Measuring the Natural Interest Rate for the Turkish Economy*

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This paper measures the natural interest rate for the Turkish economy as an unobserved stochastic variable. In doing so, the study adopts a systems approach, based on a parsimonious New Keynesian model consisting of a Phillips curve, an IS curve, and a backward-looking Taylor-type interest rate rule linking the real interest rate to the natural interest rate. The model also includes stochastic laws of motion for the natural interest rate and potential output. As a contribution to the existing literature on natural interest rate and in view of the volatile nature of the Turkish economy, the parameters are assumed to be time varying. However, the requirement to simultaneously estimate parameters and to solve the state-space problem introduces non-linearity to the model. The issue of non-linearity can be handled by employing the extended Kalman filter (EKF), i.e., the use of standard Kalman filter equations to the first-order Taylor approximation of the non-linear model about the last estimate. Estimation results suggest that both the estimated natural interest rate and the real interest rate series move in tandem with the real interest rate. All the derived series are plausible and capture the significant turning points of the economy. As for the time-varying parameters, the estimated coefficients are reasonable. Overall, findings of this study provide guidance for future research on the natural interest rate, an important tool for monetary policy, and lay the basis for further work that may adopt the EKF algorithm. Most importantly, this study underlines the need to assess the stance of the monetary policy by using the natural interest rate.

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> "One problem is that [the policymaker] cannot know what the 'natural' rate is. Unfortunately, we have as yet devised no method to estimate accurately and readily the natural rate of either interest or unemployment. And the 'natural' rate will itself change from time to time."
>
> Friedman (1968)

1. Introduction

Policymakers are facing the growing challenge to foresee the future course of price dynamics in fulfilling their commitment to maintain price stability. In doing so, another challenge that is encountered by policymakers is to gather and employ all the relevant information in the data set in order to evaluate the monetary policy stance. Due to the overriding emphasis on price stability and the associated use of monetary policy rules based on short-term policy rates over the last decades, the natural interest rate has become a useful benchmark for assessing the monetary policy stance and determining whether the current level of the interest rate is expansionary or contractionary for the economic activity. Besides, policy rates in advanced economies hit the zero lower bound[1] amid the unconventional monetary policy implementations after the global crisis,[2,3] drawing renewed attention to the natural interest rate,

[1] Zero lower bound is the situation when the short-term nominal interest rate hits or nears zero, causing a liquidity trap in the economy.

[2] The global crisis in 2008 is considered to be the worst financial crisis since the Great Depression and led to the Great Recession, which was felt across the globe.

[3] The global crisis challenged central banks in advanced economies in the conduct of monetary policy. Prior to the crisis, central banks used the short-term policy rates as their primary instrument of monetary policy, by lowering the rate to provide stimulus and raising it to slow economic activity and control inflation. In addition, central banks also had the option to exercise monetary policy via required reserves and open market operations. But after the global crisis, reducing policy rates further to induce production was no longer an option as policy rates hit the zero lower bound. Meanwhile, reserve requirements could not be reduced radically against financial stability risks. In turn, central banks were left with the only option—to expand the money supply through open market operations. In periods of crisis, however, government securities tend to become bid up due to their perceived safety, which limits their effectiveness as a policy tool. Hence, major central banks had to resort to quantitative easing as well as credit

which is estimated to have been low for a prolonged period of time.[4]

The natural interest rate is the real interest rate that would prevail if there were no inflationary or deflationary pressures requiring the central bank to lean in either direction (Archibald and Hunter 2001). In other words, the natural interest rate is the real interest rate consistent with stable output and inflation, thus implying a neutral monetary policy stance. Accordingly, a real interest rate above (below) the natural rate for a prolonged period of time means lower (higher) consumption and investment, which would eventually decrease (increase) output and inflation in the absence of other shocks to the economy (Laubach and Williams 2003; De Fiore and Tristani 2011). Thus, it is vital to quantify the level of the natural interest rate in assessing the monetary policy stance.

The natural interest rate was originally defined by Wicksell (1898) as a certain rate of interest on loans, which is neutral[5] in

easing, which correspond to balance sheet policies comprising large-scale asset purchases and long-term funding with the objective to affect long-term interest rates and ease banks' collateral and funding liquidity constraints (Smaghi 2009). The unconventional monetary policy tools in the post-crisis period also included forward guidance, which was used effectively by the Federal Reserve (Fed) and other major central banks to affect long-term interest rates (Bernanke 2013).

[4]Blanchard, Furceri, and Pescatori (2014) discuss that the natural interest rate fell sharply after the global crisis due to several factors. These may be listed as the collapse of financial intermediation and the increase in uncertainty, which had effects on precautionary savings and investment; higher risk and market risk aversion, which led to a reduced safe rate relative to the rate on risky assets; and the monetary policy, which prevented the actual rate from declining as much as the natural rate due to the zero lower bound on nominal rates and low inflation.

[5]The terms "natural" and "neutral" are used interchangeably in earlier studies on natural interest rate theories (Laubach and Williams 2003; Williams 2003; Amato 2005; Hamilton et al. 2015; Olson and Wessel 2015), whereas equilibrium interest rate and Wicksellian interest rate are other terms that are used as substitutes for natural interest rate. Yet, Ferguson (2004) and Hamilton et al. (2015) criticize the multiplicity of these terms, while Pescatori and Turunen (2015) note the subtle conceptual differences among these terms. Garrison (2006) distinguishes between natural and neutral interest rate by underlining that these seemingly synonymous terms provide a contrast between pre-Keynesian and post-Keynesian thinking. In particular, Keynes (1936) makes an important distinction

the sense that it neither raises nor lowers the commodity prices. Put differently, this is the rate of interest that would be determined by supply and demand conditions if no use were made of money and all lending were effected in the form of real capital goods. In that sense, natural interest rate corresponds to the current value of the natural interest rate on capital.

The seminal work of Wicksell (1898) contributed greatly to the understanding of the role of interest rate in income and price dynamics. This pioneering work also induced further research and launched controversial debates on the natural interest rate.[6] However, in the second half of the twentieth century, natural interest rate was less tempting, as unemployment became the new focus of attention with the work by Phelps (1967) and Friedman (1968).[7]

It was only through the increased emphasis on price stability by policymakers and the influential work of Taylor (1993), which proposed a simple interest rate rule based on natural rates, that the concept of natural interest rate was revived and given significant consideration in both the academic and the policymaking front.[8,9]

between neutral and natural interest rate. Accordingly, neutral interest rate is the equilibrium interest rate where the elasticity of employment is zero. On the other hand, natural interest rate is the rate of interest that equates savings and investment while also maintaining a stable price level. Yet, the natural rate, according to Keynes (1936), is not unique, whereas if any rate is unique, it is the neutral rate.

[6]Wicksell's theory had a strong influence on Cassel (1903), Keynes (1936), and Hayek (1939).

[7]Layard, Nickell, and Jackman (1991), Laxton and Tetlow (1992), Weiner (1993), Kuttner (1994), King, Stock, and Watson (1995), Gordon (1997), Nickell (1997), Staiger, Stock, and Watson (1997a, 1997b), Stiglitz (1997), Cross, Darby, and Ireland (1998), Gerlach and Smets (1999), Richardson et al. (2000), Laubach (2001), Ball and Mankiw (2002), and Benes and N'Diaye (2004) are succeeding works on natural rate theories of unemployment.

[8]Taylor (1993) proposed a simple monetary policy rule that stipulates how much the central bank should change the nominal interest rate in response to changes in inflation and output. The rule postulates that the nominal interest rate i_t should respond to divergences of actual inflation rate from target inflation and actual GDP from potential GDP in the following form, where $i_t = r_t^* + \pi_t + 0.5(\pi_t + \pi_t^*) + 0.5ygap_t$. Here, i_t is the policy rate; r_t^* is the equilibrium real interest rate (the natural interest rate); π_t is the inflation rate (GDP deflator); π_t is the desired (target) rate of inflation; and π_t^* is the output yap.

[9]The Taylor rule became highly controversial after the global crisis. In particular, Taylor (2015) asserts that the Fed kept interest rates much lower than

On the policymaking front, the priority of central banks to maintain price stability by the adoption of an inflation-targeting regime in both advanced and emerging economies over the last decade designated the natural interest rate as a convenient benchmark that policy rates can be measured against directly.

On the academic front, the concept of natural interest rate was invigorated especially after Woodford (2003), which focused on the gap between the current level of the natural interest rate and the interest rate controlled by the central bank as the key variable for the analysis of inflationary or deflationary pressures. In other words, the monetary policy authority should adjust its policy instrument in response to deviations of output and employment from their natural levels.

Natural rate has gained significance after the global crisis, given the persistently low interest rates in advanced economies amid unconventional monetary policy practices. In particular, the exceptionally near-zero interest rates have prompted the question of whether low interest rates will be a permanent feature of the future economic outlook (Bernanke 2015b; Laubach and Williams 2015). Accordingly, natural interest came to the forefront amid intense debates about why it may continue to be low in the future.[10]

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prescribed by the Taylor rule during 2003–05. This caused the housing bubble and other financial excesses, which eventually evolved into the global crisis in 2008. Taylor (2015) also argues that the Fed's monetary policy since the financial crisis has been too easy and discretionary, especially with regards to the implementation of the quantitative easing policies, and this caused the Fed to abide by the zero interest rate policy longer than envisioned by the rule. Bernanke (2015b), on the other hand, claims that a modified Taylor rule, which comprises core inflation and higher weight on output gap, is more descriptive of the Fed's policy during the last two decades. Yet, this modified rule envisions a negative interest rate in the post-crisis period, which, according to Bernanke (2015a), is not feasible. Obviously, this warrants keeping interest rates at the zero lower bound while providing additional monetary easing via unconventional tools.

[10]Summers (2013, 2016) argues that the decline in natural interest rate may be defended by the secular stagnation view. Originally developed by Hansen (1939) to describe the stagnant 1930s, the view asserts that secular stagnation occurs due to the imbalance between higher propensity to save and lower propensity to invest. This results in excessive saving that pulls down real interest rates and also the natural interest rate. Bernanke (2015c) justifies the decline on the basis of the savings-glut view that rationalizes the fall by excess global savings emanating largely due to China and other Asian emerging market economies and oil-producing countries. Krugman (2013) explains decreasing rates by the

Meanwhile, these extraordinary monetary policy tools implemented in advanced economies led to massive global liquidity, which compelled many emerging economies to adjust their monetary policy framework in order to address financial stability concerns posed by volatile capital flows.[11] Accordingly, central banks of emerging economies, including Turkey,[12] resorted to macroprudential tools in order to observe financial stability besides maintaining the price stability objective.

Yet, recently, monetary policy across advanced economies has diverged as U.S. monetary policy has started to normalize with a policy rate liftoff while monetary policies in other major economies have continued to be expansionary.[13] This poses additional challenges to

liquidity trap, whereas Reinhart, Reinhart, and Rogoff (2012) ascribe lower rates to debt overhangs. Gordon (2012) attributes the decline to lower productivity growth, while Kasparov and Thiel (2012) validate it by the innovation stagnation.

[11]The unconventional policy tools employed by advanced economies after the crisis led to post-crisis spillovers, causing massive capital flows to emerging economies. This resulted in rapid credit growth, which posed risks to financial stability. Heightened concerns about financial stability triggered a search for an alternative monetary policy framework in small open economies, including Turkey (International Monetary Fund (IMF) 2012; Akçelik et al. 2013; Kara 2013).

[12]The Central Bank of the Republic of Turkey (CBRT) was prompted by the global crisis to adopt financial stability as a supplementary objective to its primary goal of maintaining price stability. The framework was centered on containing the adverse effects of rapid credit growth and the associated macrofinancial risks by using several tools jointly in the new monetary policy mix that included policy rate, the interest rate corridor, and required reserves (Başçı and Kara 2011; IMF 2012; Akçelik et al. 2013; Alper, Kara, and Yörükoğlu 2013a). Also, liquidity policy was used effectively along with the reserve options mechanism, which was engineered as a unique macroprudential tool (Küçüksaraç and Özel 2012; Alper, Kara, and Yörükoğlu 2013b; Oduncu, Akçelik, and Ermişoğlu 2013).

[13]The exit from the prolonged use of unconventional monetary policies by advanced economies in the post-crisis period was initiated by the Fed's recent policy rate hike. Yet, it should be noted that other major central banks seem to diverge from the Fed by continuing to ease their policies. In particular, the Bank of Japan and the European Central Bank have delivered a recent rate cut and have embarked upon more aggressive quantitative easing programs, with the former entering into negative territory while the latter has already ventured into the sub-zero zone since 2014. Also, central banks in other advanced economies have reduced their rates. In particular, Sveriges Riksbank, Danmarks Nationalbank, and the Swiss National Bank reduced their policy rates below zero. On the other hand, the Reserve Bank of New Zealand and Norges Bank cut their policy rates, where the latter warned about a likely negative interest rate. Also,

emerging market economies, especially Turkey,[14] while having serious implications regarding the proper measurement of the natural interest rate and the assessment of the monetary policy stance.

