar form as Equation 4.

The variable in the gap form, can reflect the lack of knowledge and uncertainty (American Institute of Aeronautics and Astronautics, 1998). For the economic uncertainty model's constructions, this study assumes that the gap variable implies uncertainty. Thus, rearranging terms in Equation 8 such that $(\alpha_1 + \alpha_2) y_{g_t} + \beta_{\pi_1} \pi_{g_t} - (\delta_1 + \delta_2) e_{g_t} - \lambda_1 r_{g_t} = 0$, the left-hand side equation expresses the joint uncertainty components that lie on the domains of key economic variables. This expression can also be written as the basic economic uncertainty index model that encompasses the joint uncertainty components associated with gap variables; this is given by:

$$eu_t = \alpha_3 y_{g_t} + \beta_{\pi_2} \pi_{g_t} - \delta_3 e_{g_t} - \lambda_3 r_{g_t} \tag{10}$$ [8]

where eu_t is the economic uncertainty expressed as an index level, α_3 represents $\alpha_1 + \alpha_2$, $\beta_{\pi 2}$ represents $\beta_{\pi 1}$, δ_3 represents $\delta_1 + \delta_2$, and λ_3 represents λ_1. Note that, the economic uncertainty index (eu_t) can be negative, positive, or zero. A zero eu_t level implies that the macroeconomic conditions are close to its equilibrium position. A negative eu_t level implies that the macroeconomic conditions negatively deviate from the equilibrium path. Potential examples for such uncertainty include a large deflationary gap, excessive deflation, future currency depreciation, and long-term decline in interest rate.[9] From the above equation setting, $\alpha_3 > 0$, $\beta_{\pi 2} > 0$, $\delta_3 < 0$, and $\lambda_3 < 0$ describe, respectively, the relative relationships of y_g, π_g, e_g, and r_g to the eu. Thereby, Equation 10 captures the idea that a decline in the output gap, a reduction in inflation, a rise in interest rate, and a domestic currency appreciation can reduce economic uncertainty (see, e.g., Golob, 1994; Gan, 2014b; 2019 for further details).[10]

Because Equation 10 is not an optimal design, it cannot reach conclusions about the optimal policy. Indeed, the actual economic uncertainty data is unknown. The grid search algorithm can overcome these problems by constructing the optimal design for Equation 10, namely the optimal economic uncertainty index ($eu_t^{optimal}$) model (see Appendix A), that can be used to calculate the ($eu_t^{optimal}$) value. Given that the ($eu_t^{optimal}$) is at zero, the central bank's loss function (L) is equal to zero, and $eu_t = eu_t^{optimal} = 0$, the $eu_t^{optimal}$ model (i.e., Appendix A, Equation A.4) is similar in form to Equation 10. Thus, there is no harm in using Equation 10 to specify the optimal mitigation of economic uncertainty.

The Monetary Rules for Economic Uncertainty Elimination

Motivated by the previous section, this section augments the derived economic uncertainty index model, i.e., Equation 10, to yield monetary rules to eliminate unwanted economic uncertainty. Considering that the occurrence of a non-zero uncertainty level may indicate the presence of macroeconomic disequilibrium conditions, Equation 11 can help rectify this condition by eliminating the unwanted economic uncertainty through the combination of a set of monetary rules.

$$eu_{t+1}^{anti} = -\delta_3 e_{g_{t+1}}^{target} - \lambda_3 r_{g_{t+1}}^{target} \tag{11}$$

where eu_{t+1}^{anti}, $r_{g_{t+1}}^{target}$, and $e_{g_{t+1}}^{target}$ are the anti-economic uncertainty expressed as an index level, the target deviation of the real interest rate from its potential level, and the target deviation of the real exchange rate from its potential level, respectively. The $e_{g_{t+1}}^{target}$ and $r_{g_{t+1}}^{target}$ imply the target changes of the exchange rate and the interest rate to create eu_{t+1}^{anti}. In other words, the creation of the anti-economic uncertainty index (eu^{anti}) targeting occurs in period $t + 1$ and implies a temporal sequence of policy response to economic uncertainty at time t. The measures to derive monetary rules, namely $e_{g_{t+1}}^{target}$ and $r_{g_{t+1}}^{target}$, respectively, for the optimal use of operating targets, namely the exchange rate and the interest rate, are weighted with the help of the weights of the real exchange rate gap (δ_3) and the real interest rate gap (λ_3) in the economic uncertainty index model (Equation 10 in The Economic Uncertainty Index Model section). Note that, the optimal mitigation of economic uncertainty is required to eliminate economic uncertainty to satisfy macroeconomic conditions for equilibrium, which signifies that the central bank's loss function (L) is minimised, equal to zero. Thereby, eu_{t+1}^{anti} can eliminate the economic uncertainty index (eu_t) through the combination of the $e_{g_{t+1}}^{target}$ and $r_{g_{t+1}}^{target}$ in the sense that $eu_t + eu_{t+1}^{anti} = 0$. This is demonstrated in Equation 12.

$$\begin{aligned} eu_t + eu_{t+1}^{anti} &= \alpha_3 y_{g_t} + \beta_{\pi_2} \pi_{g_t} - \delta_3 \left(e_{g_t} + e_{g_{t+1}}^{target} \right) - \lambda_3 \left(r_{g_t} + r_{g_{t+1}}^{target} \right) \\ &= \alpha_3 y_{g_t} + \beta_{\pi_2} \pi_{g_t} - \delta_3 e_{g_t} - \lambda_3 r_{g_t} + \left(-\delta_3 e_{g_{t+1}}^{target} - \lambda_3 r_{g_{t+1}}^{target} \right) \end{aligned} \tag{12}$$

Equation 12 shows that the target changes in the exchange rate and the interest rate should be managed to reach $eu_t + \left(-\delta_3 e_{g_{t+1}}^{target} - \lambda_3 r_{g_{t+1}}^{target} \right) = 0$ and an anti-economic uncertainty index equals to:

$$eu_{t+1}^{anti} = -eu_t = -\delta_3 e_{g_{t+1}}^{target} - \lambda_3 r_{g_{t+1}}^{target} \tag{13}$$

Equation 13 shows that the anti-economic uncertainty index targeting of period $t + 1$ can rectify the deviation of the economic uncertainty index from zero in period t. Following the logic of Equation 13, a set of monetary rules can be derived, and it is given by the equations:

$$e_{g_{t+1}}^{target} = \frac{eu_t - \lambda_3 r_{g_{t+1}}^{target}}{\delta_3} \tag{14}$$

$$r_{g_{t+1}}^{target} = \frac{eu_t - \delta_3 e_{g_{t+1}}^{target}}{\lambda_3} \tag{15}$$

Equations 14 and 15 show that the use of operating targets can be said to be interdependent. Thus, to achieve the desired level of eu_t, the central bank can choose a combination of target changes in the interest rate and the exchange rate; in this study, the desired level of eu_t is zero. However, empirical evidence[11] reveals that the central bank cannot fine-tune the interest rate and the exchange rate simultaneously in open economies without considering foreign developments. The UIP expresses a condition relating interest differentials to an expected change in the domestic currency's spot exchange rate, i.e., $i_t - i_t^f = q_{g_t}$; let i_t^f, i_t, and q_{g_t} denote, respectively, the foreign nominal interest rate, the domestic nominal interest rate, and the nominal exchange rate in gap form [Note that, the gap form is the deviation between the actual level and its potential level]. For our purpose, one can transform the UIP mentioned above into its real counterpart. This transformation is done in Appendix B and yields for the target variables the following:

$$e_{g_{t+1}}^{target} = r_{t+1}^{target} - r_{t+1}^{f} \tag{16}$$

where r_{t+1}^{target} and r_{t+1}^{f} express, respectively, the target level of the real interest rate for period $t + 1$ and the foreign real interest rate for period $t + 1$. Because the r_{t+1}^{f} is usually unknown in reality, this study assumes the r_{t+1}^{f} is 2% for describing consistency policy rules in praxis.[12] This assumption makes the formation of capital transfer or trade weighted index of r_{t+1}^{f} dispensable. Inserting Equation 16 into Equations 14 and 15, while considering $r_{g_{t+1}}^{target} = r_{t+1}^{target} - r_t$ that can also express in the form of $r_{t+1}^{target} = r_{g_{t+1}}^{target} + r_t$. This yields:

$$e_{g_{t+1}}^{target} = \frac{eu_t - \lambda_3\left(r_{t+1}^{f} - r_t\right)}{\lambda_3 + \delta_3} \tag{17}$$

$$r_{g_{t+1}}^{target} = \frac{eu_t - \delta_3\left(r_t - r_{t+1}^{f}\right)}{\lambda_3 + \delta_3} \tag{18}$$

These changes in the $e_{g_{t+1}}^{target}$ and the $r_{g_{t+1}}^{target}$ ensure that $eu_t + eu_{t+1}^{anti} = 0$. To see this, assuming that a flagging economy lowered the eu_t to below zero, one can nullify this effect on the eu_{t+1}^{anti} by adding the eu_t again, as is done in Equation 13. This, in turn, means that the change required in the eu_t to reach the eu_{t+1}^{anti}, equals $-\delta_3 e_{g_{t+1}}^{target} - \lambda_3 r_{g_{t+1}}^{target}$, where the values of $e_{g_{t+1}}^{target}$ and $r_{g_{t+1}}^{target}$ are determined by Equations 17 and 18, respectively. In other words, the change required in the eu_t (brought about by $-\delta_3 e_{g_{t+1}}^{target} - \lambda_3 r_{g_{t+1}}^{target}$) equals the negative of the non-zero value of the eu_t to ensure that the eu_t returns to zero in period $t + 1$. The process above corresponds to the simple policy rule of keeping the eu_t constant at zero, so that $eu_{t+1}^{anti} = 0$. Hence, to eliminate the eu_t via the eu_{t+1}^{anti}, the derived rules—the $r_{g_{t+1}}^{target}$ and the $e_{g_{t+1}}^{target}$—are optimal.

