Why is Inflation Targeting Successful?: Analysis of Inflation Targeting Transparency

Abstract

This paper theoretically investigates the effect of inflation targeting (IT) on the information dynamics between the Central Bank (CB) and the public. We construct and solve a model of asymmetric information and learning. The paper introduces time-varying implicit inflation targets of the CB as the potential source of asymmetric information. The model shows that IT central banks attain the desired outcomes because IT eliminates the asymmetric information about the implicit inflation targets of the CB and the frictions caused by that asymmetric information. The solution of the model presents that inflation and output expectations of the public are significantly affected by the inflation target under the IT case. Thus, we theoretically present the mechanism through which IT anchors inflation and output expectations. There are three main results of this paper. First, inflation and output expectations of the public are significantly affected by the inflation target under the case of IT. Second, the variance of inflation expectations of the public is lower under IT. Finally, credibility of the CB is significantly affected by the target under the IT case. In other words, the CB can improve its credibility by announcing a credible target. The model provides theoretical arguments for the empirical results about IT in the literature. Also, the theoretical findings have practical implications for effective adoption of IT.

JEL classification: E31; E52; D82; D83

Keywords: Inflation Target, Asymmetric Information, Monetary Policy, Kalman Filter, Learning

1 Introduction

Since its first adoption by the Reserve Bank of New Zealand in 1990 more than 26 countries adopted inflation targeting (IT)[1]. Studies like Mishkin and Schmidt-Hebbel (2007) and Peturrson (2004) present that IT has been a success in the sense that IT is associated with significant improvement in overall economic performance of IT adopters. Although there are many studies that empirically investigate the impact of IT on several aspects of the economy, the mechanisms through which IT improves the economic conditions are not studied extensively. A theoretical study is needed to present the dynamics of IT and uncover the reasons behind the success of IT.

In this paper, we theoretically investigate the mechanisms through which IT effects the expectations of the public and achieve desired levels of inflation, inflation uncertainty and credibility. The study considers two mechanisms through which IT achieves its goals: (1) improvement in the credibility of the Central Bank (CB) (2) improvement in the ability of the central bank to alter the expectations of the public. To analyze these mechanisms, we construct and solve a model of asymmetric information and learning between the CB and the public. The source of the asymmetric information is the time-varying inflation targets of the CB. The model depends on unobserved-components modelling with state-space representations. The model is solved using the Kalman filtering algorithm. The results present that IT countries attain the desired outcomes

[1] Peturrson (2004) identifies 21 IT countries. Slovakia, Indonesia, Romania, Turkey and Ghana joined these IT countries since 2004.

because IT eliminates the asymmetric information and the frictions caused by that asymmetric information. As a result, we propose and theoretically show that in non-IT countries the private agents are uncertain about the implicit inflation target of the CB and they construct their expectations about the target by following the actions of the CB. That learning dynamics increases the uncertainty and the level of inflation significantly. IT eliminates that uncertainty about the inflation target since the target is announced and becomes public information. The announcement of a credible target anchors inflation expectations as empirically shown by Gurkaynak et al. (2010) and lower levels of inflation and inflation uncertainty are achieved as a result.

The model developed in this paper is based on two findings of the previous studies. First, IT anchors inflation expectations. Gurkaynak et al. (2010) investigate the extent to which inflation targeting helps anchor long-run inflation expectations by comparing the behavior of daily bond yield data in the United Kingdom, Sweden and US. They show that a well-known and credible inflation target helps anchor the private sector's views regarding the distribution of long-run inflation outcomes. Second, even though a non-IT CB does not announce it to the public the CB has an implicit inflation target that changes over time as stated by Ireland (2007) and Leigh (2008). Thus, the private agents use the actions of the CB to form their expectations about the inflation target of the CB.

Existence of time-varying implicit inflation targets are shown by Leigh (2008) and Ireland (2007). They estimate the parameters of the state space representation model for the US economy where the Federal Reserve is assumed to have a time-varying implicit inflation target. Using maximum likelihood estimation of the state-space parameters, Ireland (2007) and Leigh (2008) determine the implicit inflation targets of the Federal Reserve. Both studies show that the inflation target of the Federal Reserve changes significantly over time. Figure I presents the figures of Ireland (2007) and Leigh (2008) which show the significant quarterly changes in the implicit inflation target of the Federal Reserve.

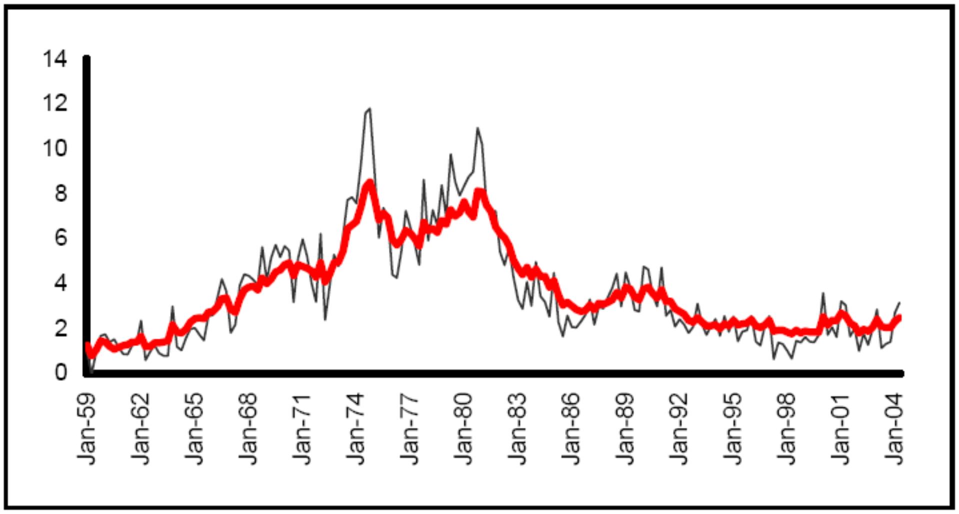

Figure 4. Actual inflation (thin black line) and the Federal Reserve's target (thick red line), as implied by the unconstrained model with an endogenous inflation target.

