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Exchange Rate – Price – Output Dynamics in an Inflation Targeting Small Open Economy: Analysis with A Modified Dornbusch Model

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Abstract

For the countries that apply inflation targeting monetary policy to maintain price stability the exchange rate pass-through effect on the inflation rate arises as a serious issue. Countries with a high import dependency in manufacturing and with high foreign debt stocks cannot leave exchange rates to market dynamics; therefore, their central banks use policy interest rates to control their exchange rates with fear of floating. In this study, a dynamic model based on the dynamic versions of the Mundell – Fleming and Dornbusch models is developed to analyze the dynamic behavior of output, price, and exchange rate in an inflation-targeting small open economy. The steady-state and simulation results suggest that central banks with a fear of floating cannot determine their inflation target independently of the foreign interest rates. There is a unique value of the fear of floating parameter that can keep the economy stable.

Keywords: *Open Economy Macroeconomics, Inflation Targeting Monetary Policy, Fear of Floating, Difference-Differential Equation Systems, Simulation.*

JEL Codes: *E43, E47, E58*

Enflasyon Hedeflemesi Yapan Küçük Açık Bir Ekonomide Döviz Kuru – Fiyat – Çıktı Dinamikleri: Modifiye Edilmiş Dornbusch Modeliyle Analiz

Öz

Fiyat istikrarını sağlamak için enflasyon hedeflemesi politikası uygulayan ülkeler için döviz kurunun enflasyon geçişkenliği dikkate almaları gereken bir husus olarak ortaya çıkmaktadır. Üretimlerinin ithalat bağımlılığı ve dış borçluluğu yüksek ülkeler döviz kurlarını piyasada dalgalanmaya bırakamazlar. Bu nedenle, bu ülkelerin merkez bankaları dalgalanma korkusu ile politika faiz oranlarını döviz kurlarını stabilize etmekte kullanır. Bu çalışmada, enflasyon hedeflemesi yapan küçük açık bir ülkede çıktı, fiyat ve döviz kurlarının dinamik davranışını incelemek için Mundell-Fleming ve Dornbusch modellerine dayanan, dinamik bir model kurulmuştur. Modelin durağan durum çözümü ve simülasyon sonuçları, dalgalanma korkusu ile politika faizini belirleyen bir merkez bankasının, dünya faiz oranlarından bağımsız olarak enflasyon hedefini belirleyemeyeceğini ortaya koymuştur. Ayrıca, ekonomik istikrarla uyumlu tek bir dalgalanma korkusu parametresi vardır.

Anahtar Kelimeler: *Açık Ekonomi Makro İktisadı, Enflasyon Hedeflemesi Para Politikası, Dalgalanma Korkusu, Fark – Türevsel Denklem Sistemleri, Simülasyon.*

JEL Kodları: *E43, E47, E58*

1.Introduction

The Mundell-Fleming framework is the primary textbook model for analyzing the interaction between the exchange rate and other macroeconomic variables. It is a comparative static model that assumes prices to be constant (Mundell, 2001). Dornbusch (1976) extended this model into the dynamical sphere by including flexible price and exchange rate expectations while taking output as given. Later, other studies followed the same approach and assumed either output or price to be constant while analyzing the interaction of exchange rates with macroeconomic variables. For instance, Blanchard and Fisher (1989) and Sarno and Taylor (2002) built dynamic versions of the Mundell-Fleming model for analyzing the output-exchange rate interactions. On the other hand, Dornbusch (1976) and its modified versions, Daniel (1989) and Mark (2001), provided a similar dynamic toolbox for analyzing the price-exchange rate interactions.

On the other hand, with the contributions of Taylor (1993, 1994, 2000, 2001), Romer (2000), Ball (1997, 1999), and Svensson (1996), inflation targeting monetary policy has become the primary monetary policy framework both in the literature and also in practice in the 2000s. In this framework, monetary aggregates such as the monetary base were replaced by the policy interest rate, which is determined by a central bank reaction function set by Taylor (1993). Although some studies (Gregorio & Parrado, 2006) attempted to insert the inflation targeting policy into the Mundell-Fleming-Dornbusch framework, these attempts could not succeed in starting a new theoretical approach.

Global liquidity is one of the main factors that have to be considered by small open economies that try to keep the balance between an independent monetary policy and a stable exchange rate. Although most of these countries prefer to apply inflation targeting monetary policy to maintain price stability, foreign capital goods and foreign input dependency of their manufacturing industries and foreign debt stocks of their firms and banks do not allow them to leave their exchange rates to market dynamics. While some of these *fear-of-floating countries* implement managed floating exchange rate regimes with sterilization to relax the trade-off between an independent monetary policy and a stable exchange rate under the free capital mobility, others try to use the policy interest rate to control their exchange rates.

Since the interactions of output, price, and exchange rate have significant repercussions on the complex macroeconomic dynamics, a complete dynamic analysis should include the behaviors of all these variables. One of the motivations of this study is to construct a dynamic model that allows analyzing interactions between these three variables as a potential source of complex dynamics in economics. The contribution of this study in this strand of literature can be summarized in four points: Firstly, a dynamic model based on the Mundell-Fleming and Dornbusch frameworks is developed, which allows the output, price, and exchange rate to interact endogenously to analyze the complex dynamics emerging from the interactions of these variables. Particularly, the simultaneous and conditional output-price adjustment in the commodity market, as mentioned by Keynes (1964[1936]), provides a more realistic framework than the models that assume either output or price fixed, which ignore potential dynamic interactions between output and price. Although this double adjustment usually makes the movements of output and price smoother, it may lead to a more volatile adjustment process. Although a three dynamic variable differential equation system restricts the usage of visual tools such as phase diagrams, the dynamic simulation method is used to overcome this problem. Secondly, the LM equation, which defines money market equilibrium condition, is replaced by Taylor's rule. This modification allows observing the effects of the policy reaction of an inflation-targeting small open economy. The open economy versions of Taylor, Phillips, and IS equations to focus on the role of the exchange rate on output, inflation, and the policy interest rate. Thirdly, to reflect the interaction between the values of variables in successive periods, the lagged values of some variables are used in model equations. As a result, the model becomes a mixed difference-differential equation system. This approach allows the model to generate path dependency in important variables such as output and current and expected values of inflation and depreciation rates. Finally, the expectation formation mechanisms for inflation and exchange rates do not rely on rational expectation or perfect foresight assumptions. As these assumptions ensure the existence of an equilibrium, the equilibrium is not guaranteed by such assumptions in the model presented here. Particularly, the inflation inertia and the central bank's credibility are introduced into inflation expectations, and trend following behaviors of agents are introduced into exchange rate expectations.

The model is solved for the steady-state conditions and then simulated to analyze the dynamics of the economy under different scenarios. The results presented that the central bank of an inflation-targeting small open economy cannot pursue an inflation target independent of the monetary policies of other countries as represented by the foreign interest rate. Moreover, as a reflection of its fear of floating, the central bank must consider the expected exchange rate depreciation rate in its policy actions to keep the economy's stability.

This study's outline is as follows: After this brief introduction, Section 2 gives a brief overview of open economy macroeconomics literature with precursors and successors of the Dornbusch Model. Then in Section 3, the modified Dornbusch model is developed. Section 4 presents the simulation results. Finally, Section 5 concludes the study.