Overall, the derived monetary rules for operating targets do not differ from the central bank's monetary policy convention. $r_{g_{t+1}}^{target}$ and $e_{g_{t+1}}^{target}$ imply the interest rate targeted through the open market operations by fine-tuning interest rate levels and the exchange rate targeted through the sterilised intervention operations by fine-tuning exchange rate levels, respectively. A caveat remains for the $e_{g_{t+1}}^{target}$: an act of appreciation or depreciation avoidance in the exchange rate with dependence on sterilised intervention operations is unavoidably expensive. While the caveat is in place, the central bank can create a buffer stock of its foreign assets or obtain bailout loans from the IMF (United Nations, 2002). Usually, the IMF acts as an international lender of last resort.

DATA AND ESTIMATIONS

In this section, we present the empirical application. It contains descriptions of the data and estimation results.

Data Description

This paper uses quarterly data for the period from quarter 1, 1994 to quarter 1, 2020. It covers 14 selected countries, namely Australia, Canada, China, Hong Kong, India, Indonesia, Japan, Malaysia, Philippines, Singapore, South Korea, Thailand, the United Kingdom (U.K.) and the U.S. Data sources are mainly from the Bank for International Settlements (BIS) Statistics published by BIS, Datastream, and International Financial Statistics (IFS) published by the IMF. There are four variables:

1. Consumer price index (CPI):

   The CPI time series data are obtained from the IFS. The inflation rate is calculated by the formula:

   $$inflation\,rate = \frac{(CPI_{current\ period} - CPI_{base\ period}) \times 100}{CPI_{base\ period}}.$$

2. Real output:
   A proxy for the real output is the real gross domestic product (GDP). The real GDP is calculated by the formula: $real\ GDP = nominal\ GDP / CPI_{current\ period}$; the nominal GDP time series data are obtained from both the Datastream and the IFS.

3. Real exchange rate:

   A proxy for the real exchange rate is the real effective exchange rate (REER). The REER time series data are taken from the BIS Statistics.

4. Real interest rate:

   A proxy for the real interest rate is the real money market rate (MMR). The real MMR is calculated by the formula: $real\,MMR = nominal\,MMR - inflation\,rate$; the nominal MMR time series data are obtained from the IFS.

For the purpose of research, the inflation gap (i.e.,π_g) is obtained by taking the difference between the inflation rate's actual level and its potential level. The real output gap (i.e., y_g) is obtained by taking the difference between the logged time series of the actual level of real output and its potential level and then multiplying by 100. The real exchange rate gap (i.e., e_g) is obtained by taking the difference between the logged time series of the actual level of real exchange rate and its potential level and then multiplying by 100. The real interest rate gap (i.e., r_g) is obtained by taking the difference between the actual level of real interest rate and its potential level. Note that, this paper selects the smoothing parameter of 1600 in the Hodrick Prescott filter to construct the potential level. The Kwiatkowski-Phillips-Schmidt-Shin (KPSS) stationarity test and the Phillips-Perron (PP) unit root test are employed to examine the existence of a unit root for all-time series variables. The former has the null hypothesis of stationarity versus the alternative of a unit root, whereas the latter has the null hypothesis of a unit root versus the alternative of stationarity. Table 1 reports the KPSS and PP statistics per country. In all cases, both the KPSS and PP statistics suggest the nonexistence of a unit root at level. All time-series variables are $I(0)$; $I(0)$ denotes integration of order zero.

Table 1
KPSS and PP unit root tests for variables in level

Countries	Variables							
	π_g		y_g		e_g		r_g	
	KPSS	PP	KPSS	PP	KPSS	PP	KPSS	PP
Australia	0.036 (0)	–9.133** (1)	0.041 (6)	–3.727** (7)	0.035 (6)	–3.586** (8)	0.031 (5)	–5.858*** (2)
Canada	0.011 (0)	–10.39*** (3)	0.029 (6)	–3.589** (4)	0.039 (6)	–4.234*** (3)	0.032 (7)	–5.176*** (7)
China	0.117 (8)	–7.426*** (9)	0.057 (12)	–18.91*** (12)	0.044 (6)	–3.937** (0)	0.097 (7)	–7.679*** (9)
Hong Kong	0.044 (8)	–12.28*** (7)	0.034 (9)	–7.824*** (9)	0.038 (6)	–3.835** (3)	0.036 (8)	–8.276*** (8)
India	0.035 (6)	–10.74*** (5)	0.051 (7)	–4.313*** (6)	0.024 (5)	–4.106*** (3)	0.024 (1)	–7.392*** (2)
Indonesia	0.021 (2)	–5.174*** (7)	0.035 (6)	–3.508** (0)	0.033 (3)	–3.473** (8)	0.028 (6)	–4.144*** (5)
Japan	0.027 (6)	–12.71*** (5)	0.037 (6)	–3.602 ** (3)	0.034 (7)	–3.640** (5)	0.037 (6)	–12.09*** (6)
Malaysia	0.069 (15)	–11.38*** (16)	0.031 (4)	–5.543*** (5)	0.028 (6)	–3.694 ** (2)	0.042 (6)	–6.063*** (4)
Philippines	0.031 (6)	–9.845*** (3)	0.049 (12)	–23.36*** (10)	0.037 (6)	–4.025** (3)	0.026 (2)	–7.511*** (2)
Singapore	0.027 (1)	–7.696*** (0)	0.040 (6)	–4.405*** (6)	0.047 (7)	–3.921** (3)	0.032 (5)	–5.019*** (2)
South Korea	0.01 (0)	–10.93*** (0)	0.041 (6)	–3.708** (3)	0.034 (6)	–3.879** (2)	0.033 (4)	–4.417*** (8)

(*Continued on next page*)

Table 1 (*Continued*)

Countries	Variables							
	π_g		y_g		e_g		r_g	
	KPSS	PP	KPSS	PP	KPSS	PP	KPSS	PP
Thailand	0.043 (7)	–7.734*** (6)	0.061 (7)	–4.128*** (2)	0.030 (2)	–4.575*** (2)	0.033 (5)	–4.344*** (1)
The U.K.	0.053 (9)	–14.82*** (7)	0.053 (7)	–3.626** (4)	0.035 (7)	–3.576** (4)	0.041 (7)	–5.842** (8)
The U.S.	0.019 (2)	–9.102*** (3)	0.039 (8)	–3.289* (6)	0.038 (6)	–4.124*** (5)	0.036 (7)	–4.550*** (7)

Notes: The null hypotheses for both KPSS and PP tests are defined as the presence of a stationary and a unit root, respectively. *, **, and *** indicate rejection of the null hypothesis at the 10%, 5%, 1% levels, respectively. Numbers in the parentheses, i.e., [ ], indicate the optimal bandwidth. These numbers are determined using the Bartlett kernel with Newey-West automatic bandwidth selection.

(*Source*: Own calculations using software package EViews version 12.0)

Optimal Estimation of the Economic Uncertainty Index

This section gives results to evaluate the optimal estimating model of economic uncertainty that can be used to calculate the economic uncertainty index and that can use in the optimal mitigation of economic uncertainty in the next subsection. The grid search procedure determines the optimal economic uncertainty index model in a class of estimation functions given by a simple open economy model that can yield the optimal economic uncertainty index; detailed expositions of this optimal estimating procedure are in Appendix A. For our purpose, this study uses the system generalised method of moments (GMM) method to obtain sets of estimated parameters of a simple structural model outlined in the subsection of The Economic Uncertainty Index Model as inputs for the calibration grid.[13] This method has been widely used in empirical studies in estimating a simple structural model (e.g., Smets, 2003; Han, 2014; Gan, 2018).[14] Due to space limitations, this paper does not reiterate the empirical specification of system GMM.[15] Table 2 shows the system GMM estimates of parameters of the simple open economy model. The results suggest that all estimated parameters are statistically significant and have correct signs. The results also suggest that the estimated model has valid instrumentation. Overall, the results support the theoretical expectation of the simple open economy model presented in the subsection of The Economic Uncertainty Index Model.

