A Survey on Time Varying Parameter Taylor Rule: A Model Modified with Interest Rate Pass Through

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Abstract

This paper intends to provide a broad survey of the literature on Taylor-type monetary policy rules with time-varying parameter (TVP) specification. To include TVP feature, we claim that some modification should be made in the monetary transmission mechanism of Taylor-type monetary policy models to account for altering risk preference of individuals. In line with this approach, we introduce an interest rate pass through specification of the monetary transmission process in a general equilibrium model to account for different perceptions of risk by individuals. We estimate the time variable parameters of the model by employing a structural extended Kalman Filter (EKF).

\textbf{Keywords:} Extended Kalman Filter, Interest Rate Pass Through, Monetary Policy, Taylor Rule, Time Varying Parameter

\textbf{JEL Classifications:} E43, E52, E58

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1. Introduction

Recently, New Keynesian models with microfoundations have gained a lot of attention. These models raise interest in reducing inflation volatility and accordingly inflation targeting in order to establish macroeconomic stability. Today, aims of central banking are to achieve price stability primarily and, to a lesser extent, output stability. In establishing price stability, design of optimal monetary policies and rules are essential according to New Keynesian models. In this context, short-term interest rates, used as policy instruments, are the key variables as suggested by Taylor (1993) and Woodford (2003). Importance of interest rate pattern for building efficient monetary policy rules, especially for inflation targeting countries, was further stressed by Taylor (1999a). Hence, it becomes essential for central banks to determine accurate interest rate rules to reach price stability in an economy (see, for example, Clarida et al., 1999, Taylor, 1993, and Taylor, 1999b).

In the last decade, considerable attention has been given to time-varying parameter (TVP) specification of monetary policy rules. There are mainly three reasons that emphasize the need for unsteady parameter specification. First, monetary policy rules are based on the attitude of policymakers towards the structure of the economy and opposing objectives of the monetary policy. Therefore, parameters of the interest rate rules are subject to change because of changing nature of the policy objectives and behavior of policymakers as in Favero and Rovelli (2003), Ozlale (2003) and Valente (2003).

Second, central banks utilize broader range of information set while building policy decisions instead of relying only on a single policy rule equation. Thus, for example, if the policy rule is a Taylor-type interest rate rule, then the same levels of output gap and inflation may not
produce the same level of interest rate in different periods since the information set used by central banks will be different in those periods. Besides, unstable nature of the coefficients of a policy rule can be explained by the presence of nonlinearities in the Central Bank's reaction function, which is another issue that should be addressed. For instance, Nobay and Peel (2003) discussed optimal discretionary monetary policy under the assumption that central bank has asymmetric loss function. For the monetary policy in the UK, Martin and Milas (2004) concluded that policymakers use discretionary policy for inflation targeting and monetary policy responds nonlinearly to inflation. Empirically, Dolado et al. (2005) argued that European Central Bank’s behavior can be explained by nonlinear optimal policy function opposite to the US Fed according to existing asymmetries in interest rate setting pattern. Later, Castro (2011) supported this finding so that European Central Bank and Bank of England follow nonlinear monetary policy rules whereas Federal Reserve of the United States acts according to a linear Taylor rule. However, Petersen (2007) previously found that the monetary policy of the US Fed could be associated with a nonlinear policy rule once inflation approaches to a certain threshold. Likewise, Surico (2007) investigated asymmetric behavior of the monetary policy of the US Fed. Variations in the monetary policy transmission mechanism can be the third reason for unstable nature of the coefficients of a policy rule. Thus, interest rate rules should be treated as they are dynamic instead of being static. Intuitively, due to shifts in the coefficients of policy rules, studies using stable parameters may be misleading or inefficient in formulating policy advices. Parallel to the Lucas (1976) critique, in order to conduct empirical policy analysis, changing parameter models are appropriate for accounting policy shifts contrary to fixed parameter models.
The aim of the present survey article is to review the literature on monetary policy rules with TVP specification for closed economy. Following Taylor (1993), numerous works studied implications of various versions of Taylor rule for different countries so, this line of research raised the utilization of Taylor-type interest rate rules in analyzing policy shifts. After the literature review, we will elaborate on the performance of the Taylor rule in transmitting monetary policy actions over the economy. Taylor rule conveys that firms and individuals face directly with short-term policy rate and shape their consumption and investment decisions according to this value. Our contribution will be at this point so, we claim that individuals do not face short-term policy rate directly. Instead, considering their risk and liquidity preferences, firms and households use another interest rate, long-term market interest rate, in making their consumption and investment decisions. Thus to account for risk preference of individuals, we will consider interest rate pass through specification in a structural model which is not investigated deeply to our knowledge. Our paper will contribute to the current debate on the efficiency of Taylor-type rules in explaining the monetary transmission mechanism in an economy. Another important aspect of our article is the introduction of extended Kalman Filter (EKF) technique as a new estimation