Ireland (2007)

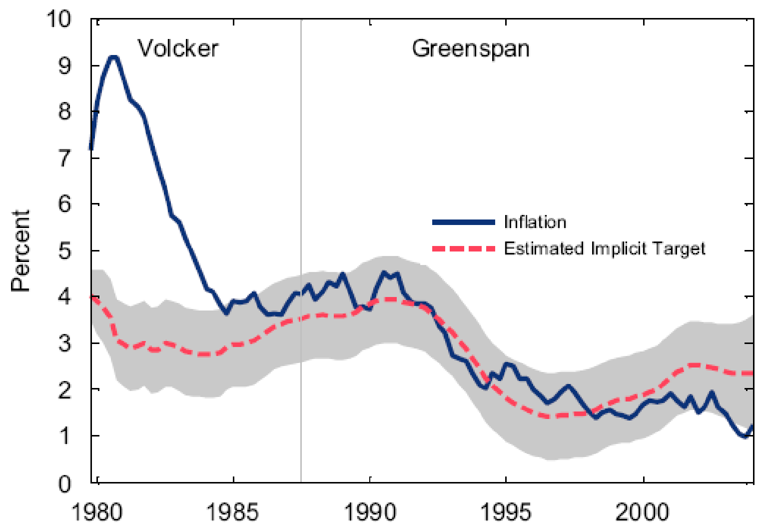

Fig. 1. Inflation, estimated implicit target, and 90% confidence band.

(Leigh 2008)

Figure I: Time varying inflation targets of the Federal Reserve as in Ireland

(2007) and Leigh (2008)

Figure I presents that the the Federal Reserve has an implicit inflation target and that target changes significantly over time. The Federal Reserve does not announce its target to the public and the private sector agents have to deduce the target from the actions of the Federal Reserve when forming their expectations. This asymmetric information introduces frictions since the private agents do not have perfect information about the target and they estimate it with an error. This error term increases the variance of inflation and also increases the level of inflation in the economy.

Starting from these empirical arguments, we analyze the underlying dynamics of IT by constructing a model of asymmetric information and learning dynamics of inflation expectations and time-varying inflation targets. We argue that under IT the CB eliminates this asymmetric information and frictions caused by it by committing itself to a target and announcing that target. Thus, the private sector agents have better expectations about future inflation. By anchoring the expectations of the private sector agents, the CB achieves lower inflation and lower output. Section 2 presents the model of time-varying implicit inflation targets.

There are three main results of this paper. First, inflation and output expectations of the public are significantly affected by the inflation target under the case of IT. In other words, we theoretically present the mechanism through which IT anchors inflation and output expectations. Second, in the discretionary CB case, the private sector agent uses a filtered estimate of the inflation target of the CB to form her expectations which increases the variance (stability) of inflation expectations of the public. Finally, credibility of the CB is significantly affected by the target under the IT case. The CB can improve its credibility by announcing a credible target.

Several related studies theoretically examine inflation target transparency. Kozicki and Tinsley (2005) set up a reduced form model of the U.S. to analyze the effect of unobservable changes in the inflation objective. They show that imperfect inflation target credibility increases volatility of inflation. Aoki and Kimura (2007) investigate the case where the private agents can not observe the inflation target and the central bank considers the perceived inflation targets of the private agents while conducting monetary policy. They conclude that the inflation target uncertainty causes high persistence and volatility of inflation. Melecky et al. (2009) study a DSGE model of the euro area to examine the effect of unknown inflation targets on the economy. They conclude that the effect of asymmetric information about the inflation target is small if private agents correctly identify the inflation target process. In contrast to the findings of this paper, they find that announcing the time-varying inflation target does not have significant gains.

To sum up, this paper is making the following contributions to the literature. First, we construct a model of asymmetric information and learning which explains the empirical findings of Gurkaynak et al. (2010) about IT anchoring inflation expectations. Second, the constructed model displays the working dynamics of IT. We present that announcing the target significantly decreases inflation uncertainty and improves the credibility and the ability of the CB to alter inflation expectations of the public. Finally, we calibrate the model for the US economy and show that unannounced implicit inflation targets of the CBs decreases transparency by causing asymmetric information between the CB and the public. As a result, the paper constructs and solves a detailed model of macroeconomic variables and expectation dynamics which can be used to investigate the success of IT.

The rest of the paper is organized as follows: Section 2 explains the fundamental elements of the model of asymmetric information and learning. Section 3 solves the model to determine the expectation dynamics. Section 4 investigates the credibility of the central bank. Sections 5 conducts calibration of the model and derives the main findings of the paper . Finally section 6 concludes.

2 Model of unknown time varying inflation targets

Following the empirical findings of Ireland (2007) and Leigh (2008), we construct a model of asymmetric information and learning where the CB has an implicit inflation target and that target is unknown to the public.