2. Literature Review: Dornbusch's Heritage in Macroeconomics

2.1. From Fixed Price Static Mundell - Fleming Model to Flexible Price Dynamic Dornbusch Model.

Mundell and Fleming[1] separately developed the fundamental model of open-economy macroeconomics with their studies written in the 1960s. This approach provides a framework for analyzing the effectiveness of monetary and fiscal macroeconomic policies under the fixed and flexible exchange rate regimes with international capital mobility[2] (Razin & Frenkel, 1987). In his words, Mundell (1968, pp. 250-251) assumed an "*extreme degree of (capital) mobility*" that equalizes the domestic interest rate to the levels in other countries. The perfect capital mobility assumption requires assets to be perfect substitutes. Since currencies can also be considered as assets, the perfect substitution of different currencies implies that exchange rates are expected to remain the same in the future.

Hossain and Chowdhury (1998, p. 52) and Snowdon and Vane (2005, p. 133) considered the Mundell-Fleming model as an extension of the standard IS-LM model with restrictive assumptions such as fixed nominal wages and fixed prices. According to Argy (1994, p. 79), another critical limitation such as the Mundell-Fleming model is the exclusion of expectations because, as cited from Mundell (1968, p. 250) above, this view implies the current and expected exchange rates to be equal to each other.

The IS-LM model and the Mundell-Fleming model, which is simply the extension of the former to open economy, can be regarded as Keynesian models in the sense that they only consider the output adjustment process and exclude the price mechanism. The fixed price assumption is the main criterion to classify Mundell – Fleming model as Keynesian (Gartner, 2006, p. 447). However, Keynes's view is more complicated. Keynes (1964[1936], p. 296), in the 21st chapter of his *General Theory*[3], connected the price and output adjustment processes through employment. He argued that while monetary policy would cause a change in employment when the economy is in underemployment, it would cause a change

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[1] In his introductory article to open economy macroeconomics, Mundell (1960) emphasized the expansionary effect of a decrease in the interest rate in addition to its impact on investment. Under a flexible exchange rate regime, a lower interest rate leads to a depreciation in the domestic currency through capital outflows and stimulates net export. He also pointed out the multiplier effect of the exchange rate depreciation on employment (Mundell, 1961). Therefore, under the flexible exchange rate regime, an expansionary monetary policy is more effective on output through exchange rate depreciation (Mundell, 1963). Mundell (1963) also explained why government expenditures would not positively affect output and employment under the flexible exchange rate regime. Fleming (1962) reached similar results about the effects of the exchange rate regime on monetary policy before Mundell (1963).

[2] Textbook models developed on the Mundell-Fleming model allow analyzing different degrees of capital mobility (Eicher, Mutti, & Turnovsky, 2009).

[3] The General Theory of Employment Interest and Money

in prices when the economy is in full employment[4] . With this argument, he implied the coexistence of conditional price and output adjustments. As Lorenz (1992) emphasizes, complex dynamics can emerge as a result of the simultaneous price-quantity adjustment. The multi-adjustment process literature analyzes the complex behavior of these dynamic systems. For example, Chiarella and Flachel (1999) set a Keynes-Meltzer-Goodwin model.

Even though, in general, the Mundell-Fleming model is classified as a static model with a fixed-price assumption, as Sarno and Taylor (2002, p. 98) noted, the Mundell-Fleming model has the potential to contain flexible or sticky-but-adjustable prices. Indeed, after analyzing static systems in the previous chapters of his textbook, in the 11th chapter, Mundell (1968, p. 157) deepened his analysis and added the price adjustment process into the model. In this chapter, he developed a dynamic model and analyzed the system's dynamic behavior through phase diagrams. Obstfeld (2001) pointed out Mundell's emphasis on the role of difference adjustment speeds of markets on the emergence of the dynamic behavior of economies. Therefore, while the textbook Mundell-Fleming model can be classified as a static model with a fixed-price assumption, one should bear in mind the fact that it is a simplification for educational purposes.

According to the common perception in the macroeconomics literature, with Dornbusch's (1976) famous article on the overshooting dynamics of exchange rates and with his subsequent studies (Dornbusch, 1980a, 1980b, 1987), He extended the fixed-price and static Mundell-Fleming open economy macroeconomics model into a flexible price and dynamic model. Contrary to the textbook Mundell–Fleming model, in Dornbusch (1976), the commodity market adjusts via price changes, and the output level is assumed to be constant. As prices are flexible, excess demand increases the price level instead of output. The weakest aspect of Dornbusch's (1976) model was his assumption that long-run levels of exchange rates can be known. Although he did not explain what this assumption was based on and just claimed that it was consistent with perfect foresight, considering the fact that the macroeconomics literature of the late 1970s and early 1980s period was largely built on the purchasing power parity (PPP)[5] hypothesis (Frenkel, 1978), Dornbusch might have implied the validity of the PPP hypothesis[6].

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[4] "*So long as there is unemployment, employment will change in the same proportion as the quantity of money; and when there is full employment, prices will change in the same proportion as the quantity of money*" (1964[1936], p. 296).

[5] The Purchasing Power Parity (PPP) hypothesis argues that the value of a currency in terms of another currency must be at the level that a given amount of money buys the same amount of goods both at home country and abroad (Gerber, 2018, p. 246). It implies that the price of identical goods traded in different countries must be the same in terms of the same currency. The PPP is a generalization of the law of one price for the general price level of the same reference basket across countries (Krugman, Obstfeld, & Marc, 2018, p. 452).

[6] As Rogoff (2002) stated in his speech on the 25th anniversary of Dornbusch's (1976) article, Dornbusch might have implicitly referred to the PPP hypothesis. Like Rogoff, according to Walsh (2011), one of the main assumptions of the Dornbusch model is the long-run PPP.

According to Dornbusch (1980a), an extended version of the Mundell-Fleming model can be derived by relaxing five restrictive assumptions: (i) fixed prices, (ii) demand-determined output, (iii) absence of exchange rate expectations, (iv) absence of effects of the current account on the exchange rate and, (v) perfect substitutability of domestic and foreign assets. Dornbusch (1976) relaxed the first three of these assumptions at the first step. Since asset holders exploit interest differences adjusted for expected exchange rate depreciation rate in different countries, exchange rate expectations play a vital role in Dornbusch's model. In this study, he defined the price and exchange rate as functions of time through the solutions of two separate, first-order, single-variable, linear differential equations. Instead of formulating the dynamics of exchange rate and price with a two-variable, single differential equation, setting separate differential equations for each of these two interacting variables is not mathematically accurate. However, it would not be wrong to say that macroeconomics entered into a new phase with Dornbusch's (1976) model.

Then, in his textbook, Dornbusch (1980b, p. 202) emphasized three points: (i) domestic prices adjust over time by goods market disequilibrium, (ii) adjustment speeds of prices and exchange rates are different, and (iii) exchange rate expectations play an important role in the adjustment process of exchange rates. According to Dornbusch (1980b, p. 202), the Mundell-Fleming model supposes that interest rates would be equalized across countries under perfect capital mobility and ignores the possibility of interest rate differentiation that would be offset by the expected rate of depreciation. His main argument to explain overshooting[7] movements of exchange rates in response to monetary policy was the difference between the adjustment speeds of commodity and foreign exchange markets[8]. Moreover, the connection between these two markets was provided by the expected rate of depreciation in exchange rate (Dornbusch, 1976).

Dornbusch (1987) was aware that his *Extended Mundell-Fleming Model* [9] had become the primary textbook model to analyze an open economy. He added adjustment speeds of interest rates in his model and distinguished between adjustment speeds of prices in different markets. Namely, while commodity price adjustment is sluggish, prices, or interest rates, adjust more rapidly in asset markets.