1 The theoretical literature has mainly assumed a closed economy framework. The literature that analyzes the open economy monetary policy tools are also exist. But in this survey article we would like to focus on only interest rate channel rather than the exchange rate channel. Since the main open economy alternatives may perform poorly in the face of specific types of exchange rate shocks, such as a rule based on a monetary conditions index (MCI). Since the MCI is a function of the real exchange rate, the MCI is influenced by events such as terms of trade shocks, and changes in business and consumer confidence, which do not necessarily affect interest rates.

2 Long-term interest rate plays an important role in conduct of monetary policy. Especially the recent financial crisis highlighted the importance of understanding alternative ways to conduct monetary policy. A potential use for long-term nominal interest rates is the possibility of using them as instruments of monetary policy. In fact previous research suggests that long-term interest rate rules share the desirable properties of Taylor rules, can support unique equilibria, and their performance is better than conventional Taylor rules (see, McGough et al., (2005), Kulish M (2007), and Gerlach-Kristen P and B Rudolf (2010), Jones and Kulish(2011)). In the United States, the United Kingdom, Canada, Japan and the euro area short rates have been close to zero during the recent crisis, long rates have remained well above, suggesting that there may be greater capacity to stimulate the economy with long-term rates.
methodology. That EKF is not widely employed for estimating non-linear systems in this field makes this study significant in demonstrating the strength of EKF in predicting TVP models. Section 2 will give the literature review on TVP monetary policy rules in detail. Section 3 will present the structural model and its dynamics. Section 4 will introduce interest rate pass through to our structural model and discuss the efficiency of Taylor-type policy rules. Section 5 will give brief information about the state space models and characteristics of EKF. Section 6 will conclude the study.

2. Literature Review on TVP Monetary Policy Rules

Substantial effort is devoted to monetary policy changes and TVP specification of monetary policy rules. The changes in policy implementation were tried to be captured by subsample analysis, generalized method of moments (GMM), least squares (LS), maximum likelihood estimation (MLE), vector autoregression (VAR), Markov switching and Kalman filter.

Judd and Rudebusch (1998) illustrated how the Fed’s reaction function has changed over time using ordinary least squares (OLS) and subsample analysis. The study resulted in that parameters of Taylor-type rule significantly differed for each sub period considered, indicating that monetary policy regime varies in time. This study also pointed out dependency of monetary policy on the attitude of policymakers towards the structure of the economy. Similarly, Clarida et al. (2000) presented that the US monetary policy has changed significantly before and after Paul Volcker was the chairman of the Fed using another estimation technique GMM. Parallel to these studies, Orphanides (2004) provided evidence about the changes in the interest rate rule of the US using the estimations of a forward-looking Taylor rule for two subperiods.
The studies that use Kalman filter to estimate TVPs of Taylor rule include Elkhoury (2006), Trecroci and Vassalli (2006), Trehan and Wu (2007) and Hatipoglu and Alper (2009). Elkhoury (2006) examined the TVP monetary policy rule for an open economy, Switzerland. The study used Kalman filter to embed policy shifts and structural changes into the model and found that uncertainty associated with the policy rule was mostly due to time-varying characterization of the parameters and, to a lesser extent, monetary shocks. Trecroci and Vassalli (2006) estimated forward-looking TVP Taylor rule for the UK, Germany, France, Italy and the US, using Kalman filter. It was demonstrated that the countries analyzed have different interest rate rules and TVP Taylor rules are preferred, compared to fixed parameter rules, in capturing the variations in the policy rates. Furthermore, the coefficients of the policy rules are changing over time in a gradual fashion. Trehan and Wu (2007) employed Kalman filter to predict a Taylor rule for the backward-looking US economy focusing on time-varying equilibrium real interest rate. It was interpreted that taking into account the time-variation in the equilibrium real interest rate makes substantial difference in the assessment of monetary policy. Hatipoglu and Alper (2009) estimate an augmented Taylor policy rule that responds to an exchange rate gap in the context of emerging markets utilizing Turkish data. To estimate time varying parameters and unobserved variables, such as exchange rate target and potential output simultaneously they employ a dual extended Kalman filter which allows them to trace any changes in central bank behavior including regime shifts. Boivin (2006), Jalil (2004), Kim and Nelson (2006) and Mandler (2007) used Kalman filter and MLE together to estimate time varying Taylor rule for the US. Jalil (2004) estimated a TVP backward-looking Taylor rule with ex-post and real-time data for the US and stated that there are gradual adjustments in the coefficients of the policy rule in the US, which cannot be captured adequately by sub-sample analysis. Boivin (2006) estimated forward-looking Taylor
rule for the US employing Kalman filter to construct likelihood function. The conclusion was similar to Jalil (2004) and Trecroci and Vassalli (2006) in the sense that the parameters of Taylor rule are changing slowly. Following Boivin (2006), Kim and Nelson (2006) attempted to characterize a forward-looking Taylor rule with TVP using ex post data. Besides TVP property, this study also considered the uncertainty included in the forecasts of future inflation and output gap. Two-step MLE procedure with Kalman filter was used to estimate the model and their empirical result was in favor of division of monetary policy history of the US into three periods instead of two (contrary to Orphanides, 2004). Mandler (2007) suggested Taylor rule with TVPs and unobserved components model for the output gap together to predict uncertainty in the future values of the Fed rate using MLE technique via Kalman filter. It was found that the predicted uncertainty can be divided into three namely, uncertainty due to time-dependent coefficients of the Taylor rule, uncertainty about the future economic events and residual uncertainty.