Despite the increased need for an accurate measure of the natural interest rate as a useful monetary policy guide, its unobservable nature and the considerable uncertainty associated with its estimation creates many difficulties.[15] These are particularly severe in the case of structural breaks, which cause natural rates to vary unpredictably amid higher uncertainty (Staiger, Stock, and Watson 1997a; Orphanides and van Norden 2002; Laubach and Williams 2003).

In spite of these problems, there are numerous techniques developed to measure the natural interest rate. Among these, one simple method is to calculate the average real interest rate, which is considered to be a proxy for the natural interest rate when taken over a long period of time.[16] Yet, this technique is too basic, as it ignores

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Czech National Bank raised the possibility of introducing negative rates. Despite these divergences, evidence shows larger international interest rate spillovers for U.S. policy announcements than those for other central banks, which marks the Fed's policy rate liftoff as a crucial step towards normalization of global monetary policies (Ehrmann and Fratzscher 2005; Rogers, Scotti, and Wright 2014; Fischer 2015).

[14] The CBRT released a road map in August 2015 regarding the policies to be implemented during the normalization of the global monetary policies (CBRT 2015b). The road map included simplification steps for the Turkish lira (TL) liquidity management, and also contained measures for managing foreign exchange (FX) liquidity and supporting financial stability. These measures were reiterated in the CBRT's press release in December 2015, addressing the monetary and exchange rate policy for 2016 (CBRT 2015a).

[15] The estimation of natural interest rate is challenging, as it varies over time in response to shifts in preferences and technology (Berger and Weber 2012). Besides, changes in other factors, such as fiscal policy, may induce persistent changes in the natural interest rate (Laubach and Williams 2003). Orphanides and Williams (2002) discuss that problems pertaining to the estimation of the natural interest rate had already been brought up by Friedman (1968), who acknowledged that the policymaker cannot know the level of the natural rate, that no method was devised to estimate it accurately and readily, and that it also changes over time. Wicksell (1898) and Cassel (1928) also argued that the central bank cannot know what the equilibrium rate of interest is and that it is not fixed or unalterable.

[16] Taylor (1993) assumes an equilibrium real interest rate at 2 percent, which is close to the average of the steady-state growth rate of 2.2 percent. Reifschneider and Williams (2000) estimate natural interest rate for the U.S. economy by

persistent changes in demand and supply factors that cause large movements in the natural interest rate. Besides, by treating the natural interest rate as constant, this method also ignores structural breaks and regime switches (Baksa et al. 2013). Hence, a relatively more advanced technique in this regard is to compute the multiyear averages in moving-average terms, which allows for time variation in the natural interest rate (Hamilton et al. 2015; Laubach and Williams 2015).

Other simple estimation methods may include conventional filtering techniques, such as the Hodrick-Prescott filter and the bandpass filter,[17] which decompose the real interest rate series to its cyclical and trend components (Borio, English, and Filardo 2003; Muinhos and Nakane 2006; Barcellos Neto and Portugal 2009). Despite their simplicity, Orphanides and Williams (2002) report that these univariate filters are sensitive to final observations. This is also argued by St. Amant and van Norden (1997), Orphanides and van Norden (2002), van Norden (2002), and Christiano and Fitzgerald (2003).

In addition to these simple univariate techniques, natural interest rate may also be estimated with the adoption of a monetary model with microfoundations having a money-in-the-utility specification of money demand (Andres, López-Salido, and Valles 2006; Andres, López-Salido, and Nelson 2009; Berger and Weber 2012). Alternatively, the natural interest rate may be computed by large-scale econometric models such as MIT-Penn-SSRC (MPS) or the FRB/US models of the U.S. economy.[18]

Moreover, natural interest rate can also be measured using economic theory. This may be in the context of the capital asset pricing model (Browne and Everett 2006; Fuentes and Gredig 2007) or those based on estimates of the marginal productivity of capital (Chadha

taking the average of the real funds rate over the 1960–98 period. Hamilton et al. (2015) assume that the average real interest rate, when taken over a sufficiently long period of time, will approximate the equilibrium rate, which equals the natural interest rate at steady-state level of output. Behera, Pattanaik, and Kavediya (2015) also argue that the average real interest can be used as a proxy for the natural rate.

[17]For further details, see Hodrick and Prescott (1997), Baxter and King (1999), and Christiano and Fitzgerald (2003).

[18]Bomfim (1997) estimates natural interest rate using the MPS model, while Bomfim (1998) uses the FRB/US model.

and Nolan 2001). Also, natural interest rate may be derived using the uncovered interest rate parity condition (Fuentes and Gredig 2007) or total factor productivity growth where an expected increase in total factor productivity is assumed to raise the natural interest rate and vice versa (Woodford 2003; Amisano and Tristani 2008; Galí 2008; Justiniano and Primiceri 2010; Lundvall and Westermark 2011; Carlstrom and Fuerst 2016).[19]

Besides these models, natural interest rate may also be computed by structural vector autoregressive (SVAR) models. Brzoza-Brzezina (2002) applies an SVAR model to estimate natural interest rate.[20] Accordingly, a two-component SVAR model is constructed for the GDP increment (as an approximation of the output gap) and the real interest rate, where the model calculates unobserved shocks, of which one corresponds to the equilibrium interest rate and the other corresponds to the disequilibrium component of the interest rate.

Alternatively, the natural interest rate may be estimated by time-varying parameter vector autoregressive (TVP-VAR) models that enable the study of the complex relationships among macroeconomic data, allowing for the lagged coefficients and the variances of the economic shocks to vary over time. However, the TVP-VAR model fails to impose sufficient economic structure, even though it captures a variety of non-linear behaviors that are apparent in macroeconomic time series (Lubik and Matthes 2015).

The natural interest rate has also been commonly estimated via more sophisticated procedures like dynamic stochastic general

[19] This relates to the Wicksellian view defining natural interest rate as the rate of interest that equates savings with investment. The Wicksellian view also treats the natural interest rate as the marginal productivity of capital and the rate of interest that is consistent with aggregate price stability, which fed into the neo-Wicksellian/New Keynesian view perceiving natural interest rate to be dependent on various economic factors. These factors are households' rate of time preference and their willingness to substitute consumption across time, the marginal productivity of capital (in particular, the level of the capital stock), and shocks that affect households' savings decisions such as innovations to total factor productivity and exogenous changes in government spending (Amato 2005). Important New Keynesian models along this line can be noted as Rotemberg and Woodford (1997, 1999), Erceg, Henderson, and Levin (2000), Smets and Wouters (2002), Amato and Laubach (2003a, 2003b, 2004), Giannoni and Woodford (2003), Neiss and Nelson (2003), Woodford (2003), and Giannoni (2007).

[20] This is in the spirit of Blanchard and Quah (1989) and Claus (1999), who estimate potential output using SVAR.

equilibrium (DSGE) models with nominal rigidities.[21] Accordingly, the natural interest rate is computed essentially via reverse engineering, by imposing that the output gap is equal to zero after a certain horizon, and then solving for the level of the interest rate that is consistent with this output gap.

The complexity of large-scale DSGE models encouraged the development of small-scale macroeconomic models that are easier to apply yet more structured than simple statistical approaches. In this respect, an alternative technique for estimating the natural interest rate was proposed by Laubach and Williams (2003), who use a simple small-scale macroeconomic model to jointly estimate the natural interest rate and the potential output. In doing so, the natural interest rate and the potential output are treated as unobserved variables in a multivariate unobserved-components model, where the Kalman filter features out as the appropriate estimation algorithm.[22]

The Kalman filter has been used widely as a standard method to estimate natural interest rate. In particular, Orphanides and Williams (2002), Basdevant, Bjorksten, and Karagedikli (2004), Cuaresma, Gnan, and Ritzberger-Gruenwald (2004), Larsen and McKeown (2004), Clark and Kozicki (2005), Garnier and Wilhelmsen (2005), Benati and Vitale (2007), Bernhardsen and Gerdrup (2007), Fuentes and Gredig (2007), Mésonnier and Renne (2007a, 2007b), Barcellos Neto and Portugal (2009), and Humala and Rodríguez (2009), among many others, use the Kalman filter to compute natural interest rate for various advanced economies.

Despite the common use of the Kalman filter for estimating natural interest rate in advanced economies, which present rare incidences of excessive boom-bust cycles, the standard Kalman filter may fail to perform well in emerging market economies that are generally characterized by relatively higher volatility. Even though this volatility may be captured by assuming parameters to be time varying, the analysis requires the adoption of a non-linear state-space

[21] Smets and Wouters (2002), Giammarioli and Valla (2003), Neiss and Nelson (2003), Edge, Kiley, and Laforte (2008), Canzoneri, Cumby, and Diba (2012), Burgess et al. (2013), Barsky, Justiniano, and Melosi (2014), Cúrdia (2015), Cúrdia et al. (2015), and Del Negro et al. (2015) are previous works that estimate natural interest rate using DSGE models.

[22] For further details, see Kalman (1960), Kalman and Bucy (1961), and Hamilton (1994a, 1994b).

form that impedes the use of the standard Kalman filter. This problem can be handled via the extended Kalman filter (EKF), which is a widely used algorithm for linearizing non-linear systems (Grillenzoni 1993; Hamilton 1994b; McKiernan 1996; Bacchetta and Gerlach 1997; Pasricha 2006).

Accordingly, EKF has also been used for the Turkish economy, which also presents high volatility (Özbek, Özlale, and Öztürk 2003; Özbek and Özlale 2005; Sarıkaya et al. 2005; Kara, Küçük-Tuğer et al. 2007; Kara, Öğünç et al. 2007; Us 2014). Yet, these studies utilize EKF to calculate output gap or NAIRU (non-accelerating rate of unemployment). Meanwhile, natural interest rate for the Turkish economy was computed solely by Öğünç and Batmaz (2009). However, this pioneering work fails to adopt a non-linear framework.

Hence, the absence of previous studies that estimate the natural interest rate by also considering the highly volatile nature of the Turkish economy leaves a gap for measuring the natural interest rate with time-varying parameters in a state-space form. This gap establishes the main motivation of this study. To the best of our knowledge, this is the first formal attempt to compute the natural interest rate for the Turkish economy in a non-linear setting.

This paper is conjectured to be useful in several ways. First of all, findings of this study provide guidance for future research on the natural interest rate, which is an important measure of the monetary policy stance. In addition, the study contributes to the existing literature by producing other significant variables like real interest rate, inflation, potential output, output, and the output gap. Moreover, the results shed light on the course of time-varying parameters that indicate inflation persistence, the contribution of demand- and supply-side factors to inflation, as well as the determinants of aggregate demand. But most importantly, this study underlines the need to assess the stance of the monetary policy by also using the natural interest rate.

It should be underlined that this paper does not intend to explain the evolution of interest rate dynamics in the Turkish economy, nor does it seek to determine the underlying structural forces driving the natural interest rate. Also, the paper does not attempt to explain output or price developments, but it solely tries to exploit the information contained in the data set in order to extract the unobservable natural interest rate by acknowledging that it is impossible to measure it with precision. With this in mind, the paper still takes this endeavor to estimate the natural interest rate, perceiving it as a "heuristic benchmark" and "useful aid in thinking about monetary policy."[23]

It should also be kept in mind that the models tested in the paper are chosen according to their in-sample properties and the degree to which they are able to match the behavior of the original series. Thus, the model selection is based on the informal optimization of the plausibility of the resulting estimates, but without any regard to their forecasting properties.

The organization of the paper is as follows. The next section presents the benchmark model for the natural interest rate and its state-space representation as well as the alternative model specification, which is based on the inclusion of dynamic homogeneity condition as a robustness test. The third section discusses the estimation results and seeks to improve the findings by applying a smoothing algorithm and using alternative inflation target measures. Finally, the last section concludes this paper. The state-space representation of the EKF is in the appendix.

2. System Specification

Models that have been used to estimate natural interest rate are essentially based on a system of equations. In the spirit of Laubach and Williams (2003), the system is composed of a Phillips curve, which relates inflation to its lagged terms as well as the output gap and other supply-side factors that pose inflationary pressure; an IS curve that links output gap to real interest rate, the nominal exchange rate, and its lagged term; and a Taylor-type interest rate rule that connects the real interest rate to the natural interest rate, the deviation of inflation from the inflation target, and the output gap. The system also includes an identity for output besides equations defining the law of motion for potential output and the natural interest rate as well as equations defining their trend components.

[23]See, respectively, Bean (2004) and Ferguson (2004).