2.1 The framework

We begin with the framework of Svensson and Woodford (2003, 2004)[2]. As in Svensson and Woodford (2004), the structural equations are given by a system of the form

$$\begin{bmatrix} X_{t+1} \\ \Delta E_t x_{t+1} \\ \Theta R_t \end{bmatrix} = A \begin{bmatrix} X_t \\ x_t \\ R_{t-1} \end{bmatrix} + \begin{bmatrix} u_{t+1} \\ 0 \\ \tau_t \end{bmatrix} \tag{1}$$

where X_t is a vector of n_X predetermined variables in period t, x_t is a vector of n_x forward-looking variables, R_t is a vector of the central bank's policy instruments, u_t and τ_t are vectors of n_X and n_τ iid shocks with means zero and covariance matrices $\sum_{uu}$ and $\sum_{\tau\tau}$. A, B and Δ are matrices of appropriate dimensions. Δ determines the relationship between predetermined and forward-looking variables and expectations of the private sector. $E_t x_{t+1}$ denotes the

[2] Eq. 2.1 in Svensson and Woodford (2003)

rational expectation of the private-sector of forward-looking variables at time $t+1$ given the information set in period t ($E[x_{t+1} \mid I_t]$). We introduce asymmetric information into the Svensson and Woodford (2004) model to investigate effect of inflation targeting on inflation expectations of the private sector. We assume that the private sector has imperfect information about the inflation target of the CB.[3]

We define the vector of n_Z observable variables observed by the private sector, Z_t, as the following

$$Z_t = D \begin{bmatrix} X_t \\ x_t \\ R_{t-1} \end{bmatrix} + v_t \tag{2}$$

where v_t, is the vector of iid error terms of the observable variables with mean zero and covariance matrix $\sum_{vv}$.

2.2 Agents and Information Structure

The model features two agents, the Central Bank (CB) and a representative private-sector agent. The information structure is hierarchical since the CB is assumed to possess private information that the private-sector agent tries to deduce by observing the CB's actions. Hierarchical information structure is modeled as in Townsend (1983).

The information structure consists of two steps:

- The CB determines its inflation target of time t and uses a simple Taylor rule to determine the interest rate, i_t. The CB follows an AR(1) rule for the inflation target as in Gurkaynak et al. (2005). (This target is

[3]Svensson and Woodford (2004) assume that the private sector agent has full information and the central bank has partial information about the state of the economy.

announced to the public in the inflation targeting case).

- The representative private-sector agent observes the interest rate and the inflation target[4] (in the inflation targeting case) and revises her inflation and output expectations.

The CB is assumed to have perfect information about current inflation and output at time t while it determines the interest rate at time t. [5]

The private-sector agent observes the interest rate and the inflation target (in the inflation targeting case) set by the CB. As in Aoki (2003), the private-sector agent observes noisy preliminary estimates of current inflation and output. She then forms her own expectations about future inflation and output using her observations: CB interest rate, inflation target (under inflation targeting), noisy preliminary estimates of current inflation and output. The expectations of the representative private sector agent are derived in section 3.

2.3 Generic macroeconomic dynamics

As in Clarida et al. (1999) and Aoki (2003) the macroeconomic dynamics are represented in terms of two forward-looking equations about output, y_t and inflation, π_t,

[4] In the discretionary central bank case, inflation target of the CB is the source of asymmetric information since the private-sector agent does not directly observe the inflation target.

[5] We assume perfect knowledge of the current economy by the Central Bank to avoid the curse of dimensionality while solving the model for private-sector agents' expectations. Townsend (1983) considers an economy of asymmetric information where interplay of expectations of two separate agents impacts the economy. The model can easily be extended to have expectations of the CB and the private sector agent as in Townsend (1983). That kind of analysis is not necessary for this model, because we are investigating the impact of unknown inflation targets and inflation targeting on private-sector expectations. Adding imperfect information of the CB to the model will not change the expectation formation mechanism of the private sector but will unnecessarily complicate the model. Thus, we make this assumption to have a simple and tractable model and avoid unnecessary complexity.

$$y_t = E_t y_{t+1} - \delta \left[i_t - E_t \pi_{t+1} - \rho_t \right] \tag{3}$$

$$\pi_t = \gamma \left(y_t - y_t^n \right) + \alpha E_t \pi_{t+1} \tag{4}$$

where Eq.3 is an intertemporal "IS" curve that relates output inversely to the interest rate. Eq.4 is a Phillips curve that relates inflation positively to output. σ, γ, and α are positive and $\alpha < 1$. Expectations in these equations are conditional on the information set of the private sector. ρ_t and y_t^n are exogenous disturbances of inflation and output respectively.

The exogenous disturbances are assumed to evolve as AR(1) processes,

$$\rho_t = \beta_\rho \rho_{t-1} + e_t^\rho \tag{5}$$

$$y_t^n = \beta_y y_{t-1}^n + e_t^y \tag{6}$$

where $0 < \beta_\rho, \beta_y < 1$ and the disturbances e_t^ρ, e_t^y are iid normal random variables with mean zero and variances σ_ρ^2 and σ_y^2 .

2.4 Monetary policy implementation of the the central bank

After observing the current state of the economy the CB uses a simple Taylor rule to determine the policy instrument, the interest rate. The CB also determines the inflation target. Under inflation targeting it announces its current inflation target to the public but under discretionary monetary policy without commitment the private-sector agent should deduce the inflation target of the CB from the CB's actions, the interest rate.

The rule for the interest rate is specified as:

$$i_t = \lambda_1^i \{\pi_t - \tilde{\pi}_t\} + \lambda_2^i y_t + \lambda_3^i i_{t-1} + \varepsilon_t^i \tag{7}$$

where r_t is the current period interest rate and $\tilde{\pi}_t$ is the current period inflation target of the CB. λ_1^r and λ_2^r determine the response of the interest rate to current inflation and output [6]. λ_3^r is the interest rate smoothing coefficient[7]. ε_t^r is the shock to the interest rate, which is normally distributed with mean zero and variance ${}_r\sigma_\varepsilon^2$ and is independent over time.