VAR representation with Kalman filter was also employed to model TVP Taylor rule as in Canova and Gambetti (2004), Cogley and Sargent (2001), and Mesonnier and Renne (2007). Cogley and Sargent (2001) showed empirically that after World War II, policy actions alter significantly with respect to the status of the economy, implying that coefficients in the policy rule are changing with time. A similar conclusion was drawn by Canova and Gambetti (2004) by examining changes in the structure of the US economy via structural VAR framework. Their work differs from Cogley and Sargent (2001) in the sense that structural shocks were also included in the analysis. For the euro area, Mesonnier and Renne (2007) examined TVP property of natural rate of interest. The study suggested a Taylor-type policy rule with time-varying natural rate of interest for the euro area using Kalman filter.
Plantier and Scrimgeour (2002) estimated Taylor rule with TVP specification employing Kalman filter with OLS to reveal that neutral real interest rate of New Zealand follows a downward trend in recent years. Horvath (2006) modeled various forms of fixed-parameter and TVP Taylor-type rules for the Czech Republic using GMM and Kalman filter. It was found that equilibrium interest rate has decreased steadily over time. In addition to previous works made for euro area, Kuzin (2006) estimated a backward-looking (opposed to forward-looking) Taylor rule with time-dependent coefficients using Markov switching models and Kalman filter, for Germany only. The conclusion was similar to the work of Trecroci and Vassalli (2006) so that TVP Taylor rule performed well in capturing the policy shifts.

Orphanides and Williams (2005) adopted time variation in parameters of the model by allowing agents to update their expectations about the structure of the economy and monetary policy. For this, they used VAR and OLS framework and investigated changes in the view of policymakers and monetary policy implementation in the US. Likewise, Sims and Zha (2006) documented inferences about monetary policy changes in the US by allowing time variation both in the coefficients of the Taylor rule and variances of shocks to the economy within a structural VAR framework. Models allowing changes in the parameters of disturbances and monetary policy function were found to be the best-fit models for the US data.

Wesche (2003) performed a TVP Taylor rule analysis for the countries considered in Trecroci and Vassalli (2006). A similar conclusion was reached using a different estimation procedure, Markov-switching model with independent switching processes for the TVPs of the Taylor rule and variances of disturbances. Later, Wesche (2006) showed changing preferences of policymakers for interest rate setting in a Markov-switching framework for the US, the UK and Germany. Markov-switching model was also employed by Owyang and
Ramey (2004) to measure the shifts in the parameters of the policy rule of the US Fed. Parallel to previous works, Partouche (2007) estimated a forward-looking TVP policy rule for the US, as well. Instead of Kalman filter this study adopted a different technique, which combined GMM framework with smoothing splines. Such a technique is not restrictive on econometric terms so that it imposes no constraints on the form of heteroscedasticity of the shock terms and the correlations between the regressors and disturbances. Likewise, McCulloch (2007) estimated TVP forward-looking Taylor rule for the US using a different method, adaptive least squares (Adaptive LS), to model time-varying structural VAR framework. Recently, Gerlach and Lewis (2010) used smooth transition regression model to show the shifts in the parameters of monetary policy rule of European Central Bank during the financial crisis. The summary of the literature on TVP policy rules is presented in Table 1.