2.1 Benchmark Model Specification

The benchmark model specification is based on a parsimonious version of a standard New Keynesian framework consisting of a Phillips curve, an IS curve, and an interest rate rule.[24] Given the highly volatile nature of the Turkish economy, the empirical framework departs from Laubach and Williams (2003) by assuming parameters to be time varying. The variables used in the benchmark model are as follows: π_t is the inflation rate (first difference of the log of consumer price index); z_t is a vector of supply-side variables (normally taken to be changes in import prices, real exchange rate, or the nominal exchange rate) that impose pressure on inflation; r_t is the real interest rate; y_t is the (log of) output level; r_t^* and y_t^* represent the natural interest rate and (the log of) potential output, respectively; while π_t^* is the inflation target. Finally, $ygap_t$ is the output gap.

The system is composed of the following equations.

Inflation is assumed to behave according to an accelerationist-type Phillips-curve equation such that

$$\pi_t = \alpha_{1,t}\pi_{t-1} + \alpha_{2,t}\pi_{t-2} + \alpha_{3,t}ygap_{t-1} + \alpha_{4,t}z_t + \varepsilon_t^{\pi}. \tag{1}$$

According to the above equation, inflation is a function of built-in inflation, demand-pull inflation, and cost-push inflation that can be captured by the inclusion of lagged inflation terms, the output gap, and the change in nominal exchange rate, respectively.[25] The coefficients $\alpha_{1,t}$ and $\alpha_{2,t}$, which show the degree of inflation persistence, are expected to be greater than zero. The coefficients $\alpha_{3,t}$ and $\alpha_{4,t}$, which denote the degree of demand-pull and cost-push inflation, correspondingly, are also expected to be greater than zero. Obviously, ε_t^{π} is the disturbance term.

[24] Ball (1998, 1999, 2000), Rudebusch and Svensson (1998), and Peersman and Smets (1999) present insightful examples of New Keynesian small-scale macroeconomic models.

[25] Based on the triangle model of Gordon (1991), inflation has three root causes: built-in inflation (inflation results from past events and persists into the present), demand-pull inflation (falling unemployment rates or rising GDP feeds into inflation), and cost-push inflation (increases in the cost of goods and services raise inflation).

The IS curve that describes the aggregate demand can be expressed as follows:

$$ygap_t = \beta_{1,t} ygap_{t-1} + \beta_{2,t} r_{t-1} + \beta_{3,t} z_t + \varepsilon_t^{ygap}, \qquad (2)$$

where $\beta_{1,t}$ is the coefficient of the autoregressive term, $\beta_{2,t}$ is the coefficient of the real interest rate, $\beta_{3,t}$ is the coefficient of the nominal exchange rate, and ε_t^{ygap} is the error term. $\beta_{1,t}$ and $\beta_{3,t}$ are positive, while $\beta_{2,t}$ is estimated to be negative.

The real interest rate is linked to the natural interest rate in the form of a backward-looking Taylor rule such that

$$r_t = r_{t-1}^* + \gamma_{1,t}(\pi_{t-1} - \pi_t^*) + \gamma_{2,t} ygap_{t-1} + \gamma_{3,t} r_{t-1} + \varepsilon_t^r, \qquad (3)$$

where the original rule in Taylor (1993) is rewritten in terms of the real interest rate. Coefficients $\gamma_{1,t}$, $\gamma_{2,t}$, and $\gamma_{3,t}$, which denote the respective weights of the deviation of past inflation from the target, the output gap, and the autoregressive term, respectively, are expected to be positive.

The Beveridge-Nelson (1981) decomposition of output is as follows:

$$y_t = y_t^* + ygap_t. \qquad (4)$$

Potential output and the natural interest rate are assumed to follow a local linear trend model such that

$$y_t^* = y_{t-1}^* + \mu_{t-1} + \varepsilon_t^{y^*} \qquad (5)$$

$$r_t^* = r_{t-1}^* + \eta_{t-1} + \varepsilon_t^{r^*}, \qquad (6)$$

where the two stochastic trends μ and η are defined as

$$\mu_t = \mu_{t-1} + \varepsilon_t^{\mu} \qquad (7)$$

$$\eta_t = \eta_{t-1} + \varepsilon_t^{\eta}. \qquad (8)$$

Obviously, $\varepsilon_t^{y^*}, \varepsilon_t^{r^*}, \varepsilon_t^{\mu}$, and ε_t^{η} are the disturbance terms.

The model can be represented in the state-space form as follows:

$$x(t) = Fx(t-1) + Gu(t) + e_1(t) \qquad (9)$$

$$y(t) = Hx(t) + e_2(t), \qquad (10)$$

where $x(t)$ is the state vector, $y(t)$ is the observation vector, F is the transition matrix, H_k is the observation matrix, and G_k is a known matrix. $e_1(t)$ and $e_2(t)$ denote vectors of normally distributed iid shocks, which are assumed to be uncorrelated with each other and have covariance matrices R_1 and R_2, respectively. Furthermore, $u(t)$ is the vector of exogenous variables.

The measurement equation that shows the evolution of the observed variables (inflation, output, and the real interest rate) can be described as a function of the state variables as follows:

$$\begin{bmatrix} \pi_t \\ y_t \\ r_t \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} \pi_t \\ \pi_{t-1} \\ y_t^* \\ \mu_t \\ \rho_t \\ ygap_t \\ r_t \\ r_t^* \end{bmatrix}. \qquad (11)$$

The transition equation can be expressed as

$$\begin{bmatrix} \pi_t \\ \pi_{t-1} \\ y_t^* \\ \mu_t \\ \rho_t \\ ygap_t \\ r_t \\ r_t^* \end{bmatrix} = \begin{bmatrix} \alpha_{1,t} & \alpha_{2,t} & 0 & 0 & 0 & \alpha_{3,t} & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \beta_{1,t} & \beta_{2,t} & 0 \\ \gamma_{1,t} & 0 & 0 & 0 & 0 & \gamma_{2,t} & \gamma_{3,t} & 1 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \pi_{t-1} \\ \pi_{t-2} \\ y_{t-1}^* \\ \mu_{t-1} \\ \rho_{t-1} \\ ygap_{t-1} \\ r_{t-1} \\ r_{t-1}^* \end{bmatrix}$$

$$+ \begin{bmatrix} \alpha_{4,t} & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ \beta_{3,t} & 0 \\ 0 & -\gamma_{1,t} \\ 0 & 0 \end{bmatrix} \begin{bmatrix} z_t \\ \pi_t^* \end{bmatrix} + \begin{bmatrix} \varepsilon_t^{\pi} \\ 0 \\ \varepsilon_t^{y^*} \\ \varepsilon_t^{\mu} \\ \varepsilon_t^{\rho} \\ \varepsilon_t^{ygap} \\ \varepsilon_t^{r} \\ \varepsilon_t^{r^*} \end{bmatrix}. \qquad (12)$$

2.2 Alternative Model under Dynamic Homogeneity Condition

In order to analyze the robustness of the results to different model specifications, the dynamic homogeneity condition is imposed on the benchmark model specification. The dynamic homogeneity condition is the constraint that permanent changes in inflation should not affect output in the long run, thus implying neutrality. Nickell (1988) argues that "if the model does not possess this kind of neutrality, then unemployment can be shifted, even in the long run, simply by changing the level of inflation."

Hence, imposing the dynamic homogeneity condition to the above system of equations implies that the existence of a trade-off between inflation and output is only limited to the short run (Greenslade, Pierse, and Saleheen 2003; Laubach and Williams 2003; Batini and Greenslade 2006). The restriction also implies that prices are determined by nominal factors such as wages and imported costs (Gómez and Julio 2000).

One way of imposing the dynamic homogeneity condition on a system of equations is to restrict the sum of the coefficients of the explanatory inflation terms in the Phillips-curve equation to be equal to unity. Another way to impose the same condition is to use differenced inflation terms in the Phillips-curve equation, and so the unity restriction is automatically satisfied (Fabiani and Mestre 2004).

Since the original Phillips-curve equation does not contain any differenced inflation terms, this paper sticks to the former approach. Hence, the dynamic homogeneity condition is imposed by restricting the sum of the lagged inflation terms in the Phillips-curve equation to be equal to unity (Bjørnland, Leitemo, and Maih 2007). Meanwhile, the state-space representation of the alternative model remains unchanged from the benchmark model specification.

3. Estimation Results

This section reports and discusses the estimation results. The model utilizes quarterly data on inflation, output, interest rate, and nominal exchange rate for the Turkish economy between 2002:Q1 and

2015:Q4.[26,27] Inflation is measured as the logarithmic difference of the seasonally adjusted consumer price index.[28] Output is the seasonally adjusted real GDP series in logs with base year 1998. Real interest rate is the inflation-adjusted[29] overnight lending rates at the repo and reverse repo market of the Borsa Istanbul between 2002:Q1 and 2010:Q1, which is substituted for one-week repo rates and the average funding rate afterwards.[30] Exchange rate is the logarithmic difference of the USD/TRY spot rate. Target is the official

[26]The data are publicly available and can be retrieved from the electronic data dissemination system of the CBRT at https://evds2.tcmb.gov.tr.

[27]The time period covered in the analysis is crucial for the Turkish economy. In particular, after experiencing a major financial crisis in 2001, which led to the collapse of the IMF-backed exchange-rate-based disinflation program with an ultimate goal to switch to an inflation-targeting regime, the CBRT started to conduct an implicit inflation-targeting regime between 2002 and 2005. This was followed by the implementation of the strict inflation-targeting regime starting from 2006. In the last quarter of 2008, the CBRT had to face challenges originating from the global crisis that occurred in September 2008. Consequently, the CBRT adopted anti-crisis measures, which were later withdrawn starting from April 2010. Finally, as of end-2010, the CBRT has conducted a new monetary policy framework, which departed from strict inflation targeting by the inclusion of financial stability as a supplementary objective to its primary goal of maintaining price stability (Erçel 1999; Başçı, Özel, and Sarıkaya 2007; Kara 2008, 2013; Başçı and Kara 2011; IMF 2012).

[28]Inflation is estimated using the consumer price index with base year 2003. The missing data for 2002 are computed by the consumer price index series with base year 1994.

[29]The ex ante real interest rate is derived by adjusting nominal rates with the twelve-month-ahead inflation expectation series obtained from the CBRT's Survey of Expectations.

[30]The CBRT's policy rate between 2002:Q1 and 2010:Q1 is the overnight lending rate at the repo and reverse repo market of the Borsa Istanbul. However, starting from May 2010, the CBRT has opted for a technical adjustment as part of the normalization process after the global crisis, where the one-week repo rate was used as the effective policy rate. With the adoption of the new monetary policy mix at end-2010, the one-week repo rate was officially announced as the policy rate. However, an active liquidity-management policy was also implemented, which adjusted market rates without changing the policy rate. In fact, the CBRT started to impose additional monetary tightening and continued to do so occasionally until January 2014. Hence, in order to capture this switch, the policy rate in the analysis is replaced by the one-week repo rate as of 2010:Q2, and to account for the additional monetary tightening, it is replaced by the average funding rate as of 2012:Q1. This corresponds to the effective rate at which the CBRT injects liquidity (Başçı and Kara 2011; CBRT 2012, 2014; IMF 2012; Küçüksaraç and Özel 2012; Alper, Kara, and Yörükoğlu 2013a; Kara 2013; Ermişoğlu et al. 2014).

inflation target set by the CBRT. Seasonal adjustment is handled via TRAMO/SEATS (Gómez and Maravall 1996). The initial values are set according to Chan and Hsiao (2011).[31]

3.1 Benchmark Model Results

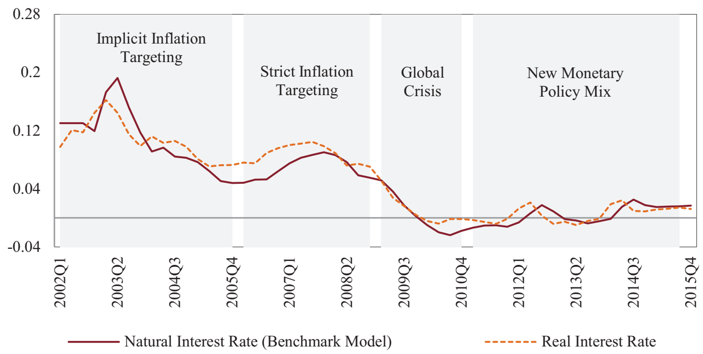
Estimation results of the benchmark model are presented in figure 1. Accordingly, model-consistent estimates for the natural rate, real interest rate, inflation, potential output, output, and output gap are illustrated over the analyzed period. In addition, actual values for the real interest rate, output, and inflation are also depicted in order to assess the plausibility of the estimation results. The analysis provides a graphical breakdown of the CBRT's regime switches, which are explained in detail in footnote 28. In particular, the monetary policy conduct is categorized as implicit inflation targeting, strict inflation targeting, global crisis, and new monetary policy mix for the periods 2002:Q1–2005:Q4, 2006:Q1–2008:Q4, 2009:Q1–2010:Q4, and 2011:Q1–2015:Q4, respectively.