Table 2
System GMM estimates for the simple open economy model

Dependent variables	Independent variable(s)	Parameters	Countries						
			Australia	Canada	China	Hong Kong	India	Indonesia	Japan
y_{g_t}	$y_{g_{t-1}}$	α_1	0.701 *** (0.057)	1.002 *** (0.080)	0.250** (0.109)	0.079** (0.037)	1.660*** (0.130)	1.272*** (0.999)	0.553*** (0.042)
	$r_{g_{t-1}}$	λ_1	–0.203 ** (0.085)	–0.106* (0.064)	–2.355** (1.084)	–1.051** (0.571)	–0.120*** (0.032)	–0.241*** (0.077)	–0.343*** (0.080)
	$e_{g_{t-1}}$	δ_1	–0.033 * (0.019)	–0.169 ** (0.073)	–1.529*** (0.286)	–0.977 *** (0.137)	–0.886 *** (0.173)	–0.120 * (0.063)	–0.012 * (0.007)
π_{g_t}	$y_{g_{t-1}}$	α_2	0.075 *** (0.010)	0.076 *** (0.012)	0.091*** (0.004)	0.066*** (0.007)	0.207 *** (0.018)	0.434 *** (0.038)	0.113 *** (0.013)
	$\pi_{g_{t-1}}$	β_{π_1}	0.059 * (0.034)	0.133 *** (0.031)	0.338 *** (0.029)	0.358*** (0.076)	0.096 ** (0.039)	0.173 ** (0.075)	0.247 ** (0.108)
	$e_{g_{t-1}}$	δ_2	–0.017 *** (0.003)	–0.039 *** (0.008)	–0.055 *** (0.011)	–0.067 *** (0.009)	–0.045 *** (0.011)	–0.085 *** (0.016)	–0.006 ** (0.003)
e_{g_t}	r_{g_t}	λ_2	1.156 *** (0.359)	1.660 *** (0.322)	0.354 ** (0.161)	0.313 *** (0.062)	0.193 *** (0.042)	0.312 * (0.169)	2.180 *** (0.719)
r_{g_t}	$y_{g_{t-1}}$	α_4	0.165 *** (0.039)	0.449 *** (0.036)	0.253 *** (0.066)	0.061 ** (0.029)	0.704 *** (0.077)	0.173 ** (0.083)	0.138 * (0.079)
	$\pi_{g_{t-1}}$	β_{π_3}	0.631 *** (0.062)	0.116 * (0.066)	0.309 * (0.185)	0.327 *** (0.088)	0.511 *** (0.077)	1.199 *** (0.095)	0.968 *** (0.092)
	$e_{g_{t-1}}$	δ_4	–0.064 *** (0.018)	–0.035 ** (0.017)	–0.307 * (0.185)	–0.122 ** (0.056)	–0.059 *** (0.022)	–0.071 ** (0.028)	–0.024 ** (0.010)
	J-statistic		0.223	0.178	0.187	0.233	0.248	0.113	0.230
	nJ-statistic		21.81	18.00	18.84	22.15	23.58	11.44	21.64
	p-value		0.747 #	0.522 #	0.467 #	0.924 #	0.929 #	0.721 #	0.867 #

(*Continued on next page*)

Table 2 (*Continued*)

Dependent variables	Independent variable(s)	Parameters	Countries						
			Malaysia	Philippines	Singapore	South Korea	Thailand	The U.K.	The U.S.
y_{g_t}	$y_{g_{t-1}}$	α_1	0.963*** (0.065)	0.302* (0.183)	0.701*** (0.024)	0.798*** (0.039)	0.965*** (0.048)	1.410*** (0.179)	0.877*** (0.031)
	$r_{g_{t-1}}$	λ_1	–0.244* (0.133)	–2.712*** (0.550)	–0.494*** (0.145)	–0.509*** (0.033)	–0.860*** (0.079)	–0.927*** (0.257)	–0.098** (0.043)
	$e_{g_{t-1}}$	δ_1	–0.132** (0.061)	–0.438*** (0.125)	–0.442 *** (0.048)	–0.038* (0.023)	–0.078*** (0.022)	–0.181* (0.094)	–0.021** (0.010)
π_{g_t}	$y_{g_{t-1}}$	α_2	0.045*** (0.004)	0.031*** (0.002)	0.028 *** (0.004)	0.131*** (0.012)	0.076*** (0.010)	0.128*** (0.017)	0.108 ** (0.052)
	$\pi_{g_{t-1}}$	β_{π_1}	0.071** (0.032)	0.345*** (0.012)	0.193 *** (0.033)	0.126* (0.075)	0.223*** (0.080)	0.535* (0.299)	0.221** (0.091)
	$e_{g_{t-1}}$	δ_2	–0.027*** (0.004)	–0.024*** (0.001)	–0.081 *** (0.008)	–0.012*** (0.004)	–0.014*** (0.005)	–0.023*** (0.005)	–0.198* (0.108)
e_{g_t}	r_{g_t}	λ_2	1.066* (0.587)	0.942*** (0.189)	1.491*** (0.302)	0.651* (0.390)	0.750*** (0.132)	1.174*** (0.225)	0.330* (0.191)
r_{g_t}	$y_{g_{t-1}}$	α_4	0.100*** (0.031)	0.133*** (0.022)	0.168*** (0.050)	0.352*** (0.034)	0.224*** (0.031)	1.511*** (0.401)	0.436*** (0.034)
	$\pi_{g_{t-1}}$	β_{π_3}	0.968*** (0.277)	0.246*** (0.081)	0.669*** (0.222)	1.026*** (0.077)	0.532*** (0.065)	1.818*** (0.419)	0.135*** (0.047)
	$e_{g_{t-1}}$	δ_4	–0.220*** (0.052)	–0.054** (0.023)	–0.164* (0.095)	–0.043*** (0.010)	–0.100*** (0.027)	–0.184*** (0.110)	–0.094*** (0.014)
	J-statistic		0.179	0.199	0.178	0.183	0.169	0.149	0.183
	nJ-statistic		18.07	20.05	18.02	18.50	17.03	15.08	18.54
	p-value		0.582 #	0.998 #	0.996 #	0.857 #	0.317 #	0.956 #	0.293 #

Notes: ***, **, and * denote 1%, 5%, and 10% significance levels, respectively. () is the standard error. Instrumental variables used are lagged values of y_g, π_g, e_g, and r_g. Because the J – statistic reported in EViews is not multiplied by number of observations (i.e.,), the J –statistic times the can be used to examine the null hypothesis of valid overidentifying restrictions; # indicates no rejection of the null hypothesis at the 5% level.

Source: Own calculations using software package EViews version 12.0

In the grid search procedure, the structural model in matrix form, as in Appendix A, Equation A.2, is calibrated with the obtained sets of estimated parameters from Table 2 and the central bank's preference parameters of the loss function; see Appendix A for details on the grid search procedure.[16] From Table 3, the obtained results of the grid search procedure include the best parameter estimates (i.e., $\alpha_3^{optimal}$, $\beta_{\pi_2}^{optimal}$, $\delta_3^{optimal}$, and $\lambda_3^{optimal}$), the loss function (L) values, and the optimal economic uncertainty index model; the optimal economic uncertainty index model contains the best parameter estimates. The estimated optimal economic uncertainty index model can then calculate the optimal economic uncertainty index value over the sample period. This study uses the optimal economic uncertainty index ($eu_t^{optimal}$) as a proxy for the economic uncertainty index (eu_t), i.e., $eu_t^{optimal} = eu_t$, because the actual economic uncertainty data is unknown. The unit root tests of KPSS and PP in each country suggest that the time series data on the is $I(0)$.[17] To determine the credibility of the calculated indices as economic uncertainty measures, this study selects a benchmarking set of five notorious economic catastrophes and five-time windows of global recession for discussion (see Table 4).

Table 3

Optimal estimates of parameters, unconditional variances, losses, and optimal economic uncertainty index model

Preference parameters $\gamma_{\pi_g} = 1.0$, $\gamma_{y_g} = 1.0$, $\gamma_{r_g} = 25$	Australia	Canada	China	Hong Kong	India	Indonesia	Japan	Malaysia	Philippines	Singapore	South Korea	Thailand	UK	US
Optimal estimates of parameters														
$\alpha_3^{optimal}$	0.97	1.93	0.31	0.08	2.97	1.93	0.97	1.49	0.31	0.97	1.49	1.49	2.97	1.49
$\beta_{\pi_2}^{optimal}$	0.31	0.01	0.01	0.01	0.16	0.45	0.23	0.23	0.01	0.01	0.08	0.01	0.01	0.16
$\delta_3^{optimal}$	–0.53	–0.38	–1.49	–1.49	–0.97	–0.23	–0.90	–0.38	–0.97	–0.97	–0.90	–0.82	–0.97	–0.16
$\lambda_3^{optimal}$	–1.49	–0.68	–2.97	–0.97	–0.01	–0.31	–1.93	–0.90	–1.93	–0.97	–0.97	–0.97	–0.97	–0.90
Unconditional variances														
$Var\ (\pi_g)$	1.012	1.021	1.151	1.157	1.176	1.664	1.085	1.007	1.137	1.042	1.043	1.062	1.388	1.098
$Var\ (y_g)$	1.640	1.796	2.282	1.686	4.289	3.131	1.318	2.233	2.522	1.479	1.475	1.619	2.552	2.561
$Var\ (r_g)$	0.696	1.965	0.438	1.440	16.16	7.504	0.360	1.995	0.509	0.858	1.960	1.894	5.562	1.862
Loss function (L) values [a]	2.826	3.308	3.543	3.203	9.504	6.671	2.494	3.739	3.786	2.736	3.008	3.154	5.331	4.125

(*Continued on next page*)

Table 3 (*Continued*)