**Table 1: Summary of Literature on TVP Policy Rules**

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<th>Methods</th>
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<td>Subsample</td>
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3. The Model

Our baseline macroeconomic framework is described with a dynamic general equilibrium model containing money. We will simply consider closed economy case. Frictions in the economy are provided by nominal price rigidities, which make the model more realistic (and exclude perfectly flexible price setting behavior). This rigidity is provided using Calvo (1983) type sticky price setting. Firms are monopolistically competitive and they produce differentiated goods, implying that goods markets are also monopolistically competitive. Infinitely lived households are the owner of the firms, that is, we have producer/consumer agents. The central bank uses short-term nominal interest rate as the monetary policy instrument. Therefore, money supply is determined endogenously to achieve determined level of nominal interest rate.

Households buy consumption goods, supply labor and hold bonds (via a financial agent) and money. Firms hire labor, produce differentiated goods and sell them in monopolistically competitive goods markets as given in Dixit and Stiglitz (1977). Using the notation of Walsh (2003), utility function of the household is described as a function of consumption of

<table>
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<th>Method</th>
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<td>Markov Switching</td>
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<td>GMM</td>
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<td>Adaptive LS</td>
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<td>Smooth transition</td>
<td>Gerlach and Lewis (2010)</td>
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differentiated goods $C_t$, real money balances $M_t/P_t$, and time allocated to employment $N_t$.

Objective of the household is to maximize present worth of expected future utility given by

$$E \sum_{t=0}^{\infty} \beta^t \left[ \frac{C_t^{1-\sigma}}{1-\sigma} + \gamma \left( \frac{M_t}{P_t} \right)^{1-b} - \chi \frac{N_t^{1+\eta}}{1+\eta} \right]$$ (1)

subject to the budget constraint

$$C_t + \frac{M_t}{P_t} + \frac{B_t}{P_t} = \left( \frac{W_t}{P_t} \right) N_t + \frac{M_{t-1}}{P_t} + \left( 1 + i_{t-1} \right) \frac{B_{t-1}}{P_t} + \Pi_t$$ (2)

where $B_t$ is the nominal holdings of one-period bonds, $W_t$ is the nominal wage, $\Pi_t$ real profit transferred from firms and $i_t$ is the nominal interest rate faced by households.

Representative firm, on the other hand, maximizes its profit given by

$$\max_{P_{jt}} E_t \sum_{i=0}^{\infty} \omega^i \beta^i \left[ \left( \frac{p_{jt}}{P_{t+i}} \right) C_{j,t+i} - \varphi_{t+i} C_{j,t+i} \right]$$ (3)

where $\omega^i$ is the probability of unchanging price of good $j$ from period $t$ to period $t+i$, $\varphi_t$ is the firm’s real marginal cost.

At the equilibrium, the Phillip’s curve is derived as a function of output gap $x_t = y_t - y^*_t$, where $y_t$ is actual and $y^*_t$ is potential output respectively, and anticipated inflation as follows:

$$\pi_t = \kappa x_t + \beta E_t \pi_{t+1} + m_t$$ (4)

where $m_t$ is a cost-push shock to the New Keynesian Phillips Curve.

The aggregate demand curve can be expressed by
\[ x_t = E_t x_{t+1} - \left( \frac{1}{\sigma} \right)(i_t - E_t \pi_{t+1}) + u_t \]  \hspace{1cm} (5)

where \( u_t \) is an exogenous productivity shock.

