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ARTICLES

HAS INFLATION TARGETING CHANGED THE CONDUCT OF MONETARY POLICY?

JÉRÔME CREEL
OFCE—Sciences Po
and
ESCP Europe

PAUL HUBERT
OFCE—Sciences Po

We aim at establishing whether the institutional adoption of inflation targeting has changed the conduct of monetary policy. To do so, we test the hypothesis of inflation targeting translating into a stronger response to inflation in a Taylor rule with three alternative econometric models: a structural break model, a time-varying parameter model with stochastic volatility, and a Markov-switching VAR model. We conclude that inflation targeting has not led to a stronger response to inflation in the reaction function of the monetary authority. This result suggests that inflation targeting being meant to anchor inflation expectations through enhanced credibility and accountability, it may enable a central bank to stabilize inflation without pursuing aggressive action toward inflation variations.

Keywords: Taylor Rule, Bayesian Inference, Time-Varying Parameters, Markov-Switching VAR

1. INTRODUCTION

The recent financial crisis has translated into renewed attention to the role of monetary policy in fueling or dampening the effects of the crisis.[1] As a consequence, the debate on the adoption of inflation targeting (IT) by central banks has been left aside. But as this debate was far from being settled [especially because of the long-standing position of the Fed's Chairman in favor of IT; see, e.g., Bernanke et al. (1999)], we reopen it in this paper by assessing empirically whether the adoption of IT induced actual changes in the conduct of monetary policy. To do so, we consider three alternative empirical models and fit them to data for Canada,

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Sweden, and the United Kingdom. We conclude that the adoption of IT has not led to a stronger response to inflation.

The debate had been centered on the idea that IT central bankers could emphasize the inflation objective in the conduct of monetary policy at the expense of other monetary policy goals [e.g., King (1997), Friedman (2004), Leijonhufvud (2007), and Walsh (2009)]. A first argument in this direction would be that to comply with its inflation target, the central bank must give more attention, and thus more weight, to inflation. We therefore propose to disentangle the IT *paradigm* (which consists in a strong response to price developments to reach low and stable inflation, to produce stable macroeconomic conditions in the end) from the IT *framework* (which consists of commitment to a numerical target, publication of forecasts, and increased transparency). As Giannoni and Woodford (2002, 2005) and Woodford (2003) suggest, the institutional adoption of IT might in fact only be a matter of communication and accountability, because optimal policy rules in the literature look like an IT rule. Second, inflation developments do not always depend on factors internal to an economy, and adjusting interest rates mechanically might prove inefficient. Third, IT adoption may be sensitive to the self-selection issue: what may have led actually to low inflation in IT countries was their decision to aim specifically at lower inflation than in earlier (pre-IT) periods. This latter argument claims that good inflation performance may stem from a policy switch toward a greater focus on inflation, at the expense of other policy objectives, and has not yet been proved. Fourth, the central bank's commitment to low and stable inflation may not necessarily lead to a stronger response to inflation.

We use a contemporaneous Taylor (1993)-type rule, which corresponds to the normative description of central banking and to the specification of the monetary policy rule in the FRB-US model [Brayton and Tinsley (1996)] and the ECB's NAWN model [Coenen et al. (2008)]. We test the hypothesis that IT translates into a stronger response to inflation with three alternative econometric models, which allow us to have to assume neither potential break dates nor the nature of the breaks: sudden switches or gradual changes. We perform structural break tests à la Qu and Perron (2007) for unknown dates and number of breaks, time-varying parameters (TVP) with stochastic volatility in the context of Bayesian inference, and Markov-switching vector autoregressive (MSVAR) estimation as developed by Hamilton (1989, 1994) and Sims and Zha (2006), which make it possible to date breaks and assess whether a new regime appears or a previous one reemerges. These three methods contrast with a split-sample approach, which needs to assume a structural break and a date for it. TVP and MSVAR methods also contrast with tests of monetary rules that do not capture multiple shifts in variance because they do not make enough allowance for heteroskedasticity. This is important because the sources of time variation might be both the coefficients and the variance–covariance matrix of innovations, as shown by Primiceri (2005).