$eu_t^{optimal}$ [b]: selected countries			
Australia	$eu_t^{optimal} = 0.97y_{g_t} + 0.31\pi_{g_t} - 0.53e_{g_t} - 1.49r_{g_t}$	Malaysia	$eu_t^{optimal} = 1.49y_{g_t} + 0.23\pi_{g_t} - 0.38e_{g_t} - 0.90r_{g_t}$
Canada	$eu_t^{optimal} = 1.93y_{g_t} + 0.01\pi_{g_t} - 0.38e_{g_t} - 0.68r_{g_t}$	Philippines	$eu_t^{optimal} = 0.31y_{g_t} + 0.01\pi_{g_t} - 0.97e_{g_t} - 1.93r_{g_t}$
China	$eu_t^{optimal} = 0.31y_{g_t} + 0.01\pi_{g_t} - 1.49e_{g_t} - 2.97r_{g_t}$	Singapore	$eu_t^{optimal} = 0.97y_{g_t} + 0.01\pi_{g_t} - 0.97e_{g_t} - 0.97r_{g_t}$
Hong Kong	$eu_t^{optimal} = 0.08y_{g_t} + 0.01\pi_{g_t} - 1.49e_{g_t} - 0.97r_{g_t}$	South Korea	$eu_t^{optimal} = 1.49y_{g_t} + 0.08\pi_{g_t} - 0.90e_{g_t} - 0.97r_{g_t}$
India	$eu_t^{optimal} = 2.97y_{g_t} + 0.16\pi_{g_t} - 0.97e_{g_t} - 0.01r_{g_t}$	Thailand	$eu_t^{optimal} = 1.49y_{g_t} + 0.01\pi_{g_t} - 0.82e_{g_t} - 0.97r_{g_t}$
Indonesia	$eu_t^{optimal} = 1.93y_{g_t} + 0.45\pi_{g_t} - 0.23e_{g_t} - 0.31r_{g_t}$	The U.K.	$eu_t^{optimal} = 2.97y_{g_t} + 0.01\pi_{g_t} - 0.97e_{g_t} - 0.97r_{g_t}$
Japan	$eu_t^{optimal} = 0.97y_{g_t} + 0.23\pi_{g_t} - 0.90e_{g_t} - 1.93r_{g_t}$	The U.S.	$eu_t^{optimal} = 1.49y_{g_t} + 0.16\pi_{g_t} - 0.16e_{g_t} - 0.90r_{g_t}$

Notes: The results rely on $\gamma_{\pi g}, \gamma_{yg}$, and γ_{rg}. [a] loss function implies $L = \gamma_{\pi g} Var(\pi_g) + \gamma_{yg} Var(y_g) + \gamma_{rg} Var(r_g)$. [b] $eu_t^{optimal}$ indicates optimal economic uncertainty index model; $eu_t^{optimal} = \alpha_3^{optimal} y_{g_t} + \beta_{\pi_2}^{optimal} \pi_{g_t} - \delta_3^{optimal} e_{g_t} - \lambda_3^{optimal} r_{g_t}$.

Source: Own calculations using software package RATS version 10.0

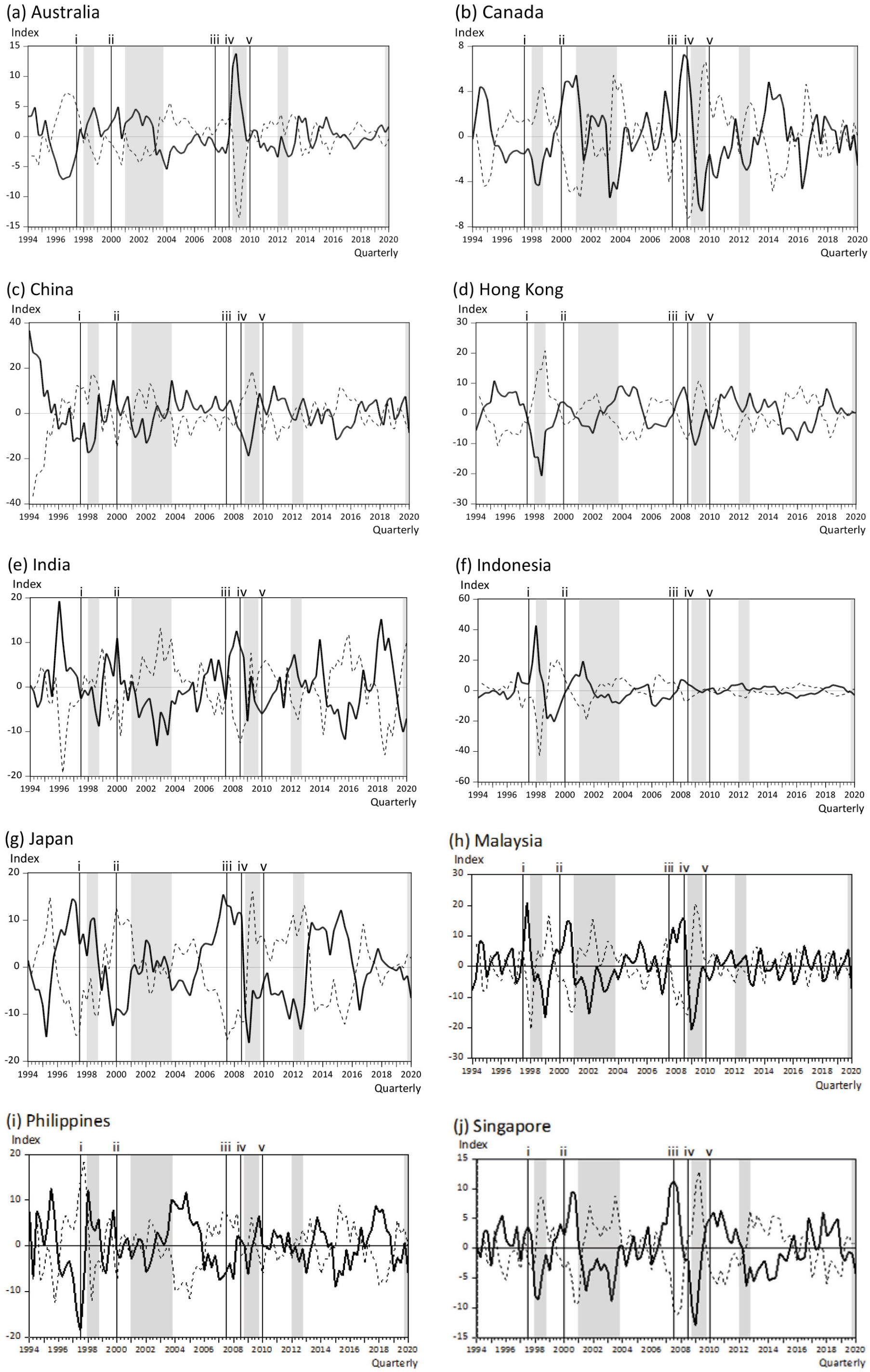
Table 4
Benchmarking set of economic catastrophes and windows of global recession

Events	Assumed start date[a]	Country of origin of the crisis	Sources[b]
Economic catastrophes:			
Asian financial crisis	1997Q3	Thailand	World Bank (1998)
Dot-com crisis	2000Q1	The U.S.	European Central Bank (2012)
Subprime crisis	2007Q3	The U.S.	BIS (2009)
Global financial crisis	2008Q3	The U.S.	BIS (2009)
Euro area (EU) debt crisis	2010Q1	Euro area	IMF (2018)

Events	Assumed time window[a]	Sources
Recessions:		
Aftermath of the Asian financial crisis	1998Q1 to 1998Q4	IMF (2007)
Aftermath of the dot-com bubble burst	2001Q1 to 2003Q4	IMF (2007)
Aftermath of the global financial crisis	2008Q4 to 2009Q4	IMF (2018)
Aftermath of the EU debt crisis	2012Q1 to 2012Q4	Kose and Ohnsorge (2020)
Coronavirus pandemic	2019Q4 to 2020Q2	IMF (2020)

Notes: [a] Q indicates quarter. [b] These sources are also available from the central bank's website of the country of origin of the crisis.

As shown in Figure 1, each country's solid line indicates that the economic uncertainty index throughout its development went through several phases from 1994 to 2020. For instance, Thailand is the country of origin for the Asian financial crisis. An easing of macroeconomic conditions before the crisis drives excessive optimism of Thailand's real economic prospects (World Bank, 1998). From Figure 1(I), the phase until approximately the third quarter of 1997 was attributed to the collapse of the Thai baht in July 1997 and marked the start of the Asian financial crisis. Precisely, the index reached its peak and plummeted in the first quarter of 1998.


(a) Australia
(b) Canada
(c) China
(d) Hong Kong
(e) India
(f) Indonesia
(g) Japan
(h) Malaysia
(i) Philippines
(j) Singapore
Index
i
ii
iii
iv
v
Quarterly

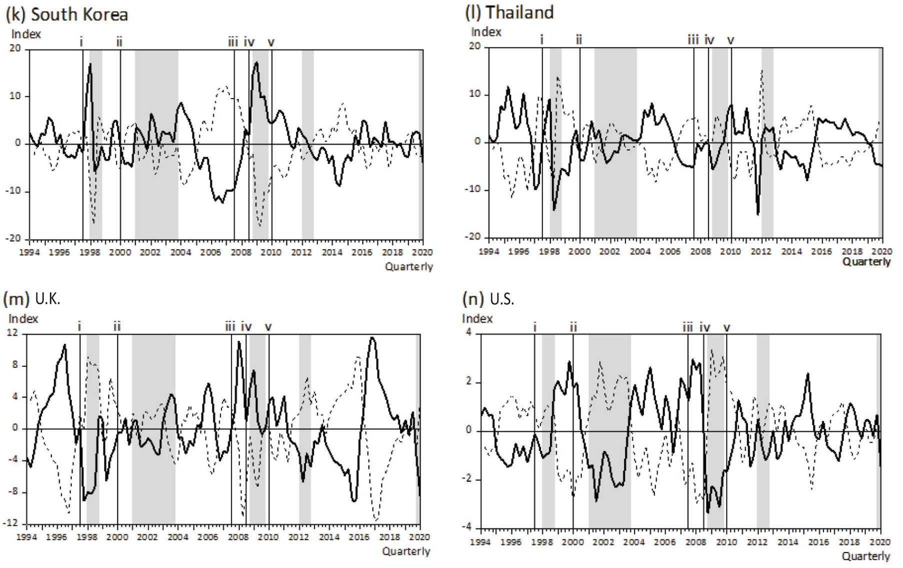


Figure 1. Economic uncertainty index (i.e., eu_t) and anti-economic uncertainty index (i.e., eu_{t+1}^{anti}) in 14 selected countries

Notes: —— and - - - - denote eu_t and eu_{t+1}^{anti} , respectively.