The fact that monetary policy influences economic activity in the short-term (see for example, Bernanke and Blinder, 1992, Bernanke and Mihov, 1997, Bernanke et al., 1997, Christiano et al., 1996, Christiano et al., 1998, and Gali, 1992). Monetary policy decisions are used to establish a stable economy in terms of prices and output growth. In this respect, it is necessary to transmit monetary policy actions to macroeconomic variables such as inflation and output so that interrelations among these variables can produce the grounds of a steady economy. For this purpose, different transmission mechanisms (interest rate, exchange rate, asset prices) are used to disseminate changes in the policy variables to other real and nominal variables. In our model, we used interest rate as the monetary policy tool that transmits actions of monetary authority to the financial system and real activity.

In order to specify monetary transmission mechanism, it is necessary to determine the behavior of monetary policy implemented by central bank. In the literature, it is common to use Taylor (1993) type monetary policy rule, which relates short-term interest rate to both inflation and output gap. Therefore, Taylor rule is expressed below to close the model:

\[ i_t^p = i^* + \delta_\pi (E_t \pi_{t+1} - \pi^*) + \delta_x E_t x_{t+1} + \nu_t \]  \hspace{1cm} (6)

where \( i^* \) is the desired rate, \( \pi^* \) is targeted inflation and \( \nu_t \) stands for the shocks to short-term interest rate.

Typically, the interest rate faced by households and firms, in equation (5), is taken equal to the policy interest rate set by central bank, in equation (6). Then, the common practice in

4. Interest Rate Pass Through

In a structural model of monetary policy analysis, monetary transmission mechanism is of importance. Since policy decisions affect the economy through these transmission channels, dynamics of propagation mechanisms should be included in policy analysis. In the literature, it is followed that policy decisions are transmitted to the economy via short-term policy interest rate. Such a construction implicitly assumes that households/firms realize policy rate without any media and, macroeconomic variables such as inflation, aggregate output are affected by policy rate, directly. Nevertheless, households/investors in the economy do not realize policy rates directly. On the contrary, short-term policy interest rates are indirectly recognized by agents through the actions of financial institutions (e.g. banks) that collect deposits from households with different maturities and buy bonds from central bank using these deposits. Since these deposits and credits spread on long horizons, investors require high interest rates due to less liquidity and credit risk. Hence, the interest rate faced by the households is not the short-term policy interest rate but it is the long-term market interest rate. Changes in the policy rate lead to changes in long-term rate, which results in changes in investment, consumption and finally aggregate output. Thus, the monetary transmission mechanism is from policy rate to long-term rate and then output and inflation.
As in Nelson (2002), application of expectations theory of the term structure also leads us to the conclusion that aggregate demand function includes long-term interest rate instead of the short-term. Iterations on equation (5) generate

\[ x_t = E_t x_{t+1} - \left( \frac{1}{\sigma} \right) (i_t - E_t \pi_{t+1}) + u_t \]

\[ = E_t x_{t+2} - \left( \frac{1}{\sigma} \right) (E_t i_{t+1} - E_t \pi_{t+2}) - \left( \frac{1}{\sigma} \right) (i_t - E_t \pi_{t+1}) + E_t u_{t+1} + u_t \]

\[ = \ldots \]

\[ x_t = - \left( \frac{1}{\sigma} \right) (i_t - \pi_t) + u_t \]

where \( i_t = E_t \sum_{j=0}^{\infty} i_{t+j}, \pi_t = E_t \sum_{j=0}^{\infty} \pi_{t+j+1} \) and \( u_t = E_t \sum_{j=0}^{\infty} u_{t+j} \), which is sum of the expected future demand shocks (productivity shocks).

It is widely accepted that aggregate demand is dependent on long-term interest rates rather than short-term interest rates (see, for instance, Basci et al., 2007, Coricelli et al., 2006, Rotemberg and Woodford, 1999, Taylor, 1995, and Woodford, 1999). Since central bank uses only short-term interest rate as the monetary policy tool, there should be a transition equation between market interest rate and policy rate, with the intention that by changing the latter, central bank can impact the economy according to this connection. Although interest rate pass through and term structure of interest rate literature has elaborated on this issue, no attempt has been made to consider interest rate pass through specification in a structural model of monetary policy analysis, as to our knowledge. Therefore, the main contribution of the present paper is the inclusion of interest rate pass through specification with Taylor-type monetary policy rule in a New Keynesian model. Particularly, a TVP interest rate pass through specification is added to structural model in a simple way to account for monetary
transmission mechanism in the economy. This specification is also functional in accounting changing attitude of investors towards risk. It will not be wrong to claim that such a composition can provide the chance of examining transition from short-term to long-term interest rates under different monetary policies.