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[7] In Dornbusch's (1976) model, expansionary monetary policy causes an overshooting in the exchange rate under the rational expectations and perfect capital movements assumptions. Price and exchange rate are the two variables modeled with differential equations. The reason for the initial overshooting of the exchange rate is the adjustment speed of the goods market being lower than that of the asset (foreign exchange) market.

[8] The slower adjustment in the commodity market compared to the asset (exchange) market is called sticky price in the literature. In Wang's (2020, s. 174) words, the sticky price assumption suggests that prices are neither totally flexible nor fixed.

[9] Dornbusch built a dynamic model to explain overshooting movements of exchange rates and defined this dynamic model as an *Extended Mundell – Fleming Model* (Dornbusch, 1987).

2.2. Mark and Daniel's Modified Dornbusch Models as Differential Equation Systems

Mark (2001) and Daniel (1989) established mathematically consistent differential equation systems based on Dornbusch models. Mark (2001, pp. 185-186, 200-202) defined the Dornbusch model as a dynamic version of the Mundell-Fleming model and used original equations of Dornbusch's (1976) with some minor differences as follows:[10]

$$\begin{cases} m - p = \alpha y - \beta i & (1a) \\ y^d = \gamma(e + p^f - p) + \phi y - \delta i + g & (1b) \\ \dot{p} = \theta(y^d - y) & (1c) \\ i = i^f + \dot{e}^e & (1d) \\ \dot{e}^e = \eta(\bar{e} - e) & (1e) \\ \dot{e}^e = \dot{e} & (1f) \end{cases}$$

$$\begin{bmatrix} \dot{e} \\ \dot{p} \end{bmatrix} = \begin{bmatrix} 0 & \frac{1}{\beta} \\ \theta\gamma & -\theta\left(\gamma + \frac{\delta}{\beta}\right) \end{bmatrix} \begin{bmatrix} e - \bar{e} \\ p - \bar{p} \end{bmatrix} \qquad (2)$$

In this notation, except the nominal domestic and nominal foreign interest rates i, i^f all variables are stated in logarithmic values, so their time derivatives represent growth rates of the variables[11]. *Equation 1a* refers money market equilibrium condition, which is called the LM equation in literature, where m, p and y are respectively money supply, price level, and real output or real income. In *Equation 1b*, y^d denotes the aggregate demand; e, p^f and g are nominal exchange rate, foreign price level and government expenditures respectively. This equation implicitly describes component of aggregate demand like net export, investment, and consumption as functions of real exchange rate $e+p^f-p$, interest rate and actual real income. *Equation 1c* can be considered as the Phillips equation. Here $\dot{p}$ represents the inflation rate determined by the difference between aggregate demand and output. Under perfect foresight, the asset market equilibrium condition is given by *Equation 1d*, which is called the uncovered interest rate parity condition. In addition to the domestic interest rate, it consists of expected depreciation rate $\dot{e}^e$ and the foreign nominal interest rate i^f. An interest rate difference indicates expectations about the change in currencies' relative values. *Equation 1e* points out the dynamics of the expected exchange rate, which is determined by the difference between the long-run equilibrium value of the exchange rate $\bar{e}$ and its

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[10] *Equations* from *1a* to *1e* are used in both Dornbusch (1976) and Mark (2001). Mark (2001) also added the rational expectations assumption with *Equation 1f*. In order to set the differential equation system in *Equation 2*, this assumption was necessary; otherwise, he would have to use the expected exchange rate depreciation rate instead of the actual depreciation rate and he would not be able to define differential equation system.

[11] The growth rate of price is the inflation rate, and the growth rate of the exchange rate is the exchange rate depreciation rate.

actual value. The equivalency of the expected and actual rate of depreciation in exchange rate is an expression of the rational expectation hypothesis in *Equation 1f.*

Daniel's (1989) model is very similar to Mark's (2001); however, she directly substitutes *Equation 1f* into *Equation 1d* and omits *Equation 1e*, which includes the long-run equilibrium value of the exchange rate. The new equation can be considered assets market equilibrium conditions under perfect foresight (Ferguson & Lim, 1998, p. 133). Additionally, instead of the difference between aggregate demand and output in the price adjustment process, she substituted the difference between output and potential output $\bar{y}$, where the latter is considered an exogenous constant in *Equation 3c*. Due to the lack of aggregate demand she defined the output as a function of the real exchange rate, real interest rate i-$\dot{p}$, and also government expenditures in *Equation 3b*.

$$\begin{cases} m - p = \alpha y - \beta i & (3a) \\ y = \gamma(e + p^f - p) - \delta(i - \dot{p}) + g & (3b) \\ \dot{p} = \theta(y - \bar{y}) & (3c) \\ i = i^f + \dot{e} & (3d) \end{cases}$$

$$\begin{bmatrix} \dot{e} \\ \dot{p} \end{bmatrix} = \frac{1}{\beta + \alpha\delta - \beta\delta\theta} \begin{bmatrix} \alpha\gamma & 1 - \delta\theta - \alpha\gamma \\ \theta\gamma\beta & -\theta(\delta + \gamma\beta) \end{bmatrix} \begin{bmatrix} e \\ p \end{bmatrix} + \begin{bmatrix} \dfrac{-(1 - \delta\theta)m - \alpha\delta\theta\bar{y} + \alpha g}{\beta + \alpha\delta - \beta\delta\theta} - i^f \\ \dfrac{\theta[\delta m + \beta g - (\beta + \alpha\delta)\bar{y}]}{\beta + \alpha\delta - \beta\delta\theta} \end{bmatrix} \qquad (4)$$

With slight differences, both Marks's and Daniel's models have been used as examples for differential equation system form of the Dornbusch's model in books on dynamic economic models (Shone, 2002, p. 554). Besides these studies, which are based on Dornbusch's (1976) model, the studies of Blanchard and Fisher (1989, p. 540)[12] and Sarno and Taylor (2002, p. 98), which are dynamic versions of the Mundell-Fleming model, show the coexistence of fixed and flexible price models in the macroeconomics literature

$$\begin{cases} m - p = \alpha y - \beta i & (5a) \\ y^d = \gamma(e + p^* - p) + \phi y - \delta(i - \dot{p}^e) + g & (5b) \\ \dot{y} = \alpha(y^d - y) & (5c) \\ i = i^f + \dot{e}^e & (5d) \\ \dot{e}^e = \dot{e} & (5e) \end{cases}$$

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[12] Blanchard and Fischer (1989) did not prefer using logarithmic forms of variables; hence, although their equations define the same functional relations, their notation seems different from that is followed in this study.