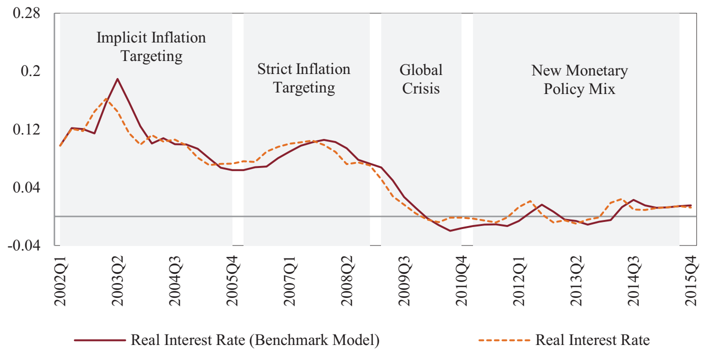
Against this background, figure 1 indicates that the model-consistent estimate for the natural interest rate mostly follows a downward path, which is in tandem with the actual real interest rate. In addition, the real interest rate estimate is reasonable given the actual real interest rate. Meanwhile, the estimated inflation rate is plausible with respect to the actual inflation rate during the analyzed period. Figure 1 also shows the model-consistent estimate for potential output and output gap besides output, which can simply be computed by equation (4).

A closer scrutiny reveals that the actual real interest rate and the estimated natural interest rate are mostly parallel despite occasional divergences. In particular, the natural interest rate estimate is above the real interest rate until 2004:Q1, while the model-consistent estimate for the real interest rate is also generally above the actual real interest rate during that period. Moreover, the inflation estimate is slightly higher than the actual inflation rate in the same period.

[31]The state-space representation for EKF is given in the appendix. Accordingly, it should be noted that the EKF needs predefined $P_{0|0}$, Q, R, and $\hat{x}_{0|0}$ for initialization. It is acceptable to assign $P_{0|0}$ arbitrarily; however, the values must be large enough to allow good tracking of the parameters. If the states are measured, $\hat{x}_{0|0}$ can be specified by taking the average of the first few data points.

Figure 1. Benchmark Model Results





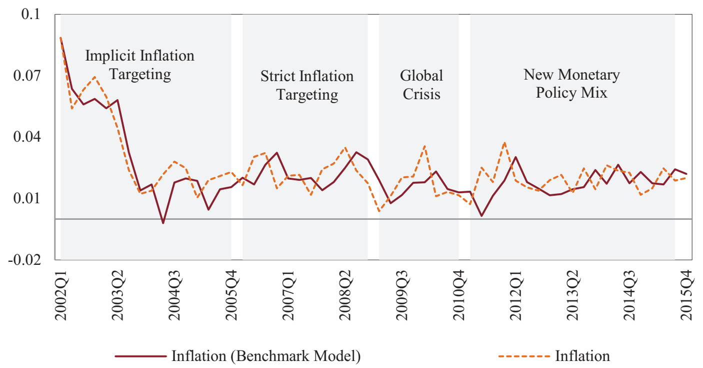
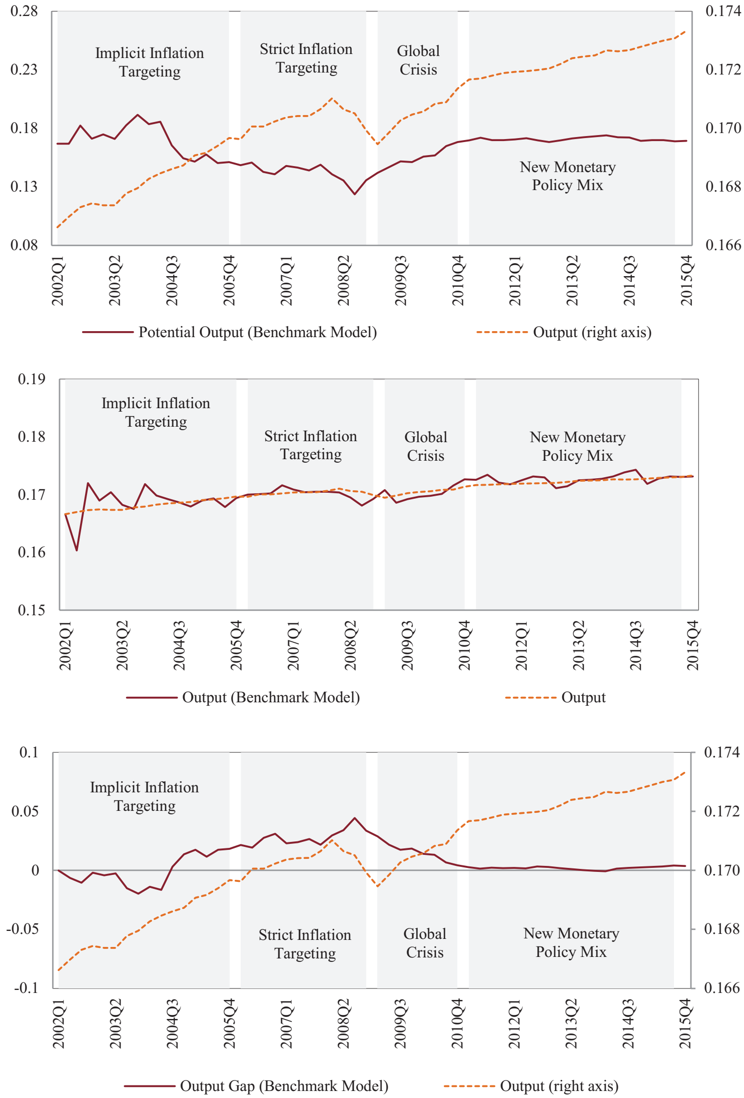


Figure 1. (Continued)



Hence, the model predicts a higher real interest rate and a slightly higher inflation rate, which may indicate that the policy rates were cut more aggressively and inflation fell more sharply than envisioned by the model.[32,33]

As of the first quarter of 2004, the benchmark model estimates the natural interest rate to be below the actual real interest rate. The gap between the two series gets wider from 2005:Q1 onwards when the natural interest rate estimate sets off for a rapid decline, whereas the actual real interest rate remains relatively unchanged during the same period. Starting from the first quarter of 2006, the natural interest rate starts to creep up, while the actual real interest rate also begins to increase.

In the meantime, the estimated real interest rate follows a slightly declining path close to the actual real interest rate between 2004:Q1 and 2004:Q4. During a brief period from 2004:Q4 to 2005:Q3, the real interest rate is estimated to be marginally higher than the actual real interest rate, whereas the real interest rate is expected to lag behind the actual real interest rate as of 2005:Q3. Hence, the model predicts the real interest rate and the inflation rate to be lower than their corresponding actual values, which indicates that there was room for an additional policy rate cut. This is especially valid immediately before and at the onset of the strict inflation-targeting regime period.[34]

[32]The policy rate was reduced from 57 percent in February 2002 to 26 percent in October 2003. The policy rate reduction was more accelerated during April–October 2003, with an initial rate cut of 300 basis points in April 2003, which was followed by regular cuts, pulling the policy rate to 26 percent in October 2003 (http://www.tcmb.gov.tr/wps/wcm/connect/tcmb+en/tcmb+en/main+page+site+area/cbrt+policy+rates/cbrt+interest+rates).

[33]Following the crisis in 2001, the CBRT acted decisively to combat inflation, which had been elevated for a long time, especially during the 1990s. Accordingly, actual inflation was recorded as 29.7 and 18.4 percent, undershooting the year-end inflation target set at 35 and 20 percent in 2002 and 2003, respectively. (http://www.tcmb.gov.tr/wps/wcm/connect/tcmb+en/tcmb+en/main+menu/monetary+policy/price+stability/inflation+targets).

[34]After delivering a policy rate cut of a total of 350 basis points in 2005, the CBRT was reluctant to reduce policy rates between January and March 2006, given the absence of signs for an improvement in the medium-term inflation outlook (CBRT 2006a, 2006b, 2006c). Consequently, the CBRT delivered a moderate policy rate cut of only 25 basis points in April 2006 (CBRT 2006d). On the other hand, the unforeseen financial turbulence driven by international conditions in

Yet, the story changes starting from the last quarter of 2007, as the estimated real interest rate series stays above the actual real interest rate, which suggests that a more preemptive monetary policy could have been implemented against the impending global crisis.[35] This is also reflected in the difference between the natural interest rate and the actual real interest rate, as the gap almost disappears in the first half of 2008 against the relatively sharper fall in the actual real interest rate. Yet, the gap rewidens as the natural interest rate declines rapidly in the second half of 2008, whereas the real interest rate rises during the same period. On the other hand, from 2009:Q1 to 2009:Q4, the natural interest rate decreases remarkably, while the actual real interest rate also drops significantly.

The radical decrease in the actual real interest rate may obviously be due to the adoption of extraordinary expansionary measures against the adverse effects of the global crisis.[36] Meanwhile, the fall in the natural interest rate may be the result of the global downturn that was experienced during that period. In particular, this downturn might have pulled down the natural interest rate amid changes in global demand and supply, which unfavorably affect the foreign demand for domestic goods. As a matter of fact, the natural interest rate falls even below zero in the first quarter of 2010 due to lingering weaknesses in the global economy, which had further adverse effects on the domestic economy. In the meantime, the actual real interest rate hits negative values in 2010:Q1. Despite the CBRT's exit from anti-crisis easing measures in the second quarter of 2010, the actual real interest rate remains below zero.[37]

May 2006 necessitated an aggressive policy rate hike. Accordingly, the CBRT raised the policy rates by a total of 425 basis points between June 8 and July 21, 2006 (CBRT 2006e, 2006f, 2006g).

[35]Following the major rate hike in July 2006, which pushed the interest rates up to 17.50 percent, policy rates were reduced gradually to 15.25 percent until February 2008. However, starting from May 2008, policy rates were raised with three consecutive hikes to 16.75 percent in July 2008 against the blurry outlook in financial markets, while further rate hikes were also signaled (CBRT 2008).

[36]From October 2008 to end-2009, policy rates were cut aggressively from 16.75 percent to 6.50 percent.

[37]The CBRT announced its exit strategy regarding the withdrawal of anti-crisis measures and normalization of the monetary policy on April 14, 2010 (CBRT 2010).

After reaching the bottom in the third quarter of 2010, the natural interest rate starts to climb up slightly. However, the benchmark model still envisions a negative natural interest rate. In fact, the natural rate is estimated to be below zero until the end of the first quarter of 2012. This may be attributed to the euro-zone debt crisis, which had unfavorable effects on the Turkish economy.[38] In the meantime, the real interest rate estimate is also negative in the same period and lower than the actual rate, implying that the monetary policy should have been looser.[39] Meanwhile, the inflation estimate rises sharply yet lags behind the actual inflation figures.

Starting from the last quarter of 2011, which is marked by the launch of occasional implementation of additional monetary tightening, the actual real interest rate starts to rise rapidly above

[38]The sovereign debt problems in some euro-zone countries led to an escalation of global risk aversion, thus resulting in sudden outflows of capital from emerging market economies, including Turkey. The so-called euro-zone debt crisis was felt heavily from August 2011 to June 2012, causing unfavorable risk perception towards Turkey, which also led to elevated volatility and deteriorated current account balance (Akçelik et al. 2013).

[39]The CBRT started to conduct the new monetary policy mix at end-2010 in an environment of strong capital inflows and an overvalued exchange rate. Hence, the monetary policy conduct was mostly oriented towards containing the adverse effects of these massive capital inflows on financial stability. This was sought to be achieved via lower overnight borrowing rates and a wider interest rate corridor along with tightened required reserve ratios, which are differentiated by maturity. In addition, the CBRT held regular FX purchase auctions in return for Turkish lira liquidity injection where the pre-announced amounts would be set according to the perceived strength of the capital inflows. However, these measures led to a significant increase in liquidity, which was fed into credit growth, widening the current account deficit and elevating inflationary pressures. Besides, the deteriorated global risk appetite due to the euro-zone debt crisis caused reversal in capital flows. Against this background, the CBRT started to hold FX sale auctions in order to provide FX liquidity in return for TL liquidity, and also reduced the volumes of quantity auctions. Furthermore, the interest rate corridor was widened upwards, while the reserve requirement ratio for TL liabilities was reduced. In the meantime, overnight interest rates were adjusted via day-to-day liquidity policy in response to the course of economic and financial developments without changing the policy rate. Against this tightening bias, the CBRT preferred to deliver the necessary tightening via episodes of additional monetary tightening, a tool that has occasionally been used as of end-2011 in order to prevent undesired exchange rate movements from deteriorating the inflation outlook through pass-through and expectations (IMF 2012; Akçelik et al. 2013).

zero.[40] Meanwhile, the natural interest rate increases but still remains in the negative territory until the second quarter of 2012. However, the increase is rather short-lived and the natural interest rate continues to be negative in the first quarter of 2013. In fact, the natural interest rate remains negative around zero for a considerably long period of time until the end of the first quarter of 2014. However, as of the second quarter of 2014, the natural interest rate starts to rise and remains unchanged above zero since the last quarter of 2014.