Consequently, our contribution to above model, given by equations (4), (5) and (6), is the inclusion of interest rate pass through as a different monetary transmission mechanism. The transition from policy rate to aggregate output and inflation is realized by means of long-term interest rate. In order to complete the above model, we incorporate interest rate pass through relationship, which is the first in the literature as far as we know. The interest rate pass through relationship establishes the link between short-term policy rate and long-term interest rate. Similar to Kwapi and Scharler (2006) and Sørensen and Werner (2006), long-term interest rate is modeled as a function of its lag, policy rate and a risk component, which is given below:

$$i_t = \lambda_1 i_{t-1} + \lambda_2 i^p_t + \epsilon_t \quad (7)$$

where $i^p_t$ stands for short-term policy interest rate. The interest rate pass through literature states that long-term interest rate is positively dependent on its lag and policy rate hence; all the coefficients in this equation are expected to be positive. The error component, $\epsilon_t$, captures the risk preference of households and firms.

4.1. Empirical Studies on Risk Modeling

The error term in equation (7) can be regarded as risk premium due to default risk, liquidity factor and inflation risk premium. Default risk is accounted for the possibility of a borrower being failed to repay principal and interest payments of a credit on time. Liquidity is another
factor that affects the determination of interbank and market interest rates (Hubbard, 2001). Perception of investors toward inflation, which is inflation risk premium, is the element of $\varepsilon$, that constitutes inflation expectations of investors. Since change in inflation rate is an important determinant of deposit/loan rate (market interest rate), inflation risk premium turns out to be a significant part of interest rate risk considered in interest rate pass through relationship. Therefore, default risk, liquidity and inflation risk premium should be taken into account seriously in empirical models of monetary policy. The impact of default risk and liquidity on transition from policy rate to market rate was shown by Martin and Milas (2008) in detail. They investigated the influence of 2007 sub-prime crisis on the gap between policy rate, set by central bank, and market interest rate, which affects aggregate demand, for the UK. They demonstrated that the difference between policy rate and market rate has widened during the sub-prime crisis and explained this gap as the combination of unsecured lending risk mainly and liquidity factor. Martin and Milas (2008) highlighted the increasing difference between policy rate and market interest rate during 2007 sub-prime crisis, then showed that this difference was resulted from unsecured lending risk (default risk) mostly and liquidity factor. Similarly, Michaud and Upper (2008) illustrated empirically the impact of credit risk and liquidity factors on the gap observed in interbank interest rates. They concluded that interest rate risk is highly influenced by credit risk and liquidity factors.

Hördahl and Tristani (2007) estimated inflation risk premium for the euro area using a structural macroeconomic model and term structure dynamics. It was shown that inflation risk premium is a significant ingredient in constructing inflation expectations of investors in euro area. Hördahl (2008), in parallel, measured inflation risk premium both in the US and the euro area employing a term structure model described in Hördahl and Tristani (2007). The link between inflation risk premium and inflation expectations of investors was
highlighted in Hördahl (2008) and it was suggested that changes in inflation risk premium is mostly driven by changes in output. Ang et al. (2008) is another study that illustrates the correlation between inflation risk premium and interest rates using a term structure model.

The above recent studies reveal that interest rate risk, which is included in interest rate pass through relationship, is important to consider and monetary policy models should take into account interest rate risk while developing monetary transmission mechanisms. So, introduction of interest rate pass through relationship as well as interest rate risk and its components will improve the monetary policy models.

5. A State Space Model

The model given by equations (4), (5), (6) and (7) is a computable general equilibrium model, which is composed of both linear and nonlinear equations illustrating the behavior of all households, firms and central bank in the economy as well as equilibrium conditions (Bergman, 1990). In this section we first propose a structural nonlinear EKF algorithm as a new method for the estimation of time variable monetary policy parameters.

The studies listed in literature review section revealed that monetary policy changes are sensitive to the way of how time variation in the coefficients of the interest rate rule is modeled and the estimation techniques used. While initial studies were using subsample analysis to indicate changes in monetary policies, later different techniques were started to be used like Markov-switching models, GMM, Kalman filter. Especially, Kalman filter (Kalman, 1960) is widely utilized due to its appropriateness in estimating past, present and future states of a model even when the exact form of the model is not known. Although the standard Kalman filter is an influential technique in estimating linear transformations
(Harvey, 1990), it fails to be reliable for non-linear state space forms. While modeling policy rule and structural equations with TVPs simultaneously, the system takes a non-linear form and usage of EKF becomes compulsory as the appropriate estimation tool. As to the knowledge of us, use of EKF is not so common in the monetary policy analysis with TVPs.