2.3. Taylor, Ball, Svensson, and Romer: Replacing the LM Equation with Taylor Rule

Romer (2000) argued that Federal Reserve Bank uses federal funds rate to achieve inflation and output targets, and monetary aggregates play a very limited role in implementing monetary policy. Therefore, in the new modeling approach, monetary authorities control the interest rate instead of the level of the money supply. Moreover, Romer (2000) claimed that the Federal Reserve's setting of the Federal funds rate could be well depicted with a simple function of the inflation and output gaps, which is first presented by Taylor (1993) as in *Equation 6*. Here $\bar{\pi}$ represents to target level of inflation rate and r denotes long run real interest rate [13]

$$i = \dot{p} + \varphi(y - \bar{y}) + \omega(\dot{p} - \bar{\pi}) + r \qquad (6)$$

Taylor (1994) summarized the monetary policy by an equation that presents the interest rate as a reaction function set by the central bank. Taylor (1994) offered a three equation (*Equations 7a, 7b,* and *7c)* model. He used two lagged variables in Phillips Equation.[14] Although the existence of lagged variables and external stochastic shock parameters u_i can be interpreted as the dynamic behavior of the system, this approximation is different from the views of Dornbusch, Daniel, and Mark, which include the adjustment process with different adjustment speeds.

$$\begin{cases} y - \bar{y} \ - \delta(i - \dot{p} - r) + u_1 & (7a) \\ \dot{p} = \dot{p}_{-1} + \theta(y_{-1} - \bar{y}_{-1}) \ + u_2 & (7b) \\ i = \dot{p} + \varphi(y - \bar{y}) + \omega(\dot{p} - \bar{\pi}) + r \ + u_3 & (7c) \end{cases}$$

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[13] Taylor (1993) tested his model econometrically with US data, in which the interest rate is determined as a function of the deviation of the inflation rate from the target level of 2% and the deviation of the real GDP from the potential GDP, which has an annual growth rate of 2.2% annual growth trend as in following *equation.* In the following equation, the last term refers to a long-run real interest rate of 2% for the US.

$$i = \dot{p} + 0{,}5(y - \bar{y}) + 0{,}5(\dot{p} - 2) + 2$$

The output gap term in Taylor (1993) was represented by just y, that indicates $\left(\frac{Y-\bar{Y}}{\bar{Y}}\right)$ where the $\bar{Y}$ refers trend real GDP.

As mentioned, Taylor (2001) did not use the real interest rate in later versions of the policy reaction function.

[14] The term $\dot{p}_{-1}$. refers to the dependency of the expected inflation rate on its previous values as an indicator of inflation inertia. This approximation $\dot{p}^{e} = \dot{p}_{-1}$ defines the expected inflation rate directly by its previous value is called *naïve* expectations (Hommes, 2013, p. 15). Two real interest rates r in *Equations 7a* and *7c* are not exactly the same in Taylor (1994), but this detail is ignored here.

Svensson (1996) [15] and Ball (1997) [16] followed Taylor›s (1994) approximation, and along with inflation (*Equations 7b* and *7c)*[17], they also used lagged values of output *Equation 8*. Hence, they set dynamic IS and Phillips equations with lagged values of variables.

$$y-\bar{y}=\phi(y_{-1}-\bar{y}_{-1})-\delta(i_{-1}-\dot{p}_{-1})+g+u \qquad (8)$$

Ball (1999) extended the Svensson-Ball Model into an open economy by defining open economy IS and Phillips equations, which are functions of the exchange rate. Open economy Phillips equation reflects the effect of a change in the exchange rate on the inflation rate, which affects inflation through import prices.

$$\begin{cases} y=\phi y_{-1}-\delta(i_{-1}-\dot{p}_{-1})+\gamma e+g+u_1 & (9a) \\ \dot{p}=\dot{p}_{-1}+\theta(y_{-1}-\bar{y}_{-1})+\psi(e_{-1}-e_{-2})+u_2 & (9b) \end{cases}$$

According to Ball (1999), while the optimal policy rate was determined by Taylor rule in which the interest rate depends on output and inflation for a closed economy; for an open economy, he modified the Taylor rule and defined policy variable as a (linear) combination of interest rate and exchange rate.

$$\varpi i+(1-\varpi)e=\varphi(y-\bar{y})+\omega(\dot{p}+\psi e_{-1}) \qquad (10)$$

Taylor (2000, 2001) developed an open economy version of his own reaction function for the policy rate. According to *impossible trinity*, Taylor (2000) evaluated the *flexible exchange rate regime* as a natural complement of the *inflation targeting policy.* Nonetheless, he did not mean that the exchange rate plays no role in the policy rule. Indeed, Taylor (2001) modified his rule by adding the real exchange rate as in *Equation 11.*[18]

$$i=\xi\dot{p}+\varphi(y-\bar{y})+\psi_0\varepsilon+\psi_1\varepsilon_{-1} \qquad (11)$$

Using graphical methods, Romer (2000) offered a macroeconomics without the LM curve. He replaced the LM curve with the MP (monetary policy) curve as a horizontal line representing the interest rate. In the new tradition of models based on Romer's framework, a Taylor rule equation for monetary policy function and an expectations-augmented Phillips curve equation for inflation adjustment function are widely used (Hsing, 2005). Considering the interest rate as the main policy tool of the monetary policy allows the money supply to be determined endogenously via credit demand. With Phillips Curve,

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[15] In *Equations 7a, 7b, and 7c,* Svensson (1996) also used an exogenous variable that is ignored here.

[16] The notation of Svensson (1996) is followed in this study, but the equations of Ball (1997) are very similar with minor differences.

[17] Svensson (1996) did not use the real interest rate in *Equation 7c.*

[18] Without the real interest rate and zero inflation target assumptions in *Equation 11,* the first term at the right-hand side implies that $\xi=1+\omega$.

the Taylor equation played an important role in expressing a foundation for the new consensus in macroeconomics (Arestis, 2009). Fontana and Setterfield (2009) defined this new framework as a simple mathematical expression of the new consensus in macroeconomics.

3. A Modified Dornbusch Model for an Inflation Targeting Small Open Economy:

This section develops a mixed difference-differential equation system based on Dornbusch's dynamic viewpoint and different adjustment speeds. Specifically, the trace of Romer, Taylor, Ball, and Svensson's approach is followed and the LM curve is replaced with an exchange-rate-extended Taylor Rule to reflect the *fear of floating* behavior of the central bank. Also, the open economy versions of IS and Phillips curves and an exchange rate determination equation are used. The lagged values of some variables are included in the equations to reflect dynamic interactions are used in the equations. Furthermore, the actual and expected values for inflation and exchange rates are included to emphasize the role of expectations on actual variables. The mixed difference-differential equation system developed here allows simultaneous adjustment of the price, output, and exchange rate.

3.1. Inflation Targeting Central Bank, Open Economy Taylor Rule, and Fear of Floating

Following Taylor (1993, 1994, 2000, 2001), Romer (2000), Ball (1997, 1999), and Svensson (1996), instead of the LM equation, a Taylor equation defines the money market. Apart from being consistent with the current developments in macroeconomics literature, this analytical framework is also used in practical applications of inflation targeting monetary policy. Similar to the model in this study, also Gregorio and Parrado (2006) attempted to introduce the inflation targeting monetary policy into the Dornbusch model. They replaced the money demand equation with the Taylor rule, which is augmented with exchange rate movements to extend the model to analyze the dynamics of a small open economy (Farrell, 2012). Albeit with a different notation, the approach of Gregorio and Parrado (2006) is adopted here, and the monetary policy rule is set as a function of the expected inflation rate in *Equation 12*.

$$i = \dot{p}^e + \omega(\dot{p}_{-1} - \bar{\pi}) + \psi\dot{e}^e \qquad (12)$$

While Mishkin and Savastano (2001) used the level of the exchange rate in the Taylor rule, following Mohanty and Klau (2004), the exchange rate depreciation rate is used in the Taylor equation. However, we use the depreciation rate of the nominal exchange rate instead of the real exchange rate as used by Mohanty and Klau (2004). In this regard, our approach about the role of exchange rate on the policy interest rate differentiates from Taylor's (2001) in notation by using percentage change of expected nominal exchange rate instead of two successive period actual values of the real exchange rate. *Equation 12* displays the policy reaction function of our model.