In the meantime, the real interest rate estimate is higher than the actual interest rate during the implementation of additional monetary tightening. However, the benchmark model predicts the real interest rate to be negative and close to the actual real interest rate during the first half of 2013, whereas in the second half, the model predicts a lower-than-actual real interest rate, which is also negative.[41] Even though the actual interest rate turns positive in the first quarter of 2014, the real interest rate estimate is still negative during this period. However, following a parallel move with the actual interest rate, the estimate for the real interest rate also turns positive in the second quarter of 2014.[42] After a period of small deviation between the two series during the second half of 2014, the real interest rate estimate almost converges with the actual real interest rate as of the beginning of 2015.

[40] In the last quarter of 2011, monetary policy had been oriented towards containing the upside risks to inflation due to weakening of the domestic currency driven by worsening risk appetite amid the euro-zone debt crisis. In response, the CBRT delivered a sizable lending rate hike in October 2011 and also implemented additional monetary tightening by widening the interest rate corridor upwards and reducing the amount of funding provided by the weekly repo auctions (Başçı and Kara 2011).

[41] The decisive steps taken to resolve the euro-zone debt crisis resulted in lower prospects for a sudden stop in capital flows in early 2012. Meanwhile, global risk appetite improved considerably. Hence, the CBRT opted for a gradual monetary easing and provided ample liquidity to the market in the third quarter of 2012. Accordingly, real interest rates fell significantly in early 2013 and reached negative values (Kara 2013).

[42] Upon the Fed's taper signal in May 2013, global risk appetite started to decline, which led to sudden outflows of capital from emerging economies, including Turkey. The elevated uncertainty regarding the Fed's exit from quantitative easing resulted in an excessive depreciation of the Turkish lira and volatility in financial markets. This caused the CBRT to adopt a tight liquidity policy and to raise the upper band of the interest rate corridor in July 2013, which was followed by a front-loaded monetary tightening in August 2013. Consequently, both nominal and real interest rates increased notably (CBRT 2014, 2015b).

Meanwhile, the benchmark model produces an output series, which is slightly more fluctuating than the actual output in general. In particular, the model envisions higher yet volatile output during the early phases of the implicit inflation-targeting regime. However, the model predicts lower output at the onset of the global crisis, which is expected to recover strongly afterwards. The model envisages somewhat higher, but slightly more volatile output during the new monetary policy mix implementation.

As for the potential output, the benchmark model's estimate is plausible, as the series is able to capture the major turning points of the economy. To be specific, the estimated potential output is on a mild upward track during the early phases of the implicit inflation-targeting regime. However, the series starts to follow a downward trend until the beginning of the global crisis, which is succeeded by a sharp decline. The potential output recovers quickly after the global crisis, and it settles on a plateau as of 2010. The potential output estimate is considered to be successful, as the series parallels the actual output especially in portraying the sharp decline during the global crisis and the subsequent strong recovery. The estimated potential output series is also able to depict the modest trend of growth in the economy during the 2010–15 period.

As for the output gap, in tandem with the upward course of the potential output series in the early phases of the implicit inflation-targeting regime, the estimated output gap series is negative, hinting at the absence of demand-side inflationary pressures. Parallel to the downtrend of the potential output series until the onset of the global crisis, the estimated output gap takes on positive values, implying that inflation has been exposed to demand-side pressures. The relatively higher increase in potential output than the actual output in the aftermath of the global crisis is reflected as a narrowing output gap, which indicates that the demand-side inflationary pressures have alleviated in this period. The flat course of the potential output and the moderate uptrend in output as of 2010 cause the output gap to close in the same period. This may be attributed to the implementation of tight monetary policy during this episode.[43]

[43]It should be noted that this paper focuses on estimating the natural interest rate. Hence, the measurement of potential output and the output gap may not be as sophisticated as those in other models, which only compute these series

Finally, the benchmark model produces an inflation series, which moves in line with the actual inflation. Both series follow a similar course, except for the last quarter of 2002 and the second quarter of 2004 when the benchmark model predicts a fall in inflation in contrast to the rise in actual inflation. Similarly, in the early phases of the global crisis period, the benchmark model envisions that the estimated inflation series increases at a relatively milder pace than the actual inflation. The benchmark model also envisages a lower and less volatile inflation during the implementation of the new monetary policy mix.

3.2 Alternative Model Results

In order to check the robustness of the model specification, the dynamic homogeneity constraint is imposed as an alternative to the benchmark model. The estimation results that are presented in figure 2 show that the restriction leaves the estimated natural interest rate series almost unchanged from the benchmark model. The same conclusion can be drawn for the real interest rate estimate.

On the other hand, imposing the dynamic homogeneity constraint results in relatively higher potential output and a lower output gap than estimated by the benchmark model. However, the constraint seems to have no major impact on these two estimates during the implementation of the new monetary policy mix. Meanwhile, the output produced by the alternative model is almost equal to the benchmark model's estimate, except for a brief period in 2003 during the strict inflation-targeting regime where the alternative model forecasts a strong fall. During the same period, the alternative model predicts higher inflation than envisioned by the benchmark model. Otherwise, the inflation estimate of the alternative model closely follows that of the benchmark model.

such as Özbek and Özlale (2005), Kara et al. (2007), Alp, Ögünç, and Sarıkaya (2012), and Erdoğan-Coşar, Kösem, and Sarıkaya (2012). Also, the estimate for the output gap may not necessarily follow the official output gap forecasts, which are produced for the latest twelve-month and the upcoming three-year period. Yet, the output gap estimate during the implementation of the new monetary policy mix is more successful, as it is consistent with IMF (2013, 2014).

Figure 2. Alternative Model Results

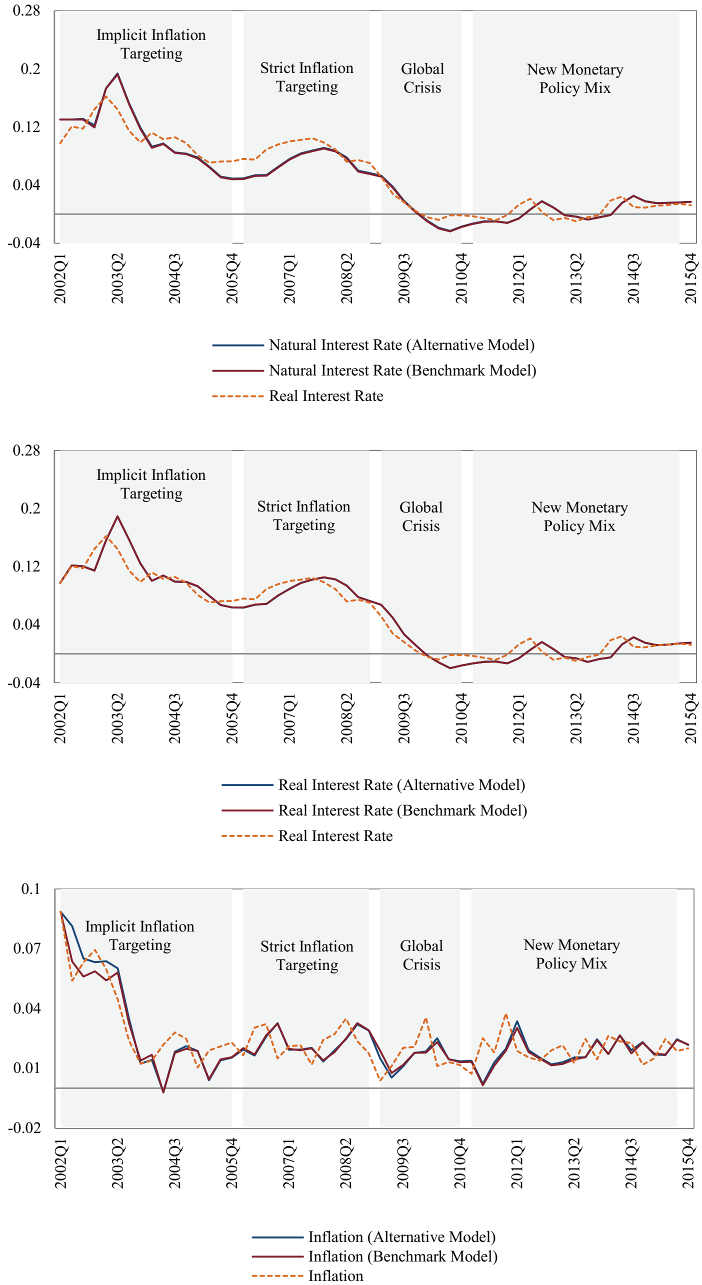
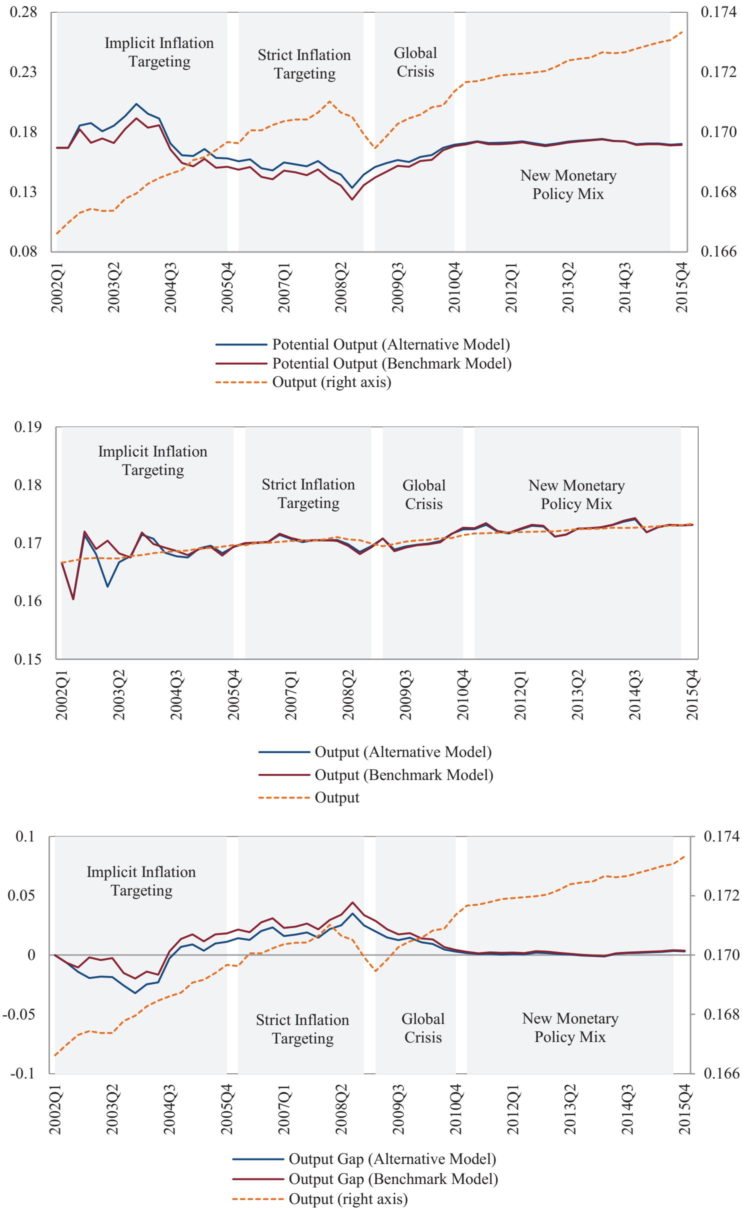


Figure 2. (Continued)



3.3 Smoothing Algorithm Results

As an additional step to check the robustness of the model specification, the Rauch-Tung-Striebel (RTS) smoothing algorithm is applied. The RTS is a two-pass smoother, which consists of a forward-pass EKF with a backward recursion smoother.[44]