In order to facilitate EKF the model needs to be written in state space form. A state space model is composed of two sets of equations, the system equations representing the evolution of state variables and the observation equations to model the observed state variables. An appropriate state space setup for the model we proposed above can be written as follows

\begin{align*}
W_{t+1} &= A_t W_t + B_t U_t + u_{t+1} \quad (8) \\
Y_t &= C_t W_t + D_t V_t + v_t \quad (9)
\end{align*}

Here, \( W_t \) is a \( r \times 1 \) vector of unobserved state variables and \( Y_t \) is an \( n \times 1 \) vector of observed signals, \( U_t \) and \( V_t \) are \( k \times 1 \) and \( j \times 1 \) predetermined variables. \( A_t, B_t, C_t \) and \( D_t \) are time-dependent parameter matrices. If one allows for time-variable coefficients the system can be rewritten as

\begin{align*}
\dot{i}_t^* &= \dot{i}_t + \delta_{x,t} (E_t \pi_{t+1} - \pi_t^*) + \delta_{x,t} E_t (y_{t+1}^* - y_{t+1}^*) + v_t \quad (10) \\
E_t \pi_{t+1} &= \rho \pi_t - \theta x_t + k_t \quad (11) \\
E_t x_{t+1} &= x_t - \left( \frac{1}{\alpha} \right) (\hat{i}_t - E_t \pi_{t+1}) + u_t \quad (12) \\
i_t^* &= \lambda_2 i_{t-1} + \lambda_3 i_t^o + \epsilon_t \quad (13) \\
y_t &= y_t^* + x_t \quad (14)
\end{align*}

where \( \dot{i}_t, E_t \pi_{t+1} \) and \( E_t x_{t+1} \) are unobservable state variables, \( i_t^o, \pi_t^*, y_t \) and \( i_t \) are observed signals and \( \delta_{x,t}, \delta_{x,t} \) are time variable policy parameters. Equations 10-12 are derived from 4-

\footnote{Explanations about the EKF are standard and adopted from Pasricha, 2006, Ribeiro, 2004, and Welch and Bishop, 2006 and Hatipoglu and Alper, 2009.}
7 and Equation 11 and 13 are slightly modified by letting the long term rates equal the desired rates to include the effect of interest rate pass through on policy rates. Equation 14 is an identity. Moreover, \( \rho = 1/\beta \), \( \theta = \kappa/\beta \) and \( k = m/\beta \). In addition to Equations 10-14 we specify the time variable parameters as a random-walk in line with the literature\(^4\).

\[
\delta_{x,t} = \delta_{x,t-1} + \varepsilon_t 
\]

\[
\delta_{z,t} = \delta_{z,t-1} + \varepsilon_t
\]

Given our model specify the system matrices for the EKF as follows.

\[
W_t^T = \left[ i_t, E_t, \pi_t, E_t, x_t, \delta_{x,t}, \delta_{z,t} \right], \quad Y_t^T = \left[ i_t, y_t, 0, 0, 0 \right], \quad U_t^T = \left[ i_{t-1}, \pi_t, 0, 0, 0 \right]
\]

\[
V_t^T = \left[ \pi_t, y_t, 0, 0, 0 \right]
\]

where \( T \) denotes the transpose. Parameter matrices are given by

\[
A_t = diag\{\lambda_2, 0, 0, 1, 1\} \quad \text{where } A \text{ is a diagonal } 5x5 \text{ matrix with the exceptions } A(1,2) = \lambda_2 \delta_{x,t},
\]

\[
A(1,3) = \lambda_2 \delta_{z,t}, \quad A(2,3) = -\theta, \quad A(5,2) = A(5,3) = -1/\sigma, \quad B_t = diag\{\lambda_t, \rho, 0, 0, 0\},
\]

\[
C_t = diag\{1, 0, 0, 0, 0\} \quad \text{with the exceptions } C(1,2) = \delta_{x,t} \text{ and } C(1,3) = \delta_{z,t} \text{ and}
\]

\[
D_t = diag\{-\delta_{x,t}, 1, 0, 0, 0\}.
\]

6. Data and Estimation Results

We estimate the model using Turkish Data as a case in point. We believe that the Turkish case is particularly interesting because a time variable rule can resemble the behavior of an emerging market central bank more closely. Both asset and liability dollarization, shallow financial markets as well as high current account deficit can lead to fear of sudden capital flights which might cause an emerging market central bank such as Central Bank of Turkey (CBT) to shift policies significantly and more frequently.