Number i, ii, iii, iv, and v denote five notorious economic catastrophes taken from various sources (see Table 4 for details); specifically, i indicates Asian financial crisis (1997Q3), ii indicates dot-com crisis (2000Q1), iii indicates subprime crisis (2007Q3), iv indicates global financial crisis (2008Q3), and v indicates EU debt crisis (2010Q1). The shaded areas represent time windows of the global recession taken from various sources; these time windows include 1998Q1–1998Q4, 2001Q1–2003Q4, 2008Q4–2009Q4, 2012Q1–2012Q4, and 2019Q4-2020Q1 (see Table 4 for details).

Source: Own calculations; these calculated values of and eu_{t+1}^{anti} are available in the supplemental material and online at https://drive.google.com/file/d/1pBzeRem2cvGeJ6QXze_b9UlygFX3Sumg/view?usp=drive_link

The U.S. is the country of origin for the dot-com bubble. From Figure 1(n) plot number (ii), the phase of economic uncertainty development until approximately the first quarter of 2000 was attributed to the dot-com bubble burst when the NASDAQ stock market crashed in March 2000. Additionally, the subprime mortgage market began to disrupt in late 2006, when lax mortgage-lending standards and rapid financial innovations created instability in mortgage financing. From Figure 1(n) plot number (iii), the phase of economic uncertainty development until approximately the third quarter of 2007 was attributed to the subprime crisis. The economic uncertainty index fluctuates around consistently high levels from late 2007 to early 2008, a period characterised by market bailout optimism. Unavoidably, the subprime crisis sparked the global financial crisis in September 2008 after the investment bank Lehman Brothers collapsed. From Figure 1(n) plot number (iv), the phase, one can perceive a sharp decline of the economic uncertainty index before and after the third quarter of 2008.

The EU debt crisis was triggered in early 2010 by Eurozone member states. Considering that the problem of data unavailability for some variables exists in the EU economies, this study uses the U.S. as a proxy to discuss the EU debt crisis.[18] From Figure 1(n) plot number (v), the phase, one can perceive negative economic uncertainty indices movement before and after the first quarter of 2010, exacerbated by the potential presence of contagious effects during the EU debt crisis. On the other hand, the coronavirus pandemic unleashes the worst economic recession from late 2019 to mid-2020. Economic activities contracted abruptly and almost simultaneously, as stay-at-home and lockdown policies forced businesses to close. From Figure 1, the resulting pandemic in all countries seems to cause the economic uncertainty index drop to below or near the zero index level after the fourth quarter of 2019.

In general, the above-mentioned crises affected the economic activity of the country of origin and subsequently spilled over to the global. Nearly all countries experienced a recession (shaded area) in crisis aftermath. The magnitude of distortion in non-crisis countries depends on the strength of their economic fundamentals and financial markets. Some findings can be drawn from the analysis. above. First, the conditions of the economic uncertainty were changing during the observation period. Given an economic uncertainty index of zero, each selected country's macroeconomic conditions were close to their equilibrium position in the defined periods; however, the macroeconomic conditions were away from their equilibrium or zero uncertainty position during periods of crisis, recession, and recovery. Second, the crisis and recession seem to be the important sources of spillovers to nearly all countries.

Estimation of the Optimal Mitigation of Economic Uncertainty

This section provides numerically precise estimates of the optimal mitigation of economic uncertainty. The combination of theoretically derived optimal mitigation of economic uncertainty with the empirical estimation of related information measures (e.g., optimal parameter estimates and optimal estimate of the economic uncertainty index; see see the subsection of Optimal Estimation of the Economic Uncertainty Index) can yield specific monetary rules for operating targets in eliminating economic uncertainty. In the context of optimal mitigation of economic uncertainty, the derived monetary rules are the target changes of the interest rate ($r_{g_{t+1}}^{target}$) and the exchange rate ($e_{g_{t+1}}^{target}$) (see the subsection of The Monetary Rules for Economic Uncertainty Elimination). The measures to derive $e_{g_{t+1}}^{target}$ and $r_{g_{t+1}}^{target}$ consider the current development in the economic uncertainty index (eu_t), the inter-temporal interest rate differential between the foreign and domestic economies, and the parameters of the real exchange rate gap (δ_3) and the real interest rate gap (λ_3); this study uses $\delta_3^{optimal}$ and $\lambda_3^{optimal}$ as proxies for δ_3 and λ_3, respectively, obtaining from the subsection of Optimal Estimation of the Economic Uncertainty Index, Table 3. Consider the following example, which illustrates the application of optimal mitigation of economic uncertainty in the U.S.

$$e_{g_{t+1}}^{target} = \frac{eu_t - 0.9\left(r_{t+1}^f - r_t\right)}{0.9 + 0.16} \tag{17a}$$

$$r_{g_{t+1}}^{target} = \frac{eu_t - 0.16\left(r_t - r_{t+1}^f\right)}{0.9 + 0.16} \tag{18a}$$

Equations 17a and 18b specify rules for the use of operating targets – the exchange rate and the interest rate, eu_t and domestic real interest rate were predetermined for the period of observation.

From the equations, we can calculate the $e_{g_{t+1}}^{target}$ and the $r_{g_{t+1}}^{target}$ for any time during the period of observation. As an example, we consider the operating target values for the fourth quarter of 2019. To calculate the targets, the following information is required:

1. eu_t of the fourth quarter 2019 = 0.67460
2. Domestic real interest rate in the fourth quarter 2019 = 1.430%
3. Foreign real interest rate = 2%

Inserting the example into Equations 17 and 18 yields:

$$e_{g_{2020:1}}^{target} = \frac{0.67460 - 0.9\left(2 - 1.43\right)}{0.9 + 0.16} = 0.15245 \tag{17b}$$

$$r_{g_{2020:1}}^{target} = \frac{0.67460 - 0.16\left(1.43 - 2\right)}{0.9 + 0.16} = 0.72245 \tag{18b}$$

In the example period, the eu_t shows that the macroeconomic conditions positively deviate from the equilibrium path.

$$eu_{2019:4} = 0.67460$$

To counteract the positive eu_t measure, the central bank can tighten its operating targets (i.e., the exchange rate and the interest rate) to keep the

eu_t constant at zero through targeted anti-economic uncertainty index for the following period (eu_{t+1}^{anti}); see Equation 11. The calculated $e_{g_{t+1}}^{target}$ (appreciate the real exchange rate by 0.2%) and the $r_{g_{t+1}}^{target}$ (increase the real interest rate by 0.7%) can help reach the target eu_{t+1}^{anti} that eliminates the unwanted economic uncertainty, i.e., $eu_t + eu_{t+1}^{anti} = 0$.

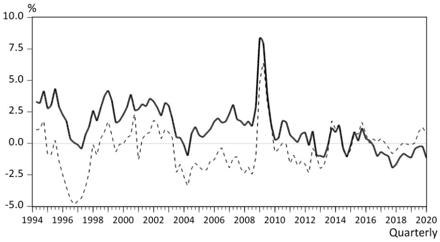
$$eu_{2020:1}^{anti} = -\delta_3 e_{g_{2020:1}}^{target} - \lambda_3 r_{g_{2020:1}}^{target} = -0.16\left(0.15245\right) - 0.9\left(0.72245\right) = -0.67460$$

For our purpose, the central bank can fine-tune the interest rate and the exchange rate simultaneously in open economies by considering foreign developments (see Equation 16 for more details). Therefore, the optimal use of operating targets obtained from the derived monetary rules fulfils interest parity simultaneously, e.g., the real target exchange rate appreciation equals the difference between domestic real interest rate and foreign real interest rate.