Similar to Gurkaynak et al. (2005), the rule for the inflation target is specified as:

$$\tilde{\pi}_t = \lambda_1^{\tilde{\pi}} \tilde{\pi}_{t-1} + \lambda_2^{\tilde{\pi}} \rho_t + \varepsilon_t^{\tilde{\pi}} \tag{8}$$

$\lambda_1^{\tilde{\pi}}$ and $\lambda_2^{\tilde{\pi}}$ determine the current inflation target of the CB. $\varepsilon_t^{\tilde{\pi}}$ is the shock to the inflation target. It is normally distributed with mean zero and variance ${}_{\tilde{\pi}}\sigma_\varepsilon^2$ and is independent over time.

2.5 Private sector agent

The private sector agent observes noisy preliminary estimates of current inflation and output, the CB interest rate and the current inflation target of the CB (in the inflation targeting case). These preliminary estimates are given by

$$\pi_t^{PRI} = \pi_t + \omega_{\pi,t} \tag{9}$$

[6]The model can easily be updated to have a forward-looking Taylor as the interest rate rule. But this will not change the results since it will not impact the formation of private-sector expectations. This will increase the dimensions of the state-space representation and make the model less tractable by causing curse of dimensionality.

[7]Rudebusch (1995) provides empirical evidence on the serial correlation of interest rate changes. Goodfriend (1991) names fear of disruption of financial markets as an explanation for interest rate smoothing, and Sack (1997) mentions uncertainty about the effects of interest rate changes.

$$y_t^{PRI} = y_t + \omega_{y,t} \tag{10}$$

$\omega_{\pi,t}$ and $\omega_{y,t}$ are iid normal random variables with zero mean and with variances σ_π^2 and σ_y^2 respectively.

3 Expectation dynamics

This section focuses on the model that illustrates the hierarchical information structure and the interplay of expectations. As shown in Svensson and Woodford (2004) and Townsend (1983) the Kalman filter provides the optimal solution to the private sector learning problem. Thus, the equations for the expectations of the private sector agent is found using a Kalman filtering algorithm. The private sector agent determines her expectations based on her information set, Ω_t^{PRI}. $\Omega_t^{PRI} = \{\pi_t^{PRI}, \ldots, y_t^{PRI}, i_t, \ldots, A, D, \Delta, \Theta, \sum_{uu}, \sum_{vv}\}$. The computation of the expectations of the private sector agent involves three steps: the definition of the appropriate state space, the solution of the filtering problem and the derivation of the expectations of the private-sector agent. The model explained in section 2 can be presented in the general framework of Eq.1 and Eq.2.

3.1 Definition of the state space

The model explained in sections 2.1-2.5 can be displayed in a convenient state-space representation. The structural equations (3)-(4), equations of the disturbances (5)-(6) and equations of the behavior of the CB (7-8) comprise the state equation (Eq.1). Thus, the state equations consists of

$$X_t = \begin{bmatrix} \rho_t \\ y_t^n \end{bmatrix} \quad x_t = \begin{bmatrix} \pi_t \\ y_t \end{bmatrix} \quad R_t = \begin{bmatrix} i_t \\ \tilde{\pi}_t \end{bmatrix}$$

The private sector agent observes the noisy preliminary estimates of current inflation and output (Eq.9 and Eq.10), the interest rate of the CB and the inflation target of the CB (under inflation targeting). So, Z_t of the observation equation (Eq.2) under inflation targeting is

$$Z_t^{IT} = \begin{bmatrix} \pi_t^{PRI} \\ y_t^{PRI} \\ i_t \\ \tilde{\pi}_t \end{bmatrix}$$

and under discretionary monetary policy without inflation targeting

$$Z_t^{disc} = \begin{bmatrix} \pi_t^{PRI} \\ y_t^{PRI} \\ i_t \end{bmatrix}$$

Define $\Psi_t = \begin{bmatrix} X_t \\ x_t \\ R_{t-1} \end{bmatrix}$ and $\Xi_{t+1} = \begin{bmatrix} u_{t+1} \\ 0 \\ \tau_t \end{bmatrix}$ then the state space representation consists of

The state equation:

$$\begin{bmatrix} I & 0 & 0 \\ 0 & \Delta & 0 \\ 0 & 0 & \Theta \end{bmatrix} \begin{bmatrix} X_{t+1} \\ Ex_{t+1} \\ R_t \end{bmatrix} = A\psi_t + \Xi_{t+1} \tag{11}$$

observation equation:

$$\Gamma Z_t^{(IT,disc)} = D^{(IT,disc)}\psi_t + \nu_t \tag{12}$$

Δ, Θ, A, Ξ_{t+1}, Γ, $D^{(IT,disc)}$ and ν_t are displayed in detail in the Appendix. I is the identity matrix of appropriate dimensions.

Define $\Phi = \begin{bmatrix} I & 0 & 0 \\ 0 & \Delta & 0 \\ 0 & 0 & \Theta \end{bmatrix}$ and $B = \Phi^{-1}A$. Define $C^{(IT,disc)} = \Gamma^{-1}D^{(IT,disc)}$.