\(^4\) A comprehensive exposition of extended Kalman filtering theory can be found in Haykin (2000).
For the policy rate we use the monthly average of the daily overnight interbank borrowing rate from 2001:01 until 2012:01. Output is calculated as the logarithm of seasonally adjusted real GDP. Inflation is taken to be logarithmic difference of monthly announced annual CPI after seasonal adjustment. Actual interest rates are market rates announced by CBT. All data are provided by CBT.

Our estimation involves several steps. Since Kalman filter is a recursive procedure one needs to specify plausible initial values. To do so, we first estimate parameters of (10) using OLS. We use these parameters as well as fitted values of the state variables obtained from regressions as initial values. Next, to show the relevance of the methodology we employ we compare efficiency results of EKF to the standard Kalman filter where we keep the policy parameters constant. We then estimate TVP by experimenting with several initial candidates to check for robustness of the results. Table 2 reports both the efficiency results and the values of the parameters. EKF parameter is reported at the last observation. According to mean square error (MSE) criteria EKF performs 15% better than the standard Kalman filter. Interest rate pass through is significant and more pronounced under the TVP rule. Another interesting fact to note is that under TVP estimation, CBT seems to have fought inflation less aggressively as the average coefficient of the inflation gap for the inflation-targeting period is 1.09\(^5\). This result might be due to the presence of high interest rate pass through effect.

\(^5\) This number is obtained by taking the simple arithmetic average of the coefficient values between 2006:01 when CBT started announcing explicit inflation targets and 2012:01.
Table 2: Estimation Results

<table>
<thead>
<tr>
<th></th>
<th>Standard</th>
<th>EKF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inflation gap</td>
<td>1.301(0.492)</td>
<td>1.022(0.704)</td>
</tr>
<tr>
<td>Output gap</td>
<td>0.039(0.335)</td>
<td>0.012(0.133)</td>
</tr>
<tr>
<td>$\lambda_1$</td>
<td>0.622(0.061)</td>
<td>0.767(0.049)</td>
</tr>
<tr>
<td>$\lambda_2$</td>
<td>0.371(0.059)</td>
<td>0.229(0.052)</td>
</tr>
<tr>
<td>Mean Square Error</td>
<td>5.653</td>
<td>4.441</td>
</tr>
</tbody>
</table>

Notes: Standard errors in parenthesis except EKF where MSE is reported. In EKF the parameter value is reported at the last observation.

7. Conclusion

Within years, monetary policies implemented by central banks, their influence over the economy and monetary transmission mechanism have been the research topic of several academicians and policymakers. Under the general tendency of carrying out monetary policy analysis and examining its impact over the economy, different directions/questions/motivations were adopted for various investigations.

This paper reviewed monetary policy rules with TVP specification. Changing behavior of policymakers, full or partial use of information set available and unstable structure of the economy are the main reasons that require employment of TVP characterization. In the light of this analysis, we claimed that changes in the risk preferences of households and firms should also be reflected in such a world. One of the ways of doing this is to include this behavior in the formation of market interest rate faced by investors and creditors. For this, we made the differentiation of short-term interest rate determined by central bank and long-term interest rate faced by households. Especially, in empirical studies this differentiation should be made to increase the robustness of the conclusions. Then, we stressed that changing
behavior of investors towards risk should be considered as a component in the determination of long-term market interest rate. This construction is given by interest rate pass through specification. This way, changing risk preferences of households and firms can be considered in a structural model, which can be worthwhile for real-time data applications.

Finally, we specified a state space model with interest rate pass-through within which we can utilize EKF to estimate a TVP Taylor rule. By utilizing Turkish Data we showed that EKF performed better than the standard Kalman filter in estimating the CBT reaction function. A future study might look into the role of exchange rate pass through together with interest rate pass-through in a Taylor type reaction function. We believe the role of exchange rates in determining the expected inflation as well as output gap in a TVP rule is not adequately analyzed.

References