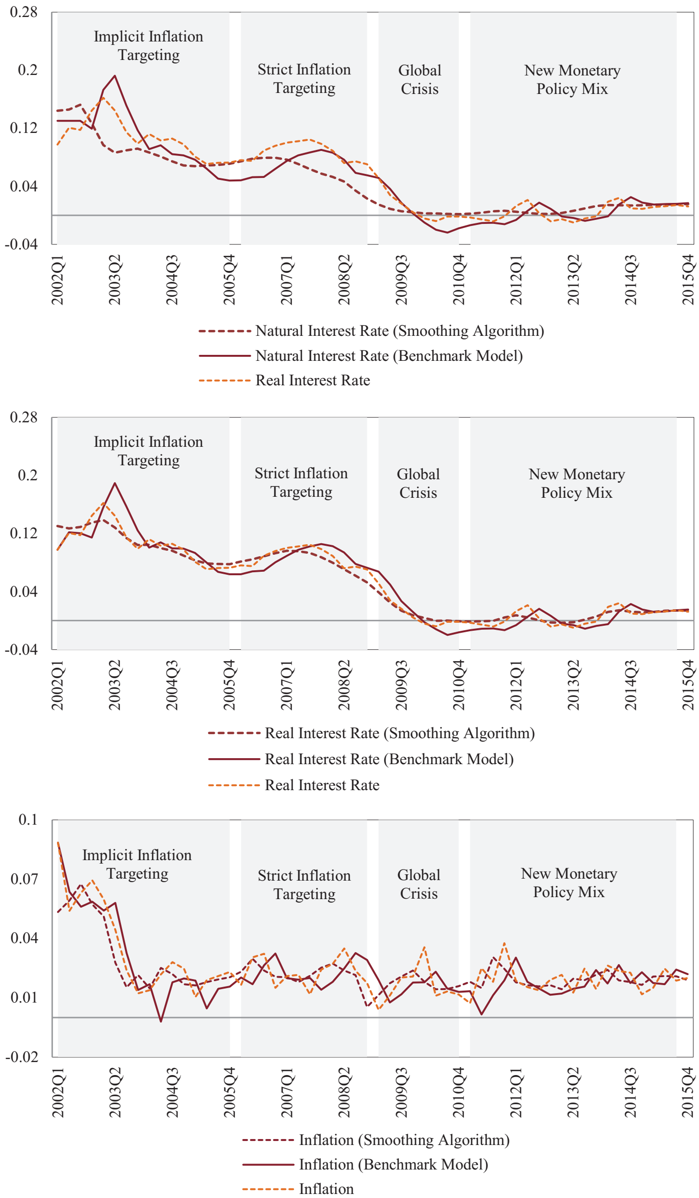
Figure 3 presents the estimation results of the application of the RTS algorithm to the benchmark model. As expected, the algorithm produces a smoother natural interest rate estimate than the benchmark model. In general, the new estimate is observed to be lower than that of the benchmark model until end-2009. However, starting from 2010, the algorithm produces a smoother series around zero, yet this fails to capture the negative zone experience as predicted by the benchmark model. The algorithm also smooths out the subsequent peak observed during the third quarter of 2012, which is followed by a decline. The smoothed series is close to the benchmark model's estimate as of 2015, which is marked by a period of relatively flat natural interest rate above zero.

As for the real interest rate, the RTS algorithm improves the results, as the smoothed series is closer to the actual real interest rate than the benchmark model's estimate. This observation is also valid for inflation, as applying the RTS algorithm results in smoother inflation series, which better reflects the actual inflation dynamics.

Meanwhile, the RTS algorithm causes virtually no significant difference in the potential output estimate as of end-2009 onwards. This corresponds to the global crisis period and the implementation of the new monetary policy mix. Otherwise, the smoothed series implies a lower potential output, which is slightly less volatile. Consequently, the output gap estimate under the smoothing algorithm is similar to that of the benchmark model during the global crisis period and the implementation of the new monetary policy mix. However, in other periods, the RTS algorithm implies a slightly higher output gap with relatively lower volatility. Meanwhile, the smoothed output series is more successful in describing the dynamics of the actual output.

[44]For further details on the RTS smoother, see Rauch, Striebel, and Tung (1965).

Figure 3. Smoothing Algorithm Results



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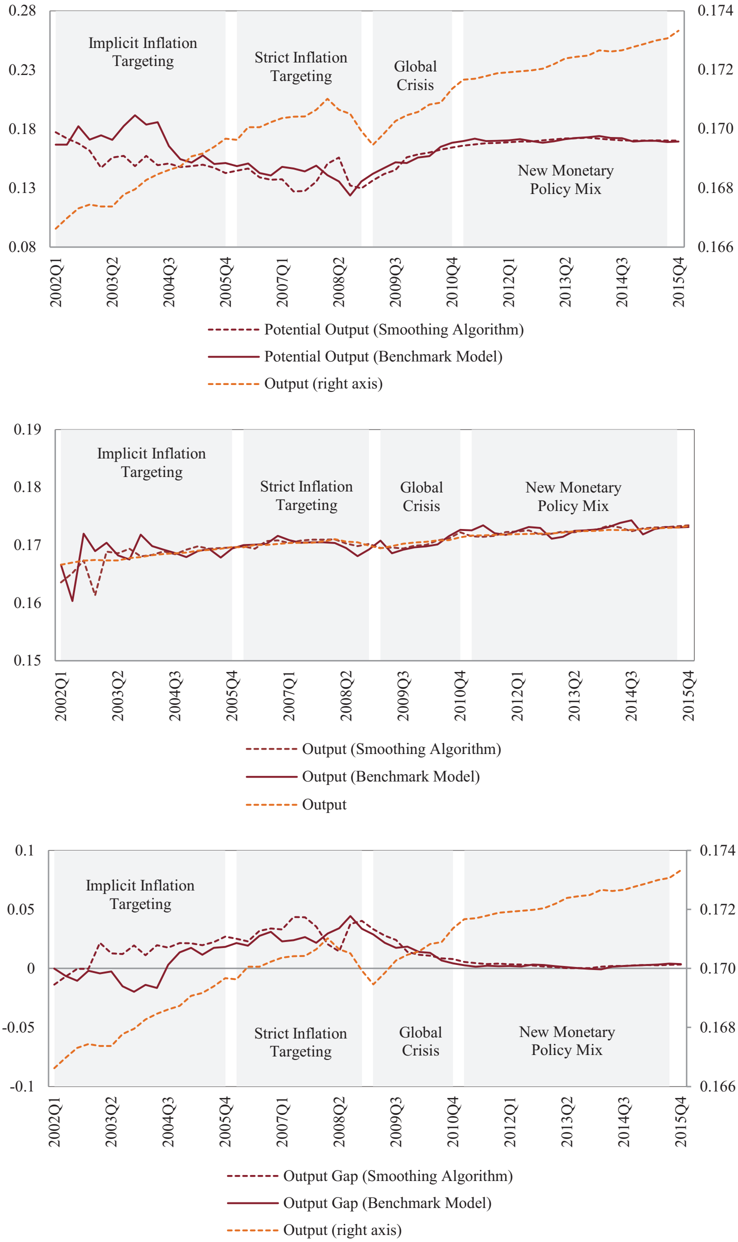


3.4 Alternative Measures of Inflation Target

As a final step in the improvement of the results, the inflation target is replaced with alternative target measures. Accordingly, the official inflation target is replaced with the twelve-month-ahead expected inflation series obtained from the CBRT's Survey of Expectations.[45]

The same exercise is repeated with the year-end inflation expectation. Using alternative target measures may enable one to see whether the model is sensitive to periods of divergences of expectations from the official inflation target.[46] Accordingly, figure 4 shows that the estimation results differ only marginally. In particular, the year-end inflation expectation produces a slightly lower natural interest rate during the implicit inflation-targeting regime, while natural interest rate estimates are similar otherwise.

The same finding is observed for the real interest rate. More specifically, the real interest rate estimate is lower during the implementation of the implicit inflation-targeting regime when the official inflation target is replaced with the year-end inflation target. However, real interest rate estimates are similar under all specifications in other periods.

3.5 Time-Varying Parameters

Figure 5 presents the time-varying parameters produced under the benchmark model and the alternative model as well as the smoothing algorithm. Accordingly, α_1, the coefficient of the lagged inflation

[45]The CBRT has been conducting a bi-monthly survey since August 2001 in order to assess expectations of selected professionals in the finance and corporate sector on major macroeconomic indicators. For details, see http://www.tcmb.gov.tr/wps/wcm/connect/tcmb+en/tcmb+en/main+menu/statistics/tendency+surveys/survey+of+expectations.

[46]The inflation target is determined jointly by the CBRT and the government as stipulated by the Central Bank Law No. 1211. The target was set as point targets during the implicit inflation-targeting regime between 2002 and 2005. However, since 2006, the target has been set as a midpoint target with a 2 percent uncertainty band. The CBRT succeeded in undershooting the inflation target for four consecutive years during 2002–05. However, since 2006, the target has been breached every year, except in 2009 and 2010, when the target was revised to 7.5 and 6.5 percent, respectively, from the previously set 4 percent. For details, see http://www.tcmb.gov.tr/wps/scm/connect/tcmb+en/tcmb+en/main+menu/monetary+policy/price+stability/inflation+targets.

Figure 4. Alternative Measures of Inflation Target

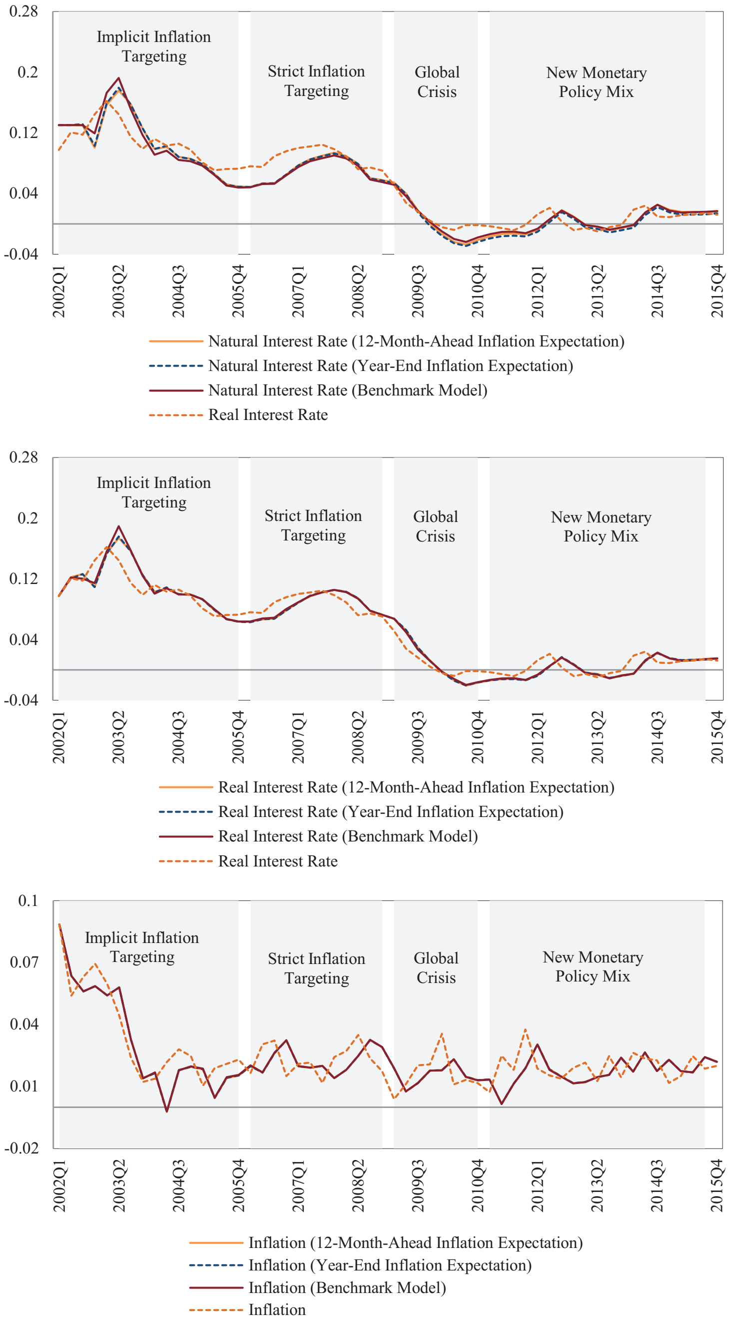
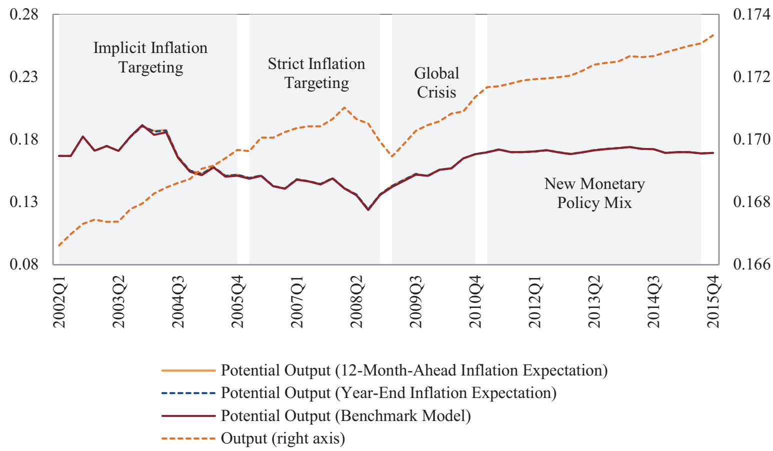
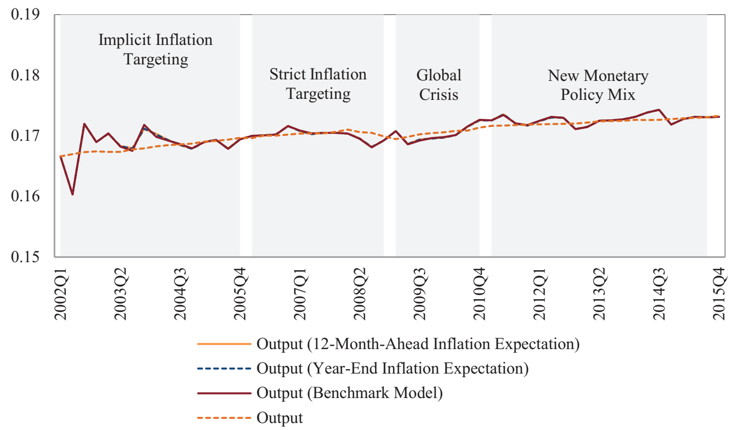