Here, $\psi > 0$ is the *fear of floating* parameter, which measures the sensitivity of the central bank›s reaction to the expected rate of depreciation in exchange rate. Additionally, we assume that the central bank's interest rate decision is based on the last observation of the inflation rate; therefore, one period lagged inflation rate is used in the Taylor equation as in Mehra and Minton (2007).

As inflation targeting policy requires nominal exchange rate flexibility to achieve independent monetary policy aim as suggested by the impossible trinity argument, exchange rate fluctuations are expected in an economy with free capital flows Mishkin (2000). These fluctuations may substantially impact the domestic price level due to the exchange rate pass-through on the inflation rate through imported final goods and inputs (Nguyen, 2008). Therefore, developing country central banks implementing inflation targeting policy cannot omit exchange rate movements. Moreover, a large depreciation in the exchange rate significantly threatens financial stability by increasing foreign currency-denominated debt burden and deteriorating balance sheets (Mishkin, 2000). This fact provides another rationale for central banks try to keep the exchange rate stable while implementing inflation targeting policy. In their groundbreaking article, Calvo and Reinhard (2002) argue that countries that proclaim to implement a free-floating exchange rate regime mostly do not allow their exchange rates to float freely with market dynamics. The evidence they present shows that while interest rates and reserves fluctuate significantly more in emerging market economies than in developed economies, exchange rates movements remain in a relatively narrower range (Nguyen, 2008). Previous studies that analyze the fear of floating phenomenon found that countries with a significant amount of foreign exchange denominated private or public debt try to keep the exchange rate stable (Honig, 2005). As limited foreign exchange reserves would be insufficient if they were used to stabilize the exchange rate, these countries generally use the policy interest rate for this aim instead. Here, the expected rate of depreciation in exchange rate is also inserted into the Taylor Equation to reflect monetary authorities' fear of floating behavior.

3.2. Dynamic Aggregate Demand and Double Adjustment of Price and Output

While output is considered as an exogenous variable in Dornbusch (1976), Groth (2017) modeled output with a differential equation as in dynamic IS-LM models (Ferguson & Lim, 1998, p. 126). In Groth (2017), the growth of output is a function of the difference between aggregate demand and current output. Here, the same approach is followed to express output adjustment process in *Equation 13.*

$$\dot{y} = \alpha(y^d - y) \tag{13}$$

Here, both y and y^d are output and aggregate demand expressed in logarithms, and g is in *Equation 14* is the logarithm of government expenditures, determined by tax revenues that are assumed to be proportional to the previous period aggregate output.

$$y^d = \gamma(e + p^* - p) + \phi y_{-1} - \delta(i - \dot{p}^e) + g \quad g = \tau y_{-1} \qquad (14)$$

3.3. Open-Economy Phillips Equation with an Exchange Rate Pass-Through Coefficient.

Since Dornbusch (1976), price adjustment has been explained by different versions of the Phillips equation in the literature. *Equation 15* represents *the expectations-augmented Phillips curve* for an open economy[19].

$$\dot{p} = \dot{p}^e + \theta(y^d - y) + \upsilon\dot{e} \qquad (15)$$

Since the tapering announcement of the Fed in 2013, the exchange rate pass-through on the inflation rate has been widely discussed in reports of international institutions[20] (World Bank , 2014).

Ball and Reyes (2008) state that even if the fear of floating term was not explicitly included in the determination of the policy interest rate, the Taylor rule would still carry the effects of the exchange rate depreciation rate on the inflation rate through import prices; namely, the pass-through effect in the open-economy Phillips curve in *Equation 15.* In other words, even if the central bank does not consider the exchange rate level, it responds to changes in the exchange rate through their influences on the inflation rate. However, as the monetary authority aims to achieve price stability, it should take a proactive stance and react before the inflation rate is affected by the exchange rate depreciation rate. In this regard, in *Equation 12* we use expected rate of depreciation in exchange rate in the fear of floating term instead of the actual rate of depreciation as in Ball and Reyes (2008).

3.4. Exchange Rate Determination by Capital Flows

In this study, the rate of depreciation in the exchange rate is modeled as a Mundell-Fleming-type capital flow equation as a component of the balance of payments (Dornbusch, Fischer, & Startz, 2018, p. 564; Caves, Frankel, & Jones, 2007, p. 449). Frenkel and Rodriguez (1982) extended Dornbusch's (1976) model by introducing imperfect substitution of assets and imperfect capital mobility into their model (Argy, 1994, p. 209). They defined the balance of payments equation as the sum of current account and capital flow equations and emphasized the role of the degree of capital mobility. Here, a similar capital flow equation

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[19] As suggested by Matheson (2006), the simplest way to reflect the impact of changes in international competitiveness is by adding the nominal exchange rate term into the Phillips equation.

[20] From a global perspective, capital flows to developing countries decelerated, and the currencies of these countries depreciated after the tapering announcement of Bernanke. In parallel, the inflation rates of these countries rose on average from 6,4% to 7,4% in 2013. According to World Bank (2014), currency-related price pressures were concentrated in a few large middle-income economies, including Argentina, Venezuela, Turkey, Ghana, South Africa, Indonesia, and India.

is used in *Equation 16*, which replaces the uncovered interest parity condition *Equation 1d*, and uses it as the argument of the function instead. Namely, the rate of depreciation in the exchange rate is determined by the capital flows stimulated by the interest rate gap adjusted for the expected exchange rate depreciation rate, which serves as an indicator of the risk premium of the domestic country.

$$\dot{e} = -\chi(i - i^f - \dot{e}^e) \qquad (16)$$

3.5. Interactions Between Actual and Expected Terms of Inflation and Exchange Rates

Expected inflation and the expected exchange rate depreciation rate are of primary importance in the dynamics of the economy. In *Equation 17*, the expected inflation rate is defined as a weighted average of the inflation target set by the central bank and the inflation rate in the previous period reflecting the inertia[21] in inflation expectations. In this equation, the weight of the inflation target is determined by the credibility of the central bank.

$$\dot{p}^e = \eta\bar{\pi} + (1 - \eta)\dot{p}_{-1} \qquad (17)$$

Finally, *Equation 18* represents the dynamics of the expected rate of depreciation in exchange rate, which extrapolates the lagged depreciation rate with the trend of the recent past (Lines & Westerhoff, 2010) [22]

$$\dot{e}^e = \dot{e}_{-1} + \sigma(\dot{e}_{-1} - \dot{e}_{-2}) \qquad (18)$$

The association between current and past values of variables through the expected value terms generate path dependency and nonlinear dynamics in economics, as exemplified in Samuelson's (1939) accelerator–multiplier model. Therefore, the interaction between *Equations 15 and 17* indicates the path dependency in the inflation rate, and the interaction between *Equations 16 and 18* in the depreciation rate.

4. Results and Discussion

4.1. Steady State Solution

In the steady-state, growth rates of output, price level, and exchange rate are all constant. According to the solution of the model for steady-state conditions, the expected inflation rate and the inflation target have to be equal to the inflation rate *Equation 19*, and the exchange rate depreciation rate has to be equal to its expected value *Equation 20*.

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[21] Inflation rate inertia becomes persistent due to pricing and contracting decisions.