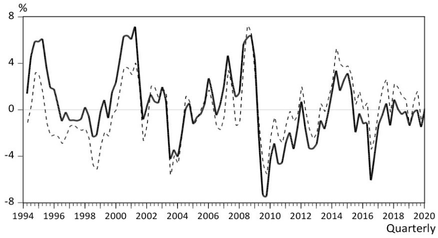
$$e_{2020:1}^{target} = r_{2020:1}^{target} - r_{2020:1}^{f} = 0.15245 = \left(0.72245 + 1.430\right) - 2$$

The estimation procedure is repeated for 14 selected countries over the sample period. To show the reaction between eu_{t+1}^{anti} and eu_t, the time series plots of eu_{t+1}^{anti} are presented in Figure 1. The dashed line plots the eu_{t+1}^{anti} for each country, which indicates that the eu_{t+1}^{anti} can nullify the unwanted eu_t. Furthermore, Figure 2 illustrates the target changes of the exchange rate ($e_{g_{t+1}}^{target}$) and the interest rate ($r_{g_{t+1}}^{target}$); $e_{g_{t+1}}^{target}$ and $r_{g_{t+1}}^{target}$ are indicated by the solid line and dashed line, respectively. Every country seems to have struggled to contain single-digit quarterly changes of $e_{g_{t+1}}^{target}$ and $r_{g_{t+1}}^{target}$ corresponding to monetary policy conventions. The quarterly changes in $r_{g_{t+1}}^{target}$ can be negative, near-zero, or zero that do not vary much from controlling key policy rates in some countries, such as Japan, the U.K. and the U.S. [19]

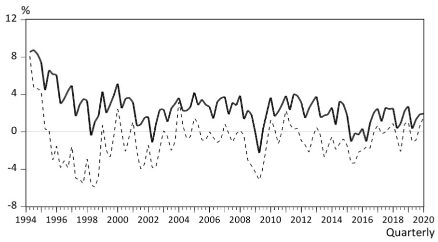
(a) Australia



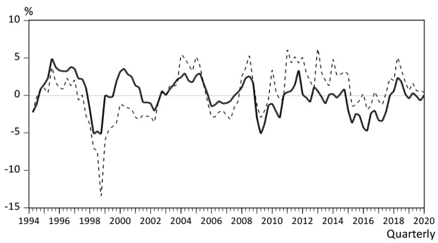
(b) Canada



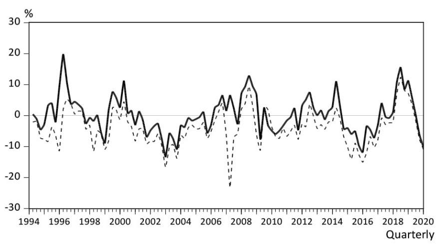
(c) China



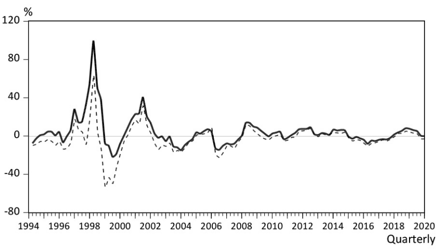
(d) Hong Kong



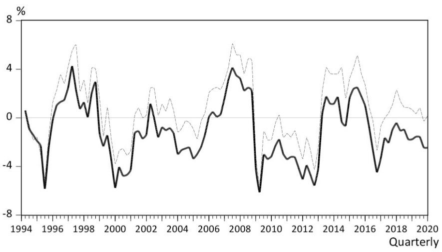
(e) India



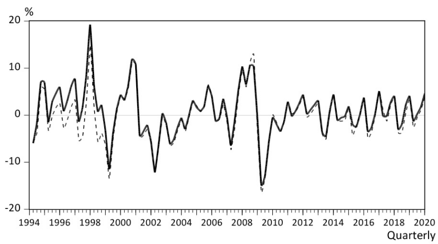
(f) Indonesia



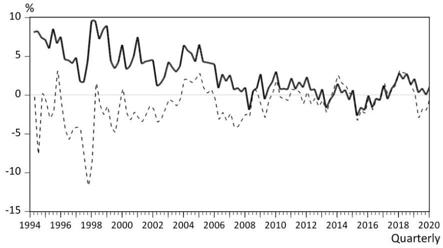
(g) Japan



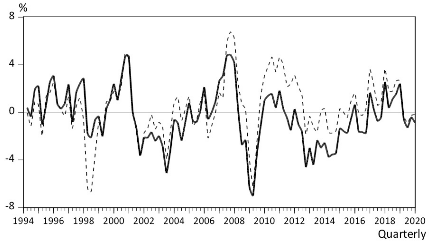
(h) Malaysia



(i) Philippines



(j) Singapore



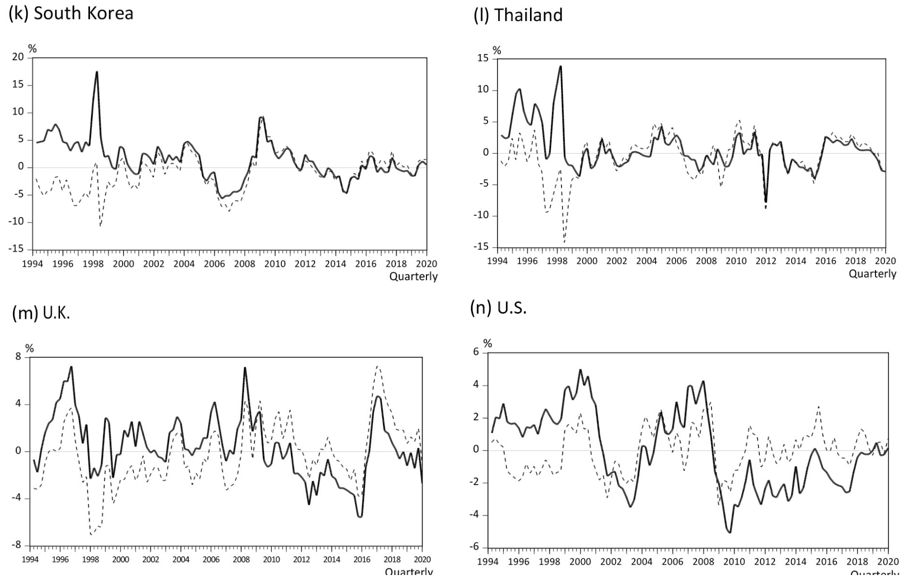


Figure 2. Target changes of the exchange rate (i.e., $e_{g_{t+1}}^{target}$) and the interest rate (i.e., $r_{g_{t+1}}^{target}$) in 14 selected countries

Notes: —— and - - - - denote $e_{g_{t+1}}^{target}$ and $r_{g_{t+1}}^{target}$, respectively.

Source: Own calculations; these calculated values of $e_{g_{t+1}}^{target}$ and $r_{g_{t+1}}^{target}$ are available in the supplemental material and online at https://drive.google.com/file/d/1pBzeRem2cvGeJ6QXze_b9UlygFX3Sumg/view?usp=drive_link

The paper also evaluates whether the premise of the optimal mitigation of economic uncertainty holds for the 14 selected countries. Following the logic of Equation 13 (see the subsection of The Monetary Rules for Economic Uncertainty Elimination), the paper examines the response function for the eu_t subjected to changes of $e_{g_{t+1}}^{target}$ and $r_{g_{t+1}}^{target}$, i.e., $eu_t = \delta_3 e_{g_{t+1}}^{target} + \lambda_3 r_{g_{t+1}}^{target}$, using the bivariate vector autoregression (VAR) approach. Note that we replace $\widehat{\delta_3}$ and $\widehat{\lambda_3}$ for δ_3 and λ_3, respectively, in $eu_t = \delta_3 e_{g_{t+1}}^{target} + \lambda_3 r_{g_{t+1}}^{target}$ for the VAR model estimation purposes, and it becomes $eu_t = \widehat{\delta_3}\, e_{g_{t+1}}^{target} + \widehat{\lambda_3} r_{g_{t+1}}^{target}$. In addition, this paper determines the unidirectional causality from $e_{g_{t+1}}^{target}$ to eu_t and $r_{g_{t+1}}^{target}$ to eu_t using the Granger causality test. From Table 5, the summary results of the bivariate VAR model show that the eu_t responds to both $e_{g_{t+1}}^{target}$ and $r_{g_{t+1}}^{target}$ innovations. The estimates of $\widehat{\delta_3}$ and $\widehat{\lambda_3}$ are all significant and have the expected signs; these signs are positive. Furthermore, the causality test results show that the directions of causality from $e_{g_{t+1}}^{target}$ to eu_t and $r_{g_{t+1}}^{target}$ to eu_t in each country are significant. These results suggest that the interest rate and exchange rate are the decisional targets of the central bank.

Table 5

Summary measures of the bivariate VAR model and bivariate Granger causality test

Countries	Method: Bivariate VAR model Dependent Variable:		Method: Bivariate Granger causality; F-Statistic	
	Coefficient		Null Hypothesis:	
	$\hat{\delta}_3$	$\hat{\lambda}_3$	$e_{g_{t+1}}^{target}$ does not Granger cause eu_t	$r_{g_{t+1}}^{target}$ does not Granger cause eu_t
Australia	0.985 ** (6) ⟨0.468⟩	2.252* (1) ⟨1.304⟩	5.433## [1]	5.387 ## [1]
Canada	1.019 ** (3) ⟨0.511⟩	1.355 ** (5) ⟨0.658⟩	7.206 ### [1]	12.28 ### [1]
China	2.636 *** (7) ⟨0.919⟩	4.351 ** (1) ⟨1.908⟩	2.695 ## [6]	7.278 ### [2]
Hong Kong	1.474 * (14) ⟨0.844⟩	1.816 * (9) ⟨0.708⟩	11.75 ### [1]	2.826 ## [4]
India	23.09 * (3) ⟨12.03⟩	0.255 ** (1) ⟨0.124⟩	3.486 ## [4]	2.484 # [3]
Indonesia	0.965 *** (1) ⟨0.233⟩	2.444 *** (2) ⟨0.330⟩	5.835 ## [1]	2.714 # [2]
Japan	2.367 * (8) ⟨1.326⟩	5.877 * (3) ⟨3.015⟩	7.183 ### [1]	4.716 ## [1]
Malaysia	2.009 ** (7) ⟨0.876⟩	3.225 * (5) ⟨1.937⟩	2.650 # [2]	2.763 # [2]
Philippines	1.331 * (7) ⟨0.677⟩	0.583 *** (15) ⟨0.215⟩	2.992 ## [3]	4.360 ### [6]