3.2 Solution of the filtering problem

Following Svensson and Woodford (2004), we implement the Kalman filter algorithm to determine the expectations of the private sector. We take into account the learning dynamics as explained above. The Kalman filtering algorithm indicates that when a system can be represented in a state-space representation form as above, the forecast equation is

$$E_t(\psi_{t+1}) = BE_{t-1}(\psi_t) + K_t\left(Z_t^{(IT,disc)} - C^{(IT,disc)}\left(BE_{t-1}(\psi_t)\right)\right) \quad (13)$$

Where K_t is the Kalman gain. It is presented in detail in the Appendix. After application of the Kalman filter algorithm and appropriate substitutions and manipulations, the private-sector agent's current expectations about one-period ahead economic structure can be written as:

$$E_t(\psi_{t+1}) = \left(B - KC^{(IT,disc)}B\right)E_{t-1}(\psi_t) + K_t Z_t^{(IT,disc)} \quad (14)$$

An alternative specification can be derived from Eq.13 to investigate the variance of expectations of the private sector agent. Insert Eq.12 into Eq.13 to get

$$E_t(\psi_{t+1}) = \left(B - KC^{(IT,disc)}B\right)E_{t-1}(\psi_t) + K_t D^{(IT,disc)}\psi_t + K_t\Gamma^{-1}\nu_t \quad (15)$$

Using Eq.15, the variance of the expectations can be written as

$$var\left[E_t\left(\psi_{t+1}\right)\right]=\left(K_t\Gamma^{-1}\right)\left(K_t\Gamma^{-1}\right)' var\left(\nu_t\right) \tag{16}$$

$var(.)$ denotes variances of variables. By proposition 13.1 in Hamilton (1994) it can be shown that K_t converges to some constant K [8].

3.3 Expectations of the private sector

Using the solution of the filtering problem (Eq.14) we can drive the inflation and output expectations of the private sector agent under discretionary central bank and under inflation targeting.

3.3.1 Expectation dynamics under discretionary central bank

Using Eq.14 with C^{disc} and Z_t^{disc}, we bring forward the determinants of current expectations of the private sector agent about future inflation and output. In particular, the following equations can be derived from Eq.14 about the expectation formation of the private-sector agent:

$$\begin{bmatrix} E_t\pi_{t+1} \\ E_t y_{t+1} \end{bmatrix} = \Pi_1^{disc}\begin{bmatrix} \cdots \\ E_{t-1}\pi_t \\ E_{t-1}y_t \\ E_{t-1}i_{t-1} \\ E_{t-1}\tilde{\pi}_{t-1} \end{bmatrix} + \Pi_2^{disc}\begin{bmatrix} \cdots \\ i_t \end{bmatrix} \tag{17}$$

[8] Proposition 13.1 in Hamilton (1994) is as follows: Let F be (rxr) matrix whose eigenvalues are all inside the unit circle, let H' denote an arbitrary (nxr) matrix, and let Q and R be positive semidefinite symmetric (rxr) and (nxn) matrices, respectively. Let $\left\{P_{t+1|t}\right\}_{t=1}^{T}$ be the sequence of MSE matrices calculated by the Kalman filter. Then $\left\{P_{t+1|t}\right\}_{t=1}^{T}$ is a monotonically nonincreasing sequence and converges as T $\rightarrow\infty$ to a steady-state matrix P. Moreover, the steady-state value for the Kalman gain matrix, defined by

$$K\equiv FPH\left(H'PH+R\right)^{-1}$$

has the property that the eigenvalues of $(F-KH')$ all lie on or inside the unit circle.

Π_1^{disc} is partition of $B - K^{disc}C^{disc}B$ and Π_2^{disc} is partition of K^{disc}. Eq.19 describes how the private sector agent constructs her expectations. In the discretionary central bank case, she uses her previous expectations and her observation of the observations, most importantly the interest rate of the central bank to determine her current expectations. Two crucial factors of Eq.19 are the inflation target expectations of the private sector agent and the interest rate of the central bank. Since, the central bank does not announce its inflation target, the agent uses her observations (notably the interest rate of the central bank) to determine her expectations about the inflation target. That inflation target expectation also determines inflation and output expectations of the private sector agent.

Following Eq.14, the agent determines her expectation about the inflation target as the following:

$$\begin{bmatrix} E_t\tilde{\pi}_t \end{bmatrix} = \Pi_3^{disc} \begin{bmatrix} \cdots \\ E_{t-1}\pi_t \\ E_{t-1}y_t \\ E_{t-1}i_{t-1} \\ E_{t-1}\tilde{\pi}_{t-1} \end{bmatrix} + \Pi_4^{disc} \begin{bmatrix} \cdots \\ i_t \end{bmatrix} \tag{18}$$

Since the CB does not announce its inflation target in the discretionary CB case, the agent has to take the interest rate of the CB as a signal about the inflation target of the CB. She uses the filtered value of the interest rate to determine her inflation target expectation.

3.3.2 Expectation dynamics under inflation targeting

Using Eq.14 with C^{IT} and Z_t^{IT}, we bring forward the determinants of current expectations of the private sector agent about future inflation and output.

In particular, the following equations can be derived from Eq.14 about the expectation formation of the private-sector agent:

$$\begin{bmatrix} E_t\pi_{t+1} \\ E_t y_{t+1} \end{bmatrix} = \Pi_1^{IT} \begin{bmatrix} \cdots \\ E_{t-1}\pi_t \\ E_{t-1}y_t \\ E_{t-1}i_{t-1} \\ E_{t-1}\tilde{\pi}_{t-1} \end{bmatrix} + \Pi_2^{IT} \begin{bmatrix} \cdots \\ i_t \\ \tilde{\pi}_t \end{bmatrix} \tag{19}$$

Π_1^{IT} is partition of $B - K^{IT}C^{IT}B$ and Π_2^{IT} is partition of K^{IT}.Compared to Eq.17, Eq.19 presents that the agent observes both the interest rate and the inflation targeting when determining her inflation and output expectations. Instead of using filtered values of her signals (observations) to deduce the current inflation target of the CB, she has direct access to the inflation target. Thus, announcing the inflation target to the public eliminates that friction by eliminating the uncertainty about the inflation target of the CB. In other words, compared to Eq.18, the agent directly observes the inflation target of the CB.

$$\begin{bmatrix} E_t\tilde{\pi}_t \end{bmatrix} = \Pi_3^{IT}\left[E_{t-1}\left(\psi_t\right)\right] + \Pi_4^{disc} \begin{bmatrix} \cdots \\ i_t \\ \tilde{\pi}_t \end{bmatrix} \tag{20}$$

3.4 Variation of expected inflation

Faust and Henderson (2004) indicates that "best-practice monetary policy can be summarized in terms of two goals: First, get mean inflation right; second, get the variance of inflation right.". Using Eq.16 under alternative regimes, we examine the impact of inflation targeting on variation of expected inflation.