[22] Hommes (2013, p. 180) defined a similar equation for price expectations and classified this type of expectation formation as Chartist.

$$\dot{p}^* = \dot{p}^e = \bar{\pi} \tag{19}$$

$$\dot{e}^* = \dot{e}^e \tag{20}$$

The steady-state levels of inflation, output growth, and exchange rate growth can be written a function of the exogenous parameters of the model as in *Equations 21* to *23*.

$$\dot{p}^* = \frac{i^f}{1 - \frac{\left(1 - \psi - \frac{1}{\chi}\right)}{\left(1 + \frac{\alpha\upsilon(1 - \phi - \tau)}{\gamma\theta}\right)}} \tag{21}$$

$$\dot{e}^* = \frac{i^f}{\psi + \frac{1}{\chi} + \frac{\alpha\upsilon(1 - \phi - \tau)}{\gamma\theta}} \tag{22}$$

$$\dot{y}^* = \frac{i^f}{-\frac{\theta}{\alpha\upsilon}\left(\psi + \frac{1}{\chi}\right) - \frac{(1 - \phi - \tau)}{\gamma}} \tag{23}$$

Notably, the steady-state inflation rate depends on global liquidity conditions as represented by the foreign interest rate. As the inflation target has to be equal to the inflation rate in the steady-state, the presence of the foreign interest rate in this expression suggests that central banks of small open economies cannot set their inflation target disregarding the policy rates of other countries. In practice, these are the policy rates of the developed countries' central banks such as the Fed, European Central Bank, Bank of England, etc. Therefore, to achieve economic stability, small open country central banks have to take into account the rates of these central banks while making their monetary policy.

The fear of floating parameter has a unique value consistent with the steady-state, which is determined by the structural parameters of the economy as in *Equation 24*. Specifically, the fear of floating parameter increases with a higher pass-through parameter, υ, and the sensitivity of output growth to the difference between aggregate demand and output, α. On the other hand, it decreases with the sensitivity of the aggregate demand to real interest rate, δ, and the sensitivity of inflation to the difference between aggregate demand and output θ.

$$\psi = \frac{\upsilon(1 + \alpha)}{\theta\delta} \tag{24}$$

4.2. Scenario Analysis with Model Simulation

Because of the presence of lagged variables, the model takes the form of a mixed difference-differential equation system. To observe the economy's dynamic behavior, the model is simulated with numerical integration using the Vensim software. In the simulations, the logarithms of the exchange rate, domestic price level, and foreign price level are normalized to 1. Other model parameters are calibrated for reasonable values of model variables (*Table 1*). Fear of floating parameter is set to its steady-state level given by *Equation 24*.

In Table 1, adjustment speeds of output, price, and the exchange rate are denoted with alpha α, theta θ, chi χ, respectively. As in Dornbusch's (1976) overshooting model, price adjustment is slower than the exchange rate adjustment ($\theta < \chi$); however, differently, the exchange rate adjustment is not instantaneous ($\chi<1$). Additionally, as in the Mundell – Fleming model, the main adjustment dynamics in the commodity market work through output, although price adjustment also takes place ($\alpha > \theta$).

Table 1. Parameter values used in simulations.

PARAMETER	VALUE
ω	0.5
ψ	0.22
σ	0.25
φ	0.9
δ	100
τ	0.2
α	0.1
θ	0.025
υ	0.5
χ	0.56179775
γ	0.05
η	0.5
i^f	0.001

Based on these parameter values, steady-state values of output growth rate, inflation rate, exchange rate depreciation rate, and the nominal interest rate are calculated and given in *Table 2*. At the steady-state, capital inflow appreciates the domestic currency. Although it affects output negatively, a higher inflation rate than nominal interest rate causes a negative real interest rate, which stimulates aggregate demand and keeps the output growth rate positive.

Table 2. Steady-state values of model variables.

VARIABLE	VALUE
$\dot{p}^*=\dot{p}^e=\bar{\pi}$	0.0015
$\dot{e}^*=\dot{e}^e$	-0.0005
$\dot{y}^*$	0.0010

Then, the model is simulated for different scenarios. The time unit is chosen as months, and the time horizon is set to 250 periods.

4.2.1.A Change in the Fear of Floating Parameter

A simulation experiment is set up to observe the sensitivity of the dynamics of the economy to the value of fear of floating parameter. Specifically, when the economy is at the steady state, the central bank changes the value of the fear of floating parameter at period 20 (*Scenario 1*). Simulation results are given in *Figure 1.*

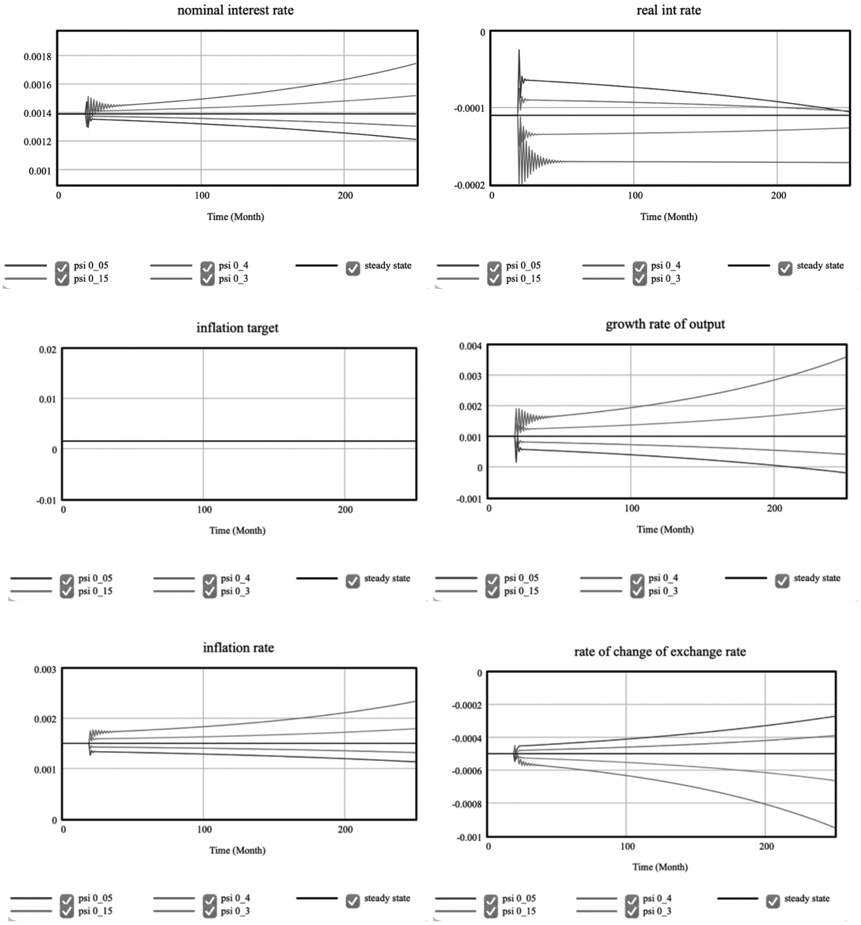

Figure 1. The Dynamic Behavior of Model Variables in Scenario 1.

A higher value of the fear of floating means that the central bank is more concerned about the exchange rate pass-through on the inflation rate. The amplitude of the central bank's reaction increases; the central bank sets a higher policy interest rate for a given exchange rate depreciation rate. As expected, the exchange rate depreciation rate decreases, accompanied by a higher output growth rate and a higher inflation rate. However, the model variables do not stabilize; they diverge from their steady-state values. These results indicate that the central bank must set the fear of floating parameter to the level congruent with the steady-state, which is determined by the structural parameters of the economy as in *Equation 24*. Any value different from the steady-state value is unsustainable in the sense that it results in a divergence in inflation, output growth, and exchange rate growth.