Figure 4. (Continued)





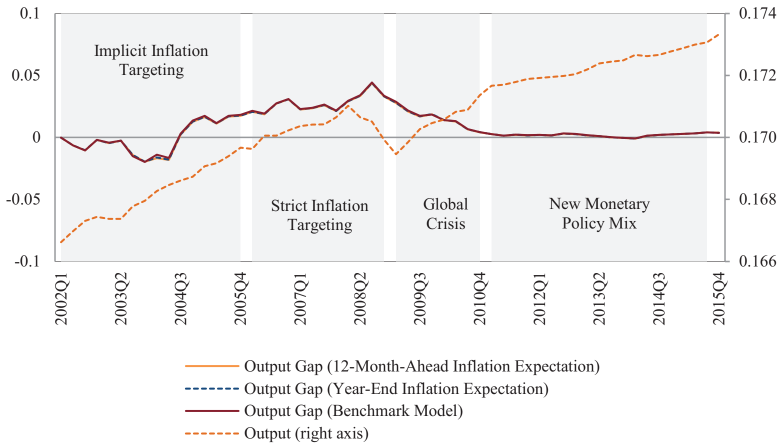
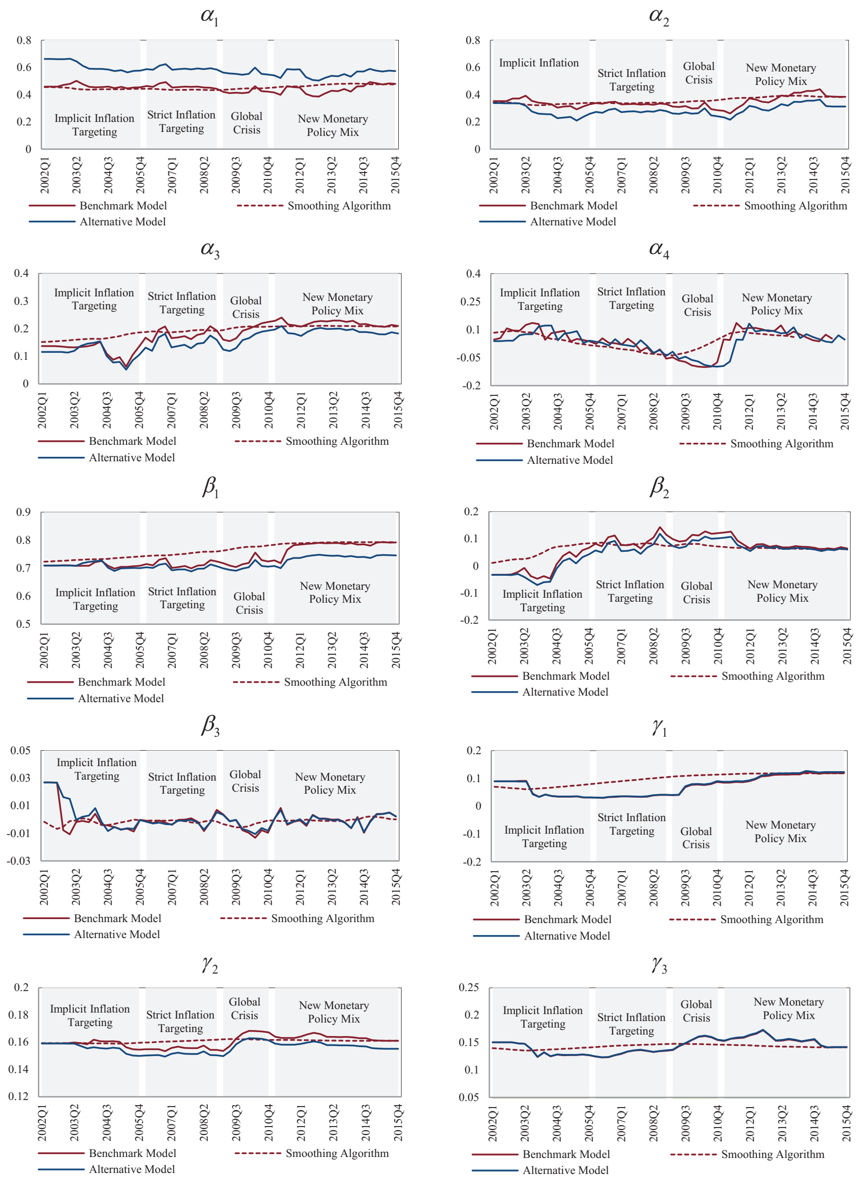


Figure 5. Time-Varying Parameters



term in the Phillips curve, shows that the inflation persistence is higher but gradually declining in the alternative model until the adoption of the new monetary policy mix. Meanwhile, inflation persistence is lower and relatively constant in the benchmark model and under the smoothing algorithm. The adoption of the new monetary policy mix reduces the persistence in the benchmark model as well as in the alternative model. However, inflation persistence increases in both models as of end-2012, while it remains unchanged under the smoothing algorithm.

Meanwhile, α_2, which denotes the coefficient of π_{t-2}, is relatively higher in the benchmark model compared with the alternative model. Yet, the coefficients in both models follow a similar course, which is mildly downwards during the implicit inflation-targeting regime but relatively stable in the strict inflation-targeting period.

The coefficient in both models declines during the global crisis. However, with the adoption of the new monetary policy mix, the coefficient assumes a significantly upward course. Yet, recently, α_2 is relatively stable in both models. On the other hand, α_2 is steady but relatively higher at the end of the analyzed period compared with the beginning of the implicit inflation-targeting regime under the smoothing algorithm.

The analysis shows that α_3, the coefficient of the output gap in the Phillips curve that captures the demand-side inflationary pressures, is comparatively higher in the benchmark model than the alternative model. The coefficient increases at a fluctuating course in both specifications until the end of the global crisis, whereas it follows a mild upward trend during the same period under the smoothing algorithm. The coefficient is steady in all specifications during the implementation of the new monetary policy mix.

The results indicate that α_4, the coefficient of the exchange rate in the Phillips-curve equation that signifies supply-side inflationary pressures, declines in all specifications until the end of the global crisis. However, the downward course followed by the coefficient is slightly volatile in both the benchmark model and the alternative model. The coefficient displays a sharp rise with the adoption of the new monetary policy mix, yet resettles on a downward course as of the beginning of 2012 in all models.

The feedback parameter β_1, which is the coefficient of the lagged output gap in the IS curve, is almost constant until the end of the global crisis. On the other hand, the smoothing algorithm implies a steady upward course for β_1 during the same period. Hence, the coefficient produced by the smoothing algorithm is relatively higher compared with other specifications, while the alternative model envisions a slightly lower coefficient compared with the benchmark model.

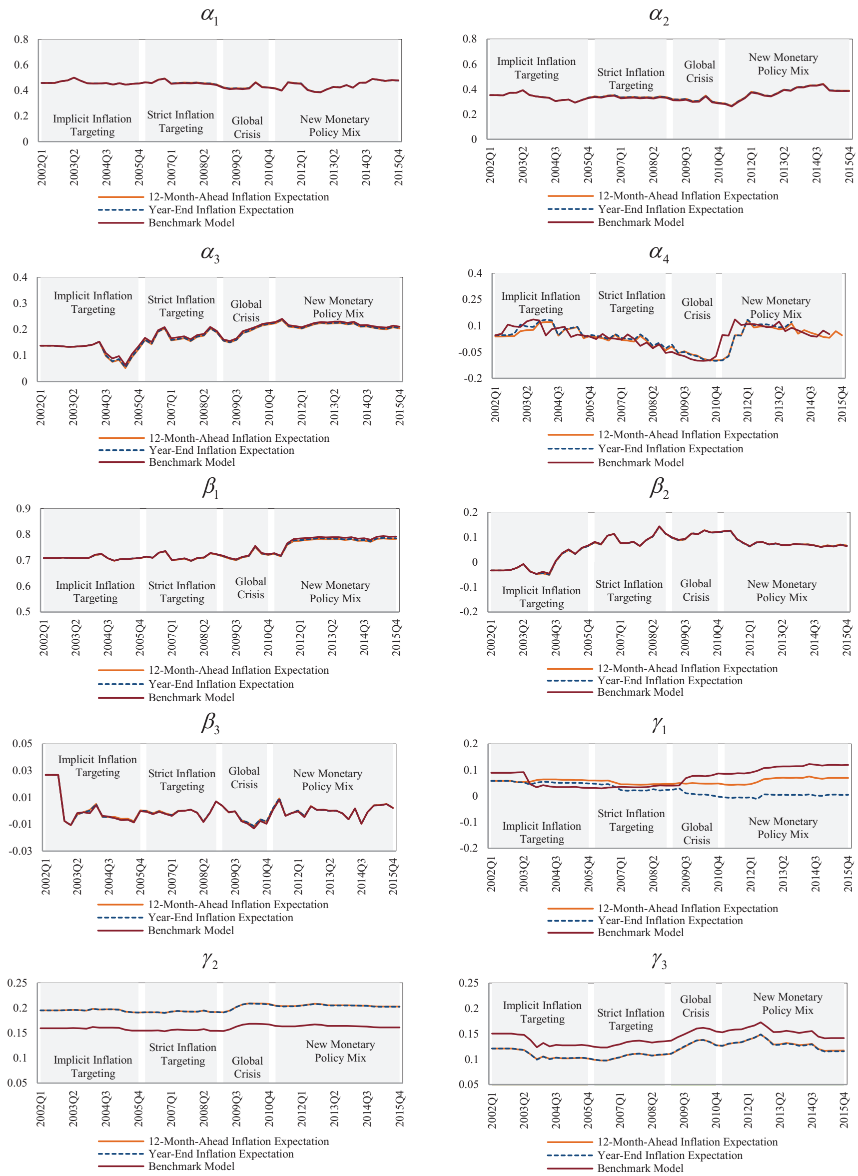
The adoption of the new monetary policy mix causes the coefficient to display a rise in both the benchmark model and the alternative model, yet this is more evident for the former. However, following this initial jump, the coefficient stabilizes in both specifications as of end-2011. In the meantime, the coefficient is stable under the smoothing algorithm.

The coefficient of the real interest rate in the IS curve that is denoted by β_2 rises in the benchmark model and also in the alternative model until the end of the global crisis. The coefficient is relatively higher in the benchmark model than in the alternative model. The adoption of the new monetary policy mix causes the coefficient to register a sharp decline in both models, while the coefficient remains constant as of the beginning of 2012. Meanwhile, the coefficient produced under the smoothing algorithm follows an upward course during the implementation of the implicit inflation-targeting regime but settles on a steady path afterwards.

As for the coefficient of the exchange rate in the IS curve that is denoted by β_3, except for the decline experienced during the implicit inflation-targeting regime, the coefficient is volatile but relatively constant in both the benchmark model and the alternative model. On the other hand, the coefficient is noticeably less fluctuating under the smoothing algorithm.

Regarding the parameters of the Taylor rule, the coefficient for the deviation of the lagged inflation term from the inflation target, which is represented by γ_1, is almost equal in both the benchmark model and the alternative model, whereas it is higher under the smoothing algorithm except for a brief period at the start of the implicit inflation-targeting regime. After a decline in the third quarter of 2003, both models predict the coefficient to be stable until the global crisis, while the smoothing algorithm foresees a mildly upward course during the same period. On the other hand, the global crisis instigates a steady rise in γ_1, which is followed by a horizontal course as of the third quarter of 2012 in both models. However, the

Figure 6. Time-Varying Parameters under Alternative Measures of Inflation Target



coefficient is flat under the smoothing algorithm during the same period.