4 Credibility of the central bank

The inflation expectation of the private sector determine the credibility of the CB. As Blinder (1999) and Faust and Svensson (2001) emphasize, there are several different definitions of credibility. Cukierman and Meltzer (1986) and Faust and Svensson (2001) use the definition "average credibility of announcements", the difference of the inflation target of the central bank and the inflation expectation of the private-sector agent. As in Faust and Svensson (2001), the credibility of the CB is defined as the negative of the absolute value of the deviation of inflation expectations from the inflation target of the CB,

$$cre_t = - \mid \tilde{\pi}_t - E_t \pi_{t+1} \mid \tag{21}$$

In our framework, the CB announces its inflation target $\tilde{\pi}_t$ under inflation targeting. In the discretionary central bank case, the private-sector agent constructs her expectations about the inflation target of the CB, $E\left(\tilde{\pi}_t \mid \Omega_t^{PRI}\right)$. Thus, under inflation targeting the credibility of the CB becomes

$$cre_t = - \mid E_t \tilde{\pi}_t - E_t \pi_{t+1} \mid \tag{22}$$

Using the equations for the expectation dynamics of the private-sector agent (Eqs14, 17, 19) we can calculate and compare the credibility of the CB as explained above.

5 Calibration of the parameters of the state space

The Kalman filter provides us a maximum likelihood estimator to estimate the unknown parameters of the state space[9]. Ireland (2007) and Leigh (2008)

[9]Hamilton (1994) describes the maximum likelihood estimator of the Kalman filter in detail

estimate the parameters of the state space of representation of implicit inflation target similar to the model formed by Eqs. 11-12 for the US economy. The Federal Reserve is an excellent example of a discretionary Central Bank with time-varying inflation targets. Using state-space approaches Ireland (2007) and Leigh (2008) determine the implicit inflation targets of the Federal Reserve. Both studies show that the inflation target of the Federal Reserve changes significantly over time. We calibrate the parameters using the findings of Ireland and Leigh (2008)[10]. Table A.1 in the Appendix display the parameters that we use to calibrate the model.

5.1 Expectations under discretion

The solution of the Kalman filtering problem with calibrated parameters indicates the following equations for expectations dynamics of Eq.17.

$$\begin{bmatrix} E_t\pi_{t+1} \\ E_t y_{t+1} \end{bmatrix} = \begin{bmatrix} \cdots & 1.7 & -1.2 & -0.04 & 0.005 \\ & -0.38 & 0.79 & -0.08 & 0.01 \end{bmatrix} \begin{bmatrix} \cdots \\ E_{t-1}\pi_t \\ E_{t-1}y_t \\ E_{t-1}i_{t-1} \\ E_{t-1}\tilde{\pi}_{t-1} \end{bmatrix} + \begin{bmatrix} \cdots & 0.07 \\ & -0.01 \end{bmatrix} \begin{bmatrix} \cdots \\ i_t \end{bmatrix} \tag{23}$$

Equation 22 displays one of the main results of the paper. The inflation and output expectations of the private agents are significantly affected by the actions of the Federal Reserve, the federal funds rate (i_t). The inflation expectation of

[10]The Kalman filter provides us a Maximum Likelihood Estimator to the estimate the parameters of the model. This method is implemented in Ireland (2007) and Leigh (2008). In this paper, we do not estimate the parameters to avoid repetition since those parameters are already estimated using MLE. The future of analysis of countries besides US will require estimation of the parameters.

private agent is affected negatively by previous interest rate where as the impact of the current interest rate is positive. The positive coefficient of i_t (0.07) presents the impact of information asymmetry. When the private sector agent observes an increase in the interest rate, she deduces that the Federal Reserve has private information that inflation will be higher in the future. Thus, first the private sector agent increases her expectation about next period inflation. The coefficient of the previous period interest rate is negative (-0.04) as expected. The private agent expected inflation to be lower following an increase in the interest rate.

Another important feature is the expectation about inflation target of the Federal Reserve. Eq. 23 displays how the private agent constructs her inflation target expectation. Eq. 23 shows that the inflation target expectation is significantly affected by changes in the interest rate.

$$\begin{aligned}\begin{bmatrix} E_t\tilde{\pi}_t \end{bmatrix} = \begin{bmatrix} \dots & 0.05 & -0.2 & 0.08 & 0.19 \end{bmatrix} \begin{bmatrix} \dots \\ E_{t-1}\pi_t \\ E_{t-1}y_t \\ E_{t-1}i_{t-1} \\ E_{t-1}\tilde{\pi}_{t-1} \end{bmatrix} \\ + \begin{bmatrix} \dots & -0.08 \end{bmatrix} \begin{bmatrix} \dots \\ i_t \end{bmatrix}\end{aligned} \tag{24}$$

5.2 Expectations under inflation targeting

Expectation dynamics under the inflation targeting case is presented in eq. 24. We compare eqs. 22 and 24 to investigate the impact of inflation targeting. Analysis of eq. 24 indicates that the announced inflation target has significant effects in inflation and output expectations of the private agent.