4.2.2.A Change in the Inflation Target

Another simulation experiment is conducted to observe the sensitivity of the dynamics of the economy to the inflation target. Specifically, when the economy is at the steady state, the central bank changes its inflation target at period 20 (*Scenario 2*). Simulation results are presented in *Figure 2*.

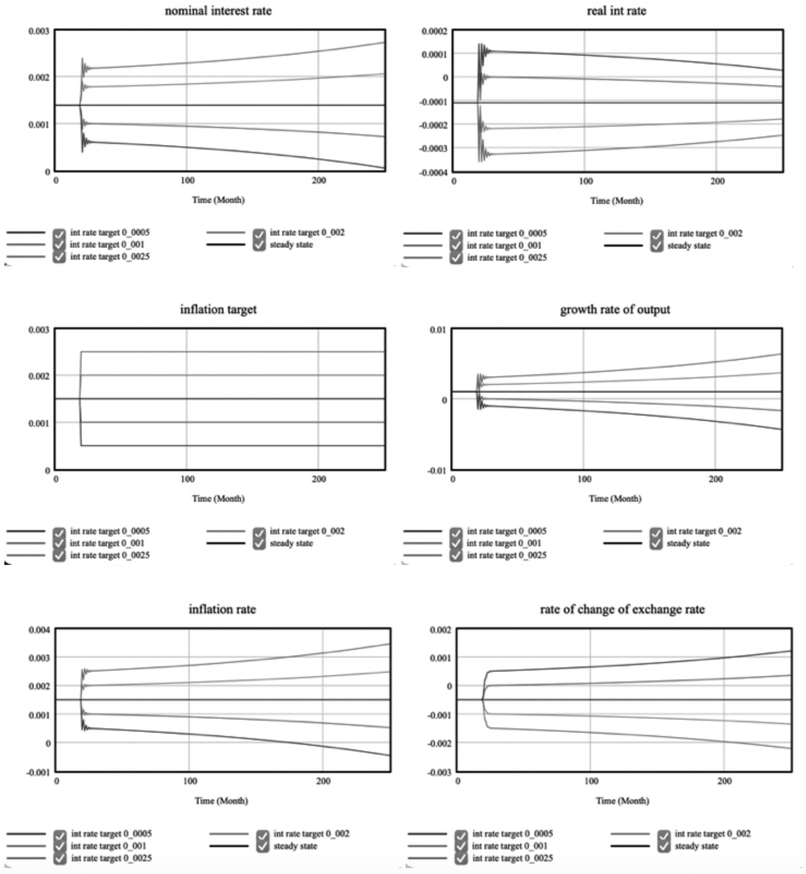

Figure 2. The Dynamic Behavior of Model Variables in Scenario 2.

Both the inflation rate and expected inflation move in the same direction as the inflation target, both of which force the nominal interest rate to increase. However, inflation increases faster than the nominal interest rate; hence, the real interest rate decreases, stimulating aggregate demand through investments. The emerging difference between aggregate demand and output also pushes inflation to higher levels. On the contrary, an increased nominal interest rate causes a decrease in the depreciation rate through increasing capital inflows. Even though appreciation of the exchange rate puts negative pressure on inflation, this effect is dwarfed by the positive effects of increasing inflation expectations, and inflation continues to increase. Therefore, model variables diverge from their steady-state values, exhibit exponential movements, and do not stabilize at a new steady-state.

4.2.3. An Increase in the Foreign Interest Rate

In this scenario, we investigate the effect of an increase in the foreign interest rate when the economy is at the steady state. Specifically, the foreign interest rate increases from 0.001 to 0.0015 at period 20 (*Scenario 3*). The simulation results are given in *Figure 3.*

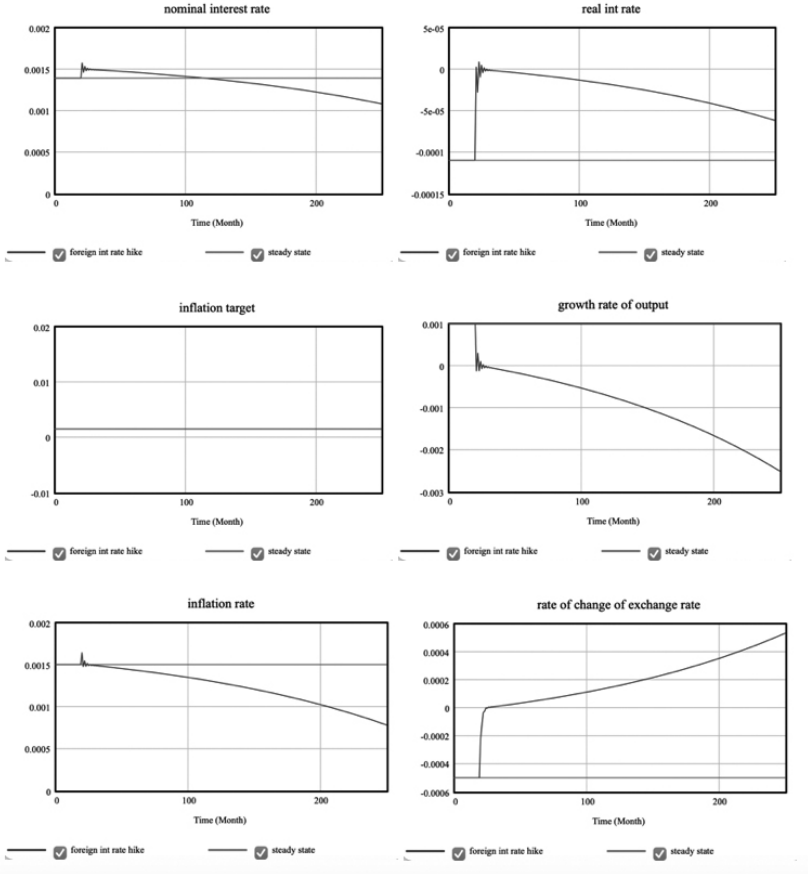

Figure 3. The Dynamic Behavior of Model Variables in Scenario 3.

When the foreign interest rate rises, capital inflows decrease, and the rate of depreciation in exchange rate increases gradually. Since the exchange rate depreciation rate was negative (appreciation) at the steady-state, it turned positive (depreciation) after a while. With fear of floating, the central bank reacts by increasing the policy interest rate. The inflation rate increases initially with the pass-through effect of a higher rate of depreciation in the exchange rate. With the central bank's reaction, real interest rates jump up along with the policy rate, which causes a sharp decrease in aggregate demand. As aggregate demand depends on past output levels through consumption and government expenditures, the decreasing trend persists once aggregate demand decreases below aggregate output. The negative effect of decreasing output growth accelerates with the growing negative effect of aggregate demand. This negative effect on inflation eventually surpasses the positive effect of increasing depreciation rate, and the inflation rate starts to decrease.

The most important implication of these results is that the aggregate variables do not converge to a new steady-state after deviating from the steady state. While the inflation target remains constant, increasing the policy rate proves to be insufficient to push the economy into a new steady-state. The output growth, inflation, nominal and real interest rates continue to decrease, and the exchange rate depreciation rate continues to increase exponentially. Therefore, the economy falls into an everlasting state of recession and deflation with the depreciation of the domestic currency in the long run.