(*Continued on next page*)

Table 5 (*Continued*)

Countries	Method: Bivariate VAR model Dependent Variable: Coefficient		Method: Bivariate Granger causality; F-Statistic Null Hypothesis:	
	$\hat{\delta}_3$	$\hat{\lambda}_3$	$e_{g_{t+1}}^{target}$ does not Granger cause eu_t	$r_{g_{t+1}}^{target}$ does not Granger cause eu_t
Singapore	1.828 * (5) ⟨1.047⟩	1.392 ** (4) ⟨0.692⟩	2.559 $^{\#\#}$ [5]	7.094 $^{\#\#\#}$ [1]
South Korea	3.277 *** (2) ⟨1.155⟩	2.364 *** (1) ⟨0.823⟩	2.274 $^{\#}$ [5]	2.401 $^{\#\#}$ [6]
Thailand	1.230 ** (13) ⟨0.549⟩	1.837 * (2) ⟨1.068⟩	3.301 $^{\#\#}$ [3]	2.278 $^{\#}$ [4]
UK	2.341 * (16) ⟨1.364⟩	2.069 * (2) ⟨1.178⟩	2.015 $^{\#}$ [4]	4.568 $^{\#\#}$ [1]
US	0.491 * (3) ⟨0.265⟩	2.074 * (6) ⟨1.044⟩	2.427 $^{\#}$ [4]	2.448 $^{\#}$ [3]

Notes: ***, ** and * denote 1%, 5%, and 10% significance levels, respectively, presenting only the smallest significance level. ⟨ ⟩ denotes the standard error. Almost every country's VAR model estimation does not suffer from autocorrelation, heteroscedasticity, and non-normal distribution. These results are not contained in the above table because of space limitations but are available upon request. $^{\#\#\#}$, $^{\#\#}$ and $^{\#}$ indicate rejection of the null hypothesis of no Granger causality at the level of 1%, 5%, and 10%, respectively. ( ) and [ ] denote the best lag length for the bivariate VAR model and the optimal lag selection in Granger Causality tests, respectively; for the VAR model estimation, the Akaike information criterion (AIC) determines the optimal lag length.

(*Source*: Own calculations using software package EViews version 12.0)

Some findings can be drawn from the analysis. First, the derived monetary rules for operating targets prescribe that the anti-economic uncertainty index nullifies the unwanted economic uncertainty index. Thereby, the target changes of the interest rate and the exchange rate used for monetary policy instruments of open market operations and the sterilised intervention operations, respectively, help ensure the simultaneous achievement of internal and external equilibrium. Second, the negative, near-zero, or zero value of the target interest rate offers support for the existence of the negative interest rate policy or QE regime.[20] In the economics of catastrophic events, the interest rate can ally with the exchange rate on a combination or independently to mitigate a detrimental economic effect.

For policy implications, this paper suggests that the optimal mitigation of economic uncertainty can serve the central bank's objectives by: (1) acting as a good prescription tool to characterise the optimal use of policy rates—the interest rate and the exchange rate—to eliminate economic uncertainty and (2) providing a guiding monetary policy for restoring macroeconomic conditions of the equilibrium in the presence of economic uncertainty. These implications notwithstanding, the optimal mitigation measurement is not a perfect guidepost to halt economic uncertainty; instead, it can help make economic uncertainty less likely to occur and help mitigate economic disruptions to macroeconomic conditions. Nevertheless, this measurement can potentially provide better performance when coordinated with other fiscal and monetary authorities, namely the government, the financial regulatory authority, the financial supervisory authority, and the treasury.

CONCLUSIONS

This paper empirically evaluates the applicability of the optimal mitigation of economic uncertainty in a simple open economy model based on 14 selected countries. For application, it is useful to note that optimal mitigation of economic uncertainty helps promote the best macroeconomic outcomes. Thus, the optimal mitigation of economic uncertainty fulfils its role as (1) a good prescription tool to characterise the optimal use of policy rates—the interest rate and the exchange rate—to eliminate economic uncertainty and (2) a monetary policy guide in the adjustment process to restore macroeconomic conditions of the equilibrium. Without harm, this paper also suggests that the optimal economic uncertainty index is a good summary information instrument for characterising optimal macroeconomic conditions. This paper corroborates IMF's (2017) recommendation that the exchange rate, in addition to the interest rate, is the key shock absorber that deploys in case of disorderly market conditions. Moreover, the estimated economic uncertainty response function in the context of economic uncertainty elimination suggests that the interest rate and exchange rate are decisional targets of the central bank. This paper also provides evidence for the existence of the negative interest rate policy or QE regime, which can help attenuate catastrophic economic consequences.

This study has some limitations. First, the study contained only 14 selected countries and four uncertainty components in the economic uncertainty index model: real output, inflation, real exchange rate, and real interest rate. Future researchers may expand the scope of analysis to include other explanatory measures of uncertainty, such as changes in regulations, changes in technology, factor prices, and fiscal policy. In addition, it would be valuable in terms of robustness to replicate the analysis from this study in other countries. Second, future investigations can address whether or not the central bank can follow the recommended policy of eliminating unwanted economic uncertainty or whether the central bank should consider other targets or time patterns of targets. Third, other issues relating to the uncertainty in the computation of the economic uncertainty and the weakness in designing the optimal mitigation of economic uncertainty are factors to be considered for further research.

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NOTES

1. Economic uncertainty refers to a consciousness of limited knowledge about future economic events (Black et al., 2017).
2. Normative evaluation makes a value judgment or how the goal of a policy ought to be (Caplin & Schotte, 2008).
3. Open market operations imply that the purchase or sale of assets (i.e., domestic assets or foreign assets) by the central bank means changing the interest rate and the money supply.
4. Sterilised intervention operations enable control of exchange rate by equalising foreign (domestic) assets change through a follow-up change in domestic (foreign)

assets. These operations nullify their effect on the domestic money supply; these operations also refer to managed floating strategy (cf. Felix, 2004).

5. This study assumes the potential level is the expected level that prevails in the long run.
6. Cf. Gan (2014b) for further elaborations of the structural relationships among the variables.
7. Because the shocks are unknown, ε_t of Equation 1 and η_t of Equation 2 are not considered in the elimination process.
8. Note that one can also express Equation 10 using Equation 9.
9. A positive eu_t level implies that the macroeconomic conditions positively deviate from the equilibrium path; potential examples for such uncertainty include a large inflationary gap, excessive inflation, future currency appreciation, and long-term increase in interest rate.
10. Indeed, to move macroeconomic conditions towards its equilibrium, the remediation of a negative (positive) eu_t may need to be complemented by softer (tighter) economic policy measures.
11. For example, the empirical failure of UIP implies that the central bank cannot influence the interest rate, which can, in turn, affect the exchange rate (Engel, 2014; Leutert, 2018).
12. This study uses the U.S.'s equilibrium long-term real interest rate proposed by Taylor (1993), usually 2%, as a proxy of the foreign real interest rate, i.e., r_{t+1}^{f} .
13. Because the actual economic uncertainty data is unknown, the system GMM does not include the basic economic uncertainty index model (i.e., Equation 10); however, the optimal economic uncertainty data can be found through the grid search procedure's help, determining the optimal economic uncertainty index model.
14. The system GMM method is efficient in economics and finance studies, and its estimators are asymptotically normal and consistent (Zivot & Wang, 2006).
15. In this paper, the empirical specification of system GMM is identical to the empirical specification of system GMM shown in Gan (2018); see Gan (2018: 397) for details on the system GMM method.
16. These preference parameters for output, inflation, and interest rate stabilisations, namely γ_{π_g}, γ_{y_g}, and γ_{r_g} , are fixed to 1.0, 1.0, and 0.25, respectively; the values, i.e., $\gamma_{\pi_g} = 1.0$, $\gamma_{y_g} = 1.0$, and $\gamma_{r_g} = 0.25$, selected here are fairly typical (Jaaskela, 2005), though their feasibility remains debatable (Levin & Williams, 2003).
17. Due to space limitations, this paper does not present the results of KPSS and PP tests.
18. The U.S. is the world's leading financial centre. The occurrence of disruptions of global economic activity can influence local or foreign financial institutions, hedge funds, and private equity firms in the U.S.
19. Information regarding the key policy rate is also available on central banks' websites.
20. This regime is an extreme policy to create money to stimulate the economy, which is approachable when the central bank cannot use a conventional monetary expansion via a reduced interest rate when the interest rate is close to zero or equal to zero.

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APPENDIX A

Grid Search Procedure: Computational Details

This section illustrates the grid search algorithm for computing the optimal economic uncertainty index model, as proposed by Gan (2014b). Specifically, this grid search procedure helps estimate unknown parameters of the basic economic uncertainty index model, i.e., Equation 10, to determine the optimal economic uncertainty index model. The estimated optimal economic uncertainty index model comprises the best parameter estimates; this model can calculate the optimal economic uncertainty index value over the sample period.