The coefficient of the output gap in the Taylor rule that is denoted by γ_2 is higher in the benchmark model than that produced by the alternative model. The coefficient declines marginally in both models until the global crisis. However, with the onset of the global crisis, the coefficient rises sharply and settles at a higher plateau afterwards. Meanwhile, the smoothing algorithm produces an almost constant coefficient throughout the analyzed period.

Finally, the coefficient of the lagged interest rate term in the Taylor rule, which is represented by γ_3, is almost similar in the benchmark and the alternative model specifications. Following a drop in the second quarter of 2003, the coefficient remains stable in both models until the global crisis. However, the coefficient rises slightly during the global crisis and also with the adoption of the new monetary policy mix. The coefficient declines as of the third quarter of 2012. Meanwhile, the coefficient is constant under the smoothing algorithm throughout the analyzed period.

Figure 6 displays the time-varying parameters of the benchmark model in comparison with the alternative inflation target measures. Accordingly, the Phillips-curve and the IS-curve coefficients remain unchanged, while the parameters of the Taylor rule differ considerably with alternative target measures. In particular, γ_1 declines quite notably with the global crisis, with the year-end inflation expectations producing the lowest coefficient. Meanwhile, γ_2 increases significantly, whereas γ_3 decreases remarkably under alternative inflation target measures.

4. Conclusion

The natural interest rate is a vital concept in representing the monetary policy stance. By definition, the natural interest rate is the real interest rate level, which is consistent with stable output and inflation. Yet, attempting to model natural interest rate in an emerging economy, like Turkey, where inflation has not been stable is obviously a problem. This problem gets even worse considering the fact that the Turkish economy is also characterized by highly volatile output and rapidly changing macroeconomic dynamics. Apparently, conventional methods for estimating natural rates may fail to capture this volatility and produce too-smooth trends.

This paper takes the above discussion as its starting point and attempts to estimate the natural interest rate for the Turkish economy. The empirical framework is based on a system of equations, which is in the spirit of Laubach and Williams (2003). However, in view of the highly volatile nature of the Turkish economy, this study improves this methodology by introducing time-varying parameters into the model. Since time-varying parameters and state variables are estimated simultaneously, the model presents non-linearity that can be handled via EKF.

EKF is a useful algorithm that can successfully control the issue of non-linearity introduced by the requirement to simultaneously estimate time-varying parameters and solve the state problem. Moreover, the use of EKF avoids the problem of finding a "too-smooth trend" without having to resort to the strong restrictions that are imposed on the parameters in previous studies.

The results reveal that the estimated series and the parameters are fairly reasonable. The natural interest rate moves in tandem with the actual real interest rate, yet the series is also sensitive to major shocks, which are believed to have an impact on the natural interest rate. In particular, the global crisis is assessed to be a significant shock, which has changed the dynamics of the economy. The period after the global crisis is dominated by the post-crisis spillovers from advanced economies to emerging markets, which require the implementation of unconventional policies and extraordinary measures in both country groups. Yet, this causes policy rates to be stuck at the zero lower bound and to decline even into the negative zone. The underlying reasons for these may obviously have important implications for the natural interest rate as well.

As for the Turkish economy, even though the monetary policy conduct after 2010 entails the joint use of multiple tools, financial market players continue to be curious about the level of the short-term policy rates by keeping a more-than-ever watchful eye on the policy rate announcements of the CBRT in this period. This is mainly due to the fact that of all the monetary policy instruments that are in the CBRT's toolkit, the short-term interest rate is the simplest one to be publicly understood and communicated.

Therefore, knowing the true level of the natural interest rate is important, as it provides information regarding how far the real interest rate is from this natural rate.

Meanwhile, the assessment of the model shows that the estimated real interest rate and inflation are plausible as they move parallel to their respective originals. Moreover, the same observation is true for the output and also for the potential output, which captures the major turning points of the actual output without following a too-smooth trend. The estimated output gap is also able to represent the stance of the demand-side inflationary pressures in the economy. These observations are valid not only for the benchmark but also for the alternative model under the dynamic homogeneity constraint. Also, the smoothing algorithm and alternative target measures leave the results virtually unchanged. Hence, one can conclude that the models are robust and correctly specified.

On the other hand, it should be noted that the estimations are based on aggregate data on output and inflation. Clearly, aggregate demand and inflation may have different dynamics by subcategories. In particular, the degree of persistence and the sensitivity of inflation to the exchange rate and the output gap may change if disaggregated data is used for inflation and output. This affects the derivation of the natural interest rate series.[47]

In conclusion, this paper serves useful for further research on measuring the natural interest rate in Turkey, which is a significant yet underexplored issue. In addition, the study contributes to the existing literature by jointly estimating the natural interest rate and its time-varying relationship with macroeconomic variables. Also, this multivariate framework produces unobserved variables like potential output and output gap besides significant variables like real interest rate, output, and inflation. Moreover, this setting generates time-varying parameters that denote inflation persistence and the contribution of demand- and supply-side factors to inflation. These parameters capture the determinants of aggregate demand and the

[47]For further details on the sensitivity of estimation results to using disaggregated data, see Altissimo, Mojon, and Zaffaroni (2009), Öğünç and Sarıkaya (2011), Özçiçek (2011), Alp, Öğünç, and Sarıkaya (2012), Başer, Kösem, and Öğünç (2012), Erdoğan-Coşar, Kösem, and Sarıkaya (2012), and Tillmann (2012).

policy response to the output gap and the deviation of inflation from the target as well.

In addition, the paper places a special emphasis on the post-crisis period, where the inflation-targeting regime is adjusted to meet the supplementary objective of maintaining financial stability. In doing so, the results highlight the significance of the policy rate, which is closely monitored by market players despite the adoption of complementary monetary policy tools after the crisis. Meanwhile, the paper addresses the zero lower bound issue, which has dominated the advanced economies during this episode. But most importantly, this paper underlines the need to find an accurate measure for representing the stance of the monetary policy to meet the challenges induced by the post-crisis period. In doing so, the paper proposes the natural interest rate, which is sought to be estimated in this context.

Appendix

Non-linear State-Space Models and the EKF

A non-linear state-space model can be represented as

$$x_{k+1} = f_k(x_k) + H_k(x_k)\xi_k \tag{13}$$

$$y_k = g_k(x_k) + \eta_k. \tag{14}$$

The f_k and g_k are vector-valued functions, while $\xi_k k$ and η_k represent white-noise processes with the covariance matrices, Q_k and R_k, respectively. The starting values for the EKF algorithm are

$$P_0 = cov(x_0) \tag{15}$$

$$\hat{x}_0 = E(x_0). \tag{16}$$

As mentioned in Chui and Chen (1991), the updating equations can be written as

$$P_{k|k-1} = \left[\frac{\partial f_{k-1}}{\partial x_{k-1}}(\hat{x}_{k-1})\right] P_{k-1} \left[\frac{\partial f_{k-1}}{\partial x_{k-1}}(\hat{x}_{k-1})\right]' + H_{k-1}(\hat{x}_{k-1})Q_{k-1}H'_{k-1}(\hat{x}_{k-1}) \tag{17}$$

$$\hat{x}_{k|k-1} = f_{k-1}(\hat{x}_{k-1}) \tag{18}$$

$$K_k = P_{k|k-1}\left[\frac{\partial g_k}{\partial x_k}(\hat{x}_{k|k-1})\right] P_{k|k-1} \times \left[\left[\frac{\partial g_k}{\partial x_k}(\hat{x}_{k|k-1})\right] P_{k|k-1} \left[\frac{\partial g_k}{\partial x_k}(\hat{x}_{k|k-1})\right]' + R_k\right]^{-1} \tag{19}$$

$$P_k = \left[I - K_k\left[\frac{\partial g_k}{\partial x_k}(\hat{x}_{k|k-1})\right]\right] P_{k|k-1} \tag{20}$$

$$\hat{x}_{k|k} = \hat{x}_{k|k-1} + K_k\left[y_k - g_k(\hat{x}_{k|k-1})\right], \tag{21}$$

where equations (17)–(21) denote the optimal Kalman gain, the updated estimate covariance, the updated state estimate, the predicted estimate covariance, and the predicted state, respectively.

In order to apply EKF, the matrices in the state-space representation above should be written in terms of functions, which depend on the unknown parameter vector θ. In other words, let the matrices be represented by $\Phi_k(\theta)$, $G_k(\theta)$, and $H_k(\theta)$. Furthermore, let θ be a random-walk process. In this case, the above equations can be rewritten as

$$x_{k+1} = \Phi_k(\theta_k)x_k + G_k(\theta_k)w_k \tag{22}$$

$$y_k = H_k(\theta_k)x_k + v_k, \tag{23}$$

and the parameter vector is

$$\theta_{k+1} = \theta_k + \zeta_k. \tag{24}$$

The state-space representation using functional form is

$$\begin{bmatrix} x_{k+1} \\ \theta_{k+1} \end{bmatrix} = \begin{bmatrix} \Phi_k(\theta_k)x_k \\ \theta_k \end{bmatrix} + \begin{bmatrix} G_k(\theta_k)w_k \\ \zeta_k \end{bmatrix} \tag{25}$$

$$y_k = \begin{bmatrix} H_k(\theta_k)x_k & 0 \end{bmatrix}\begin{bmatrix} x_k \\ \theta_k \end{bmatrix} + v_k, \tag{26}$$

where equations (25) and (26) denote the state-space representation for the state and the observation vector, respectively. The above model is non-linear, for which EKF can be readily applied. ζ_k shows the white-noise process, for which the covariance matrix is assumed to be $cov(\zeta_k) = S_k = S > 0$. In the particular case where $S = 0$, the parameter vector is assumed to be time invariant, where EKF cannot be operative. If the EKF algorithm is applied to equations (25)–(26), depending on the following starting values,

$$\begin{bmatrix} \hat{x}_0 \\ \hat{\theta}_0 \end{bmatrix} = \begin{bmatrix} E(x_0) \\ E(\theta_0) \end{bmatrix} \tag{27}$$

$$\text{and } P_0 = \begin{bmatrix} cov(x_0) & 0 \\ 0 & S_0 \end{bmatrix}. \tag{28}$$

We obtain

$$\begin{bmatrix} \hat{x}_{k|k-1} \\ \hat{\theta}_{k|k-1} \end{bmatrix} = \begin{bmatrix} \Phi_{k|k-1}(\hat{\theta}_{k-1})\hat{x}_{k-1} \\ \hat{\theta}_{k-1} \end{bmatrix} \tag{29}$$

$$\begin{aligned} P_{k|k-1} = & \begin{bmatrix} \Phi_{k-1}(\theta_{k-1}) & \frac{\partial}{\partial\theta}(\Phi_{k-1}(\theta_{k-1}))\hat{x}_{k-1} \\ 0 & I \end{bmatrix} \\ & \times P_{k-1} \begin{bmatrix} \Phi_{k-1}(\theta_{k-1}) & \frac{\partial}{\partial\theta}(\Phi_{k-1}(\theta_{k-1}))\hat{x}_{k-1} \\ 0 & I \end{bmatrix}' \\ & + \begin{bmatrix} G_{k-1}(\hat{\theta}_{k-1})\hat{\theta}_{k-1}G'_{k-1}(\hat{\theta}_{k-1}) & 0 \\ 0 & S_{k-1} \end{bmatrix} \end{aligned} \tag{30}$$

$$\begin{aligned} K_k = & P_{k|k-1} \begin{bmatrix} H_k(\hat{\theta}_{k-1}) & 0 \end{bmatrix} P_{k|k-1} \\ & \times \left[\begin{bmatrix} H_k(\hat{\theta}_{k-1}) & 0 \end{bmatrix} P_{k|k-1} \begin{bmatrix} H_k(\hat{\theta}_{k-1}) & 0 \end{bmatrix}' + R_k\right]^{-1} \end{aligned} \tag{31}$$

$$P_k = \left[I - K_k \begin{bmatrix} H_k(\hat{\theta}_{k-1}) & 0 \end{bmatrix}\right] P_{k|k-1} \tag{32}$$

$$\begin{bmatrix} \hat{x}_k \\ \hat{\theta}_k \end{bmatrix} = \begin{bmatrix} \hat{x}_{k|k-1} \\ \hat{\theta}_{k|k-1} \end{bmatrix} + K_k \left[y_k - \left[H_k(\hat{\theta}_{k-1})\hat{x}_{k|k-1}\right]\right]. \tag{33}$$

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