$$\begin{bmatrix} E_t\pi_{t+1} \\ E_t y_{t+1} \end{bmatrix} = \begin{bmatrix} \dots & 1.7 & -1.2 & -0.05 & 0.006 \\ & -0.39 & 0.81 & -0.1 & 0.01 \end{bmatrix} \begin{bmatrix} \dots \\ E_{t-1}\pi_t \\ E_{t-1}y_t \\ E_{t-1}i_{t-1} \\ E_{t-1}\tilde{\pi}_{t-1} \end{bmatrix} + \begin{bmatrix} \dots & 0.08 & 0.05 \\ & 0.01 & 0.02 \end{bmatrix} \begin{bmatrix} \dots \\ i_t \\ \tilde{\pi}_t \end{bmatrix} \tag{25}$$

By analyzing eq. 24, we deduce that there is positive relationship between the inflation target and the expectations of the private agent. The announced inflation target of the CB is one of the main determinants of inflation and output expectations of the private sector. In other words, the inflation target of the CB anchors the expectations of the public.

5.3 Variability of expected inflation and output under alternative regimes

Another important feature of monetary policy practice is variability of inflation. Eqs. 25 and 26 display equations that define the variances of expected inflation and expected output under discretion and under inflation targeting respectively. As shown in eq. 16, the variance of inflation and output depends on the error terms.

$$var\left(\begin{bmatrix} E_t\pi_{t+1} \\ E_t y_{t+1} \end{bmatrix}\right) = \begin{bmatrix} \dots & -0.09 & 0.03 \\ & -0.1 & 0.09 \end{bmatrix} var\left(\begin{bmatrix} \dots \\ \varepsilon_t^i \\ \varepsilon_t^{\tilde{\pi}} \end{bmatrix}\right) \tag{26}$$

$$var\left(\begin{bmatrix} E_t\pi_{t+1} \\ E_t y_{t+1} \end{bmatrix}\right) = \begin{bmatrix} \dots & -0.06 & 0.02 \\ & -0.1 & 0.01 \end{bmatrix} var\left(\begin{bmatrix} \dots \\ \varepsilon_t^i \\ \varepsilon_t^{\tilde{\pi}} \end{bmatrix}\right) \tag{27}$$

The coefficients under the inflation targeting case are much lower compared to the case discretion. As a result, the variances of expected inflation and expected output are smaller under inflation targeting. This result provides theoretical explanations for the empirical findings of Gurkaynak et al. (2008).

5.4 Credibility of the central bank

Faust and Svensson (2001) indicate that reputation, credibility and transparency are centerpieces of policy discussions by both academics and policymakers since these concepts help explain previous and current circumstances. We present the determinants of credibility under discretion and under inflation targeting in the following equations.

Under discretion

$$cre_t = \begin{bmatrix} \dots - 0.04 \end{bmatrix} \begin{bmatrix} \dots \\ i_t \end{bmatrix}$$

Under inflation targeting

$$cre_t = \begin{bmatrix} \dots - & 0.05 & -0.2 \end{bmatrix} \begin{bmatrix} \dots \\ i_t \\ \tilde{\pi}_t \end{bmatrix}$$

The comparison of equations indicates that the CB can alter its credibility by setting an appropriate inflation target.

6 Conclusion

Inflation targeting has been declared a big success by monetary policy academicians and practitioners and many central banks are adopting inflation targeting. But the theoretical arguments about the mechanism behind the success of IT is not investigated thoroughly. In this paper, we construct and solve a model of asymmetric information and learning between the CB and public to investigate the underlying dynamics behind the success of IT. The contribution of the paper is to introduce time-varying inflation target of the CB as the source of the asymmetric information. The model shows that IT countries attain the desired outcomes because IT eliminates the asymmetric information and the frictions caused by that asymmetric information. As a result, in this paper we propose and theoretically show that in non-IT countries the private agents are uncertain about inflation target and they generate their expectations about the target by following the actions of the CB. That learning dynamics increases the uncertainty and level of inflation significantly. IT eliminates that uncertainty about the inflation target and lower levels of inflation and inflation uncertainty occurs because IT anchors inflation expectations.

There are three main results of this paper. First, inflation and output expectations of the public are significantly affected by the inflation target under the case of IT. In other words, we theoretically present the mechanism through which IT anchors inflation and output expectations. Second, in the discretionary CB case, the private sector agent uses a filtered estimate of the inflation target of the CB to form her expectations which increases the variance (stability) of inflation expectations of the public. Finally, credibility of the CB is significantly affected by the target under the IT case. The CB can improve its credibility by announcing a credible target. To sum up, we argue that the unknown inflation targets of the CB decrease transparency and cause distortions into the expectation formation of the public. IT eliminates these distortions and significantly lowers the variance of inflation expectations of the public. This paper uncovers this crucial impact of IT on information dynamics and proposes a new mechanism to analyze the effects of IT.

A Detailed display of state-space matrices

$$\Delta = \begin{bmatrix} 1 & 0 \\ \sigma & 1 \end{bmatrix}$$

$$\Theta = \begin{bmatrix} -\sigma & 0 \\ 1 & \lambda_1^i \\ 0 & 1 \end{bmatrix}$$

$$A = \begin{bmatrix} \beta_\rho & 0 & 0 & 0 & 0 & 0 \\ 0 & \beta_y & 0 & 0 & 0 & 0 \\ 0 & \frac{\gamma}{\alpha} & \frac{1}{\alpha} & -\frac{\gamma}{\alpha} & 0 & 0 \\ \sigma & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & \lambda_1^i & \lambda_2^i & \lambda_3^i & 0 \\ \lambda_2^{\tilde{\pi}} & 0 & 0 & 0 & 0 & \lambda_1^{\tilde{\pi}} \end{bmatrix}$$