The grid search procedure requires constructing the central bank's loss function and macro model; the loss function includes a combination of output, inflation, and interest rate stabilisation. From the subsection of The Economic Uncertainty Index Model, a simple open economy model consists of Equations 1, 2, 3 and 4 encompassing Equation 10 [Note that, Equations 1, 2, 3, 4 and 10 represent the investment-saving curve, the Phillips curve, an exchange rate model in reduced form, the central bank's reaction function, and a contemporaneous basic economic uncertainty index model, respectively], can serve as a basis for the application of the grid search [Note that, for simplicity of algorithm, a contemporaneous economic uncertainty index (eu_t) is added to Equation 4 (hereafter referred to as Equation A.1) to display a more stringent countercyclical policy on economic uncertainty; the central bank increases the interest rate to combat positive economic uncertainty that may be driven by joint uncertainty domains of key economic variables, e.g., an aggravation of output gap, accelerating inflation, a fall in interest rate, and domestic currency depreciation (cf. Gan, 2014b). An error term (ϖ) is added to Equation 10 to introduce the economic uncertainty shock; an error term denotes the variation in dependent variable that cannot be explained by the included independent variables.

$$r_{g_t} = \alpha_4 y_{g_{t-1}} + \beta_{\pi_3} \pi_{g_{t-1}} - \delta_4 e_{g_{t-1}} + eu_t + \varsigma_t \tag{A.1}$$

To employ this method, the structural model (i.e., Equations. 1, 2, 3, 10 and A.1) can be written in matrix form:

$$B_1 X_t = B_2 X_{t-1} + U_t \tag{A.2}$$

where:

$$B_1 = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & -\lambda_2 & 0 \\ -\alpha_3 & -\beta_{\pi_2} & \delta_3 & 1 & \lambda_3 & 0 \\ 0 & 0 & 0 & -1 & 1 & 0 \\ 0 & 0 & 0 & 0 & -1 & 1 \end{bmatrix}, \quad B_2 = \begin{bmatrix} \alpha_1 & 0 & -\delta_1 & 0 & -\lambda_1 & 0 \\ \alpha_2 & \beta_{\pi_1} & -\delta_2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ \alpha_4 & \beta_{\pi_3} & -\delta_4 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & 0 \end{bmatrix},$$

$$X_t = \begin{bmatrix} y_{g_t} \\ \pi_{g_t} \\ e_{g_t} \\ eu_t \\ r_{g_t} \\ \Delta r_{g_t} \end{bmatrix}, X_{t-1} = \begin{bmatrix} y_{g_{t-1}} \\ \pi_{g_{t-1}} \\ e_{g_{t-1}} \\ eu_{t-1} \\ r_{g_{t-1}} \\ \Delta r_{g_{t-1}} \end{bmatrix}, \text{and } U_t = \begin{bmatrix} \varepsilon_t \\ \eta_t \\ \upsilon_t \\ \varpi_t \\ \zeta_t \\ 0 \end{bmatrix}$$

Vector X and vector U contain, respectively, the variables and the disturbances of the structural model. The disturbances have mean zero and are not serially correlated [Note that, the covariance matrix of the disturbances associated with the structural model is given by $\Omega = E(UU')$]. This equation also includes an identity formula, namely $\Delta r_{g_t} = r_{g_t} - r_{g_{t-1}}$, to avoid an unrealistic condition of interest rate volatility. In matrix form, Equation A.2 can equivalently be written as

$$X_t = DX_{t-1} + W_t \tag{A.3}$$

with $D \equiv B_1^{-1} B_2$ and $W \equiv B_1^{-1} U_t$. The covariance matrix associated with the error terms (i.e., W) is then defined by $\Sigma = E(WW') = E((B_1^{-1} U_t)(B_1^{-1} U_t)') = B_1^{-1}\Omega(B_1^{-1})'$. Therefore, estimating the system of Equation A.2 comes to estimate D, W and U.

Consider, for aversion to the variability of the inflation gap (π_g), the output gap (y_g), and the real interest rate gap (r_g), that the central bank aims to minimise a loss function (L), subjects to a simple open economy model. Next, the optimisation procedure involves solving the following:

$$\begin{cases} \text{Minimise the loss function} & L = \gamma_{\pi_g} Var(\pi_g) + \gamma_{y_g} Var(y_g) + \gamma_{r_g} Var(r_g) \\ \{\alpha_3, \beta_{\pi_2}, \delta_3, \lambda_3\} & . \\ & . \\ \text{subject to} & X_t = DX_{t-1} + W_t \end{cases}$$

where γ_{π_g}, γ_{y_g}, and γ_{r_g} denote, respectively, the relative weight on inflation gap variability, the relative weight on output gap variability, and the relative weight on real interest rate gap variability. γ_{π_g}, γ_{y_g}, and γ_{r_g} also denote the preference parameters of the central bank. $Var(h)$ denotes the unconditional variance of a goal variable h with $h = \{\pi_g, y_g, r_g\}$. α_3, β_{π_2}, δ_3 and λ_3 are parameters of the basic economic uncertainty index model. The optimisation program consists of selecting the best parameters that give the smallest loss function value. The optimal design solution is then the optimal economic uncertainty index model. This optimal form's functional part contains the best parameter estimates (i.e., $\alpha_3^{optimal}$, $\beta_{\pi_2}^{optimal}$, $\delta_3^{optimal}$, and $\lambda_3^{optimal}$), which minimises L, given γ_{π_g}, γ_{y_g}, and γ_{r_g}; see Equation A.4.

$$eu_t^{optimal} = \alpha_3^{optimal} y_{g_t} + \beta_{\pi_2}^{optimal} \pi_{g_t} - \delta_3^{optimal} e_{g_t} - \lambda_3^{optimal} r_{g_t} \tag{A.4}$$

Let ϑ of X denote the unconditional contemporaneous/concurrent covariance matrix of X, following Svensson (2000), then its matrix form is given by

$$Vec\,(\vartheta) = [I - D \otimes D]^{-1}\, Vec\,(\Sigma) \tag{A.5}$$

This configuration allows us to obtain unconditional variances for π_g, y_g and r_g by taking the appropriate element in $Vec(\vartheta)$. $Var(\pi_g)$, $Var(y_g)$ and $Var(r_g)$ are then specified by the 1st, the 8th, and the 36th element of $Vec(\vartheta)$, respectively. To find the optimal economic uncertainty index model, given an unknown combination of α_3, β_{π_2}, δ_3, and λ_3, the method consists of solving the sequence:

$$(\alpha_3, \beta_{\pi_2}, \delta_3, \lambda_3) \Rightarrow D, W \text{ and } \Sigma \Rightarrow Vec(\vartheta) \Rightarrow L \tag{A.6}$$

In this paper, the estimation algorithm has been implemented in Regression Analysis of Time Series (RATS) analysis software; an example of the RATS computer codes for obtaining an optimal design solution that may yield the optimal economic uncertainty index model is available upon request.

APPENDIX B

Deriving Equation 16

The derivation of Equation 16 uses three standard assumptions as inputs. These inputs comprise the real exchange rate definition, the UIP form, and the Fisher effect, which are, respectively, Equations B.1, B.2 and B.3.

$$e_{g_t} = q_{g_t} + \pi_t^f - \pi_t \tag{B.1}$$

$$i_t - i_t^f = q_{g_t} \tag{B.2}$$

$$i_t = r_t + \pi_t \tag{B.3}$$

Let $e_{g_t}, q_{g_t}, \pi_t^f, \pi_t$, i_t^f, i_t, and r_t denote, respectively, the real exchange rate gap, the nominal exchange rate gap, the foreign inflation rate, the domestic inflation rate, the foreign nominal interest rate, the domestic nominal interest rate, and the real interest rate. The gap variable is the deviation between the actual level and its potential level. Note that, we may also need the Fisher effect for the foreign nominal interest rate to support the derivation of Equation 16, which can be obtained by combining relative purchasing power parity (henceforth, PPP) and UIP (Daniels & VanHoose, 2013). Equation B.4 expresses the relative PPP.

$$\pi_t - \pi_t^f = q_{g_t} \tag{B.4}$$

Combining Equation B.4 and Equation B.2, we have

$\pi_t - \pi_t^f = q_{g_t} = i_t - i_t^f$, or

$\pi_t - \pi_t^f = i_t - i_t^f$, or $i_t^f - \pi_t^f = i_t - \pi_t$, or

$$r_t^f = r_t \tag{B.5}$$

Let r_t^f denotes the foreign real interest rate. From Equation B.5, it can be seen that the Fisher effect for the foreign nominal interest rate is:

$$i_t^f = r_t^f + \pi_t^f \tag{B.6}$$

Hence, inserting Equations B.3 and B.6 into Equation B.2 yields:

$$q_{g_t} = r_t + \pi_t - r_t^f - \pi_t^f \tag{B.7}$$

Thus, inserting Equation B.7 into Equation B.1 yields:

$$e_{g_t} = r_t + \pi_t - r_t^f - \pi_t^f + \pi_t^f - \pi_t = r_t - r_t^f \qquad \text{(B.8)}$$

Proof

Equation B.8 becomes Equation 16 in the subsection of The Monetary Rules for Economic Uncertainty Elimination if one adapts the targeting element to the use of domestic policy variables, that is, the exchange rate and the interest rate, for period $t + 1$ in Equation B.8, which yields:

$$e_{g_{t+1}}^{target} = r_{t+1}^{target} - r_{t+1}^f \qquad \text{(16)}$$