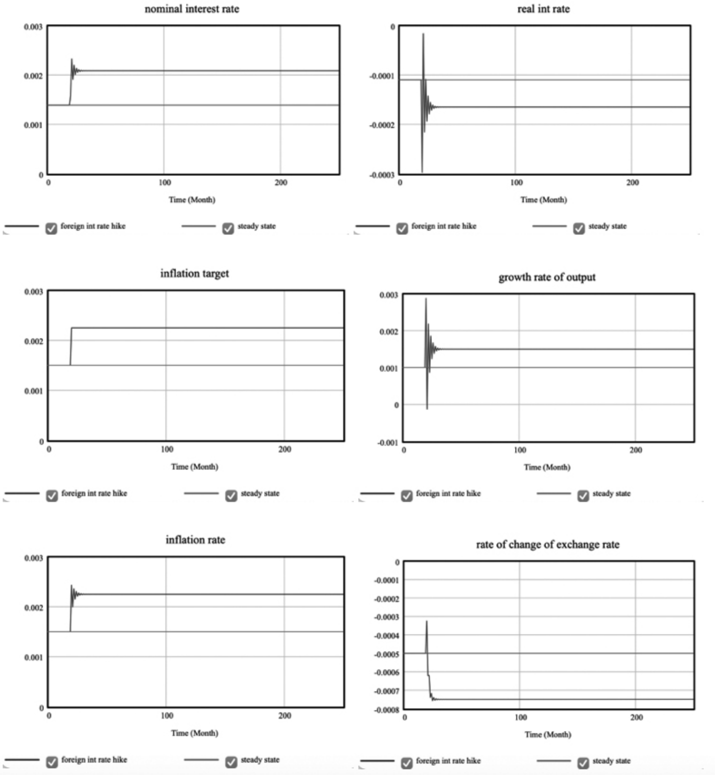

Figure 4. The Dynamic Behavior of Model Variables in Scenario 4.

As the steady-state inflation rate is an increasing function of the foreign interest rate in *Equation 21*, the steady-state inflation rate increases with the foreign interest rate. Since the inflation target has to be equal to the inflation rate in the steady-state, we set up a simulation where the central bank adjusts the inflation target to the new steady-state inflation rate immediately when the foreign interest rate rises, in order to see if the economy converges to the new steady-state (*Scenario 4*).

As the simulation results in *Figure 4* present, all the model variables converge to their new steady-state levels after a volatile transition period. When the foreign interest rate rises, the economy stabilizes at a higher inflation rate, higher output growth rate and a lower rate of depreciation in exchange rate (appreciation) compared to their initial steady-state levels. These results confirm the implications of the steady-state solutions; namely, while implementing inflation targeting monetary policy in an economy with free capital mobility, central banks must consider foreign interest rates to stabilize their economies. They cannot set the inflation target freely, independent of global liquidity conditions.

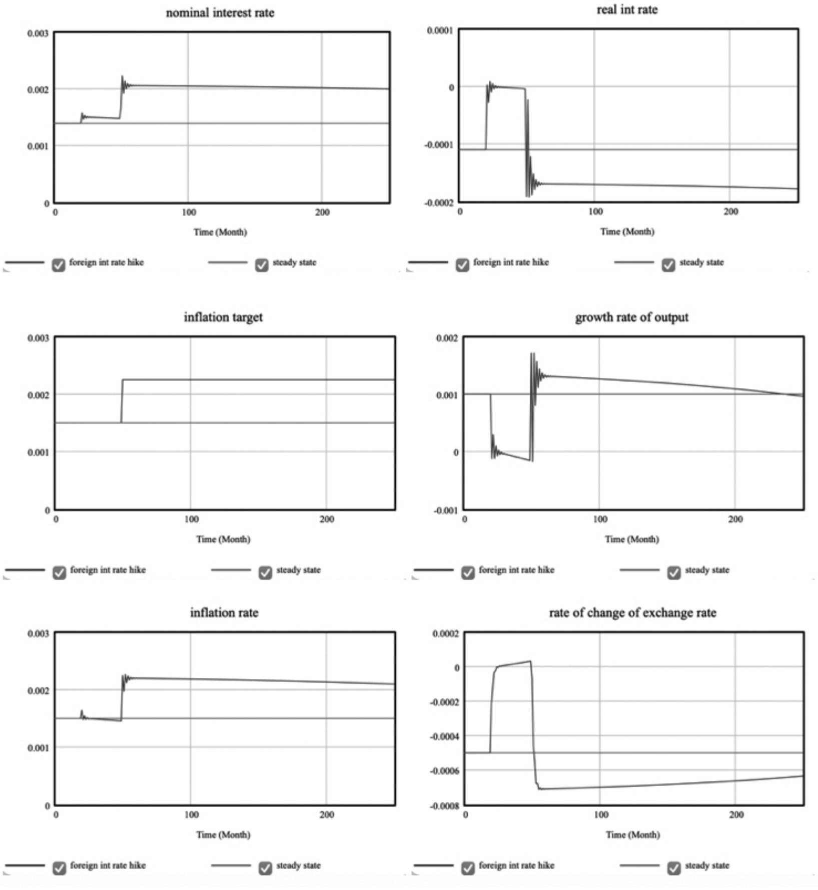

Figure 5. The Dynamic Behavior of Model Variables in Scenario 5.

Another interesting scenario might be the case in which the central bank adjusts its inflation target after the foreign interest rate rises, not immediately, but with a delay. Specifically, when the economy at the steady-state, foreign interest rate rises from 0.001 to 0.0015 at period 20, the central bank does not change its inflation target immediately to the new steady-state value, but at period 50 (*Scenario 5*). Simulation results are given in Figure 5.

After the foreign interest rate hike at period 20, the dynamics in the first scenario are observed, where all the model variables diverge from their steady-state values. When the central bank adjusts its inflation target to the new steady-state value congruent with the higher foreign interest rate at period 50, the dynamics of the model variables continue in the same manner after a sudden jump resulting from the change in the inflation target. However, the change in the inflation target proves to be insufficient to stabilize the economy if it occurs with a delay. Therefore, not only the inflation target adjustment but also the timing is important to keep the economic stability.

5.Conclusion

In this study, an extended Mundell-Fleming-Dornbusch model is developed where output, price level, and exchange rate adjust simultaneously to observe the dynamic behavior of the economy. The economy's structural parameters and foreign interest rate determine the steady-state levels of inflation, output growth, and exchange rate growth.

The simulation results indicated that the central bank of a small open economy with free capital flows could not pursue independent inflation targeting policy disregarding the foreign interest rate. An inflation target other than the steady-state level is unsustainable in the sense that it would result in a divergence in inflation, output growth, and exchange rate growth. Moreover, the central bank should react immediately to change the levels of these parameters in case of a change in the economy's structural parameters or global liquidity conditions. Any delay in the adjustment would cause the model variables to diverge away from their steady-state levels, and a return to the steady state is not possible in the case of divergence.

The steady-state solution of the mixed difference-differential equation system presented in this study resembles to saddle path solutions of Dornbusch (1976), Mark (2001), and Daniel (1989). Meaning that it will remain in the steady state if and only if it starts at the steady state. Therefore, the monetary authority must keep the inflation target and the fear of floating parameter at their steady-state values to keep the economy's stability.

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