$$\Xi_{t+1} = \begin{bmatrix} e^{\rho}_{t+1} \\ e^{y}_{t+1} \\ 0 \\ 0 \\ e^{r}_{t} \\ e^{\tilde{\pi}}_{t} \end{bmatrix}$$

$$D^{disc} = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ \left(\lambda^i_1 \lambda^{\tilde{\pi}}_2\right) & 0 & \lambda^i_1 & \lambda^i_2 & \lambda^i_3 & \left(\lambda^i_1 \lambda^{\tilde{\pi}}_1\right) \end{bmatrix} v^{disc}_t = \begin{bmatrix} \omega_{\pi,t} \\ \omega_{y,t} \\ \lambda^i_1 \varepsilon^i_t \end{bmatrix}$$

$$\Gamma^{IT} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & \lambda^i_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} D^{IT} = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & \lambda^i_1 & \lambda^i_2 & \lambda^i_3 & 0 \\ \lambda^{\tilde{\pi}}_2 & 0 & 0 & 0 & 0 & \lambda^{\tilde{\pi}}_1 \end{bmatrix} v^{IT}_t = \begin{bmatrix} \omega_{\pi,t} \\ \omega_{y,t} \\ \varepsilon^i_t \\ \varepsilon^{\tilde{\pi}}_t \end{bmatrix}$$

$$K = (BP_{t-1}B' + Q)C'(CP_{t-1}C' + R)^{-1}$$

$$P_t = E\left[\left(\psi_{t+1} - E_t\left(\psi_{t+1}\right)\right)\left(\psi_{t+1} - E_t\left(\psi_{t+1}\right)\right)'\right]$$

B Calibrated parameters

The calibrated parameters are from the maximum likelihood estimates of Ireland (2007) and Leigh (2008).

Parameter	Value	Parameter	Value
β_ρ	0.9	λ_1^i	0.6
β_y	0.9	λ_2^i	0.2
δ	0.75	λ_3^i	0.8
γ	0.25	$\lambda_1^{\tilde{\pi}}$	0.8
α	2	$\lambda_2^{\tilde{\pi}}$	0.2

References

[1] Aoki, Kosuke, 2003, On the Optimal Monetary Policy Response to Noisy Indicators, 2003, Journal of Monetary Economics 50, pp501-523.

[2] Aoki, K. and T. Kimura, 2007, "Uncertainty about Perceived Inflation Target and Monetary Policy", Discussion paper series 1:economic studies 2007-18. Frankfurt: Deutsche Bundesbank.

[3] Blinder, Alan S., 1999, Central Bank Credibility: Why Do We Care? How Do We Build It?, NBER Working Paper No. W7161.

[4] Clarida, Richard, Jordi Gali and Mark Gertler, 1999, The Science of Monetary Policy - A New Keynesian Perspective, The Journal of Economic Literature, December 1999.

[5] Cukierman, Alex, and Allan H. Meltzer (1986), A Theory of Ambiguity, Credibility, and Inflation under Discretion and Asymmetric Information, Econometrica 54, 1099-1128.

[6] Faust, Jon and Dale W. Henderson, 2004, Is Inflation Targeting Best-Practice Monetary Policy?, Review of the Federal Reserve Bank of St. Louis, 86:117-144.

[7] Faust, Jon and Lars Svensson, 2001, Transparency and Credibility: Monetary Policy with Unobservable Goals, International Economic Review, 42, 369-397.

[8] Gurkaynak, Refet S., Brian Sack, and Eric Swanson, 2005, The excess sensitivity of long-term interest rates: Evidence and implications for macroeconomic model, American Economic Review, 95(1), 425-36.

[9] Gurkaynak, Refet S., Brian Sack, and Eric Swanson, 2010, Does Inflation Targeting Anchor Long-Run Inflation Expectations? Evidence from Long-Term Bond Yields in the U.S., U.K., and Sweden, Journal of the European Economic Association 8(6), 1208–1242.

[10] Hamilton, James D., 1994. Time Series Analysis, Princeton: Princeton University Press.

[11] Ireland, Peter N., 2007, "Changes in the Federal Reserve's Inflation Target: Causes and Consequences.Journal of Money, Credit, and Banking, 39:851-1882.

[12] Kozicki, S. and P. A. Tinsley, 2005, " Permanent and Transitory Policy Shocks in an Empirical Macro Model with Asymmetric Information" Journal of Economic Dynamics and Control, 29(11):1985-2015.

[13] Melecky, M., D. R. Palenzuela and U. Soderstrom, 2009, "Inflation Target Transparency and the Macroeconomy", in Monetary Policy under Uncertainty and Learning, edited by Kalus Schmidt-Hebbel and Carl E. Walsh, Santiago, Chile.

[14] Leigh, Daniel, 2008, Estimating the Federal Reserve's implicit inflation target: A state space approach, Journal of Economic Dynamics and Control, 32:2013-2030.

[15] Peturrson, Thorarinn, 2004, The effects of IT on macroeconomic performance, Central Bank of Iceland Working Papers No. 23.

[16] Svensson, Lars and Michael Woodford, 2003, "Indicator Variables for Optimal Policy," Journal of Monetary Economics, 50:691-720.

[17] Svensson, Lars and Michael Woodford, 2004, "Indicator Variables for Optimal Policy under Asymmetric Information," Journal of Economic Dynamics and Control, 28:661-690.

[18] Townsend, Robert M., 1983, Forecasting the forecasts of others, The Journal of Political Economy 91, 546-588.

[19] Woodford, Michael, 2004, IT and Optimal Monetary Policy, Review of the Federal Reserve Bank of St. Louis, 86:15-42.