In contrast with the literature on the impact of IT on inflation performance or private expectations, we investigate whether the institutional adoption of IT has modified the conduct of monetary policy.[2] To our knowledge, only a few studies

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have been performed on this subject for countries that have adopted IT. Seyfried and Bremmer (2003) find a break in the monetary policy reaction functions of six IT countries, and they conclude that IT central banks pay more attention to inflationary pressures (proxied by the output gap) than to current inflation (whose coefficient is never significant). In opposition and for the United Kingdom specifically, Trecroci and Vassalli (2010) find, using TVP, higher response to inflation across time (but with a significantly negative interest rate smoothing parameter) and Assenmacher-Wesche (2006), using MSVAR, finds a low and nonsignificant response to inflation before IT and a higher response afterward. These two papers do not study the consequences of IT adoption in the United Kingdom per se. Davradakis and Taylor (2006) find a significant response to UK inflation only since IT adoption, but provided the latter is above target. Ammer and Freeman (1995) estimate a canonical VAR whose sample stopped just before inflation targets were first announced, and then compare actual values for GDP, inflation, and the real interest rate with the (out-of-sample) forecast ones. They interpret the differences between pairs—actual and forecasted—of all variables as evidence of a change of regime. In contrast, the use of TVP and MSVAR can reveal a new regime rather than require its assumption. Moreover, the focus on the emergence of regimes rather than on the occurrence of pure breaks also makes it possible to check the argument that anti-inflation policies had already existed before IT adoption. Finally, the closest paper to ours is Baxa et al. (in press). They find that the response to inflation became less strong after IT adoption in five IT countries with a TVP model.[3] However, they focus on potential gradual changes only, whereas we investigate this issue with two other complementary models. The main contribution of this paper is to provide empirical evidence on the changes in the conduct of monetary policy induced by IT adoption based on a multiplicity of econometric models.

The main result is that the adoption of IT has not led to a stronger response to inflation. This result is consistent across the three econometric models and across alternative specifications regarding the source or the nature of the potential break or the targeted real variable (the output gap or the unemployment rate). Moreover, there is no evidence of a greater response to output, which may suggest increased concern about inflation if output is considered as a leading indicator of inflation.

Two intertwined interpretations may be put forward, based on two supposed benefits of IT. First, IT—through central bank commitment to a target—is meant to anchor private inflation expectations, which will enable a central bank to control inflation without pursuing aggressive action toward inflation variations. Second, the central bank's decision to lower inflation may have actually led to low and stable inflation, and hence to a lower response to inflation. The credibility of the monetary policy framework change may have thus led to changes in inflation expectations and in the inflation process. Faroque and Minor (2009) and Osborn and Sensier (2009) provide strong evidence of changes in the level and persistence of inflation, respectively in Canada around 1991 and in the United Kingdom around 1992, when IT was introduced. Their results are consistent with those of Benati

(2008) for a wider range of countries. Fregert and Jonung (2008) provide evidence of a decrease of inflation expectations through wage agreements in Sweden when IT was implemented. Because long-term expectations appear to be better anchored with IT [Gürkaynak et al. (2010)], central banks have no reason to increase their response to inflation and the present empirical investigation confirms that they have not.[4]

Last, the outcome of this paper suggests that IT countries that have adopted the IT *framework* have not overemphasized inflation deviations from targets like "inflation nutters," to use the words of King (1997), whereas the IT *paradigm* common to IT and non-IT central banks in the last decade has led to a consensus around a 2% inflation target. The debate on IT adoption might therefore be centered on the level of the inflation target rather than on the supposed overemphasis of monetary policymakers on inflation at the expense of other policy targets.[5]

The remainder of the paper is organized as follows. Section 2 presents the data. Section 3 focuses on Qu and Perron (2007)'s structural break procedure. Section 4 displays the Bayesian TVP estimation. In Section 5, the regime-switching method is presented, along with estimation outcomes and related robustness tests. Section 6 concludes.

2. DATA

We concentrate on three industrialized IT countries, the largest among those that adopted it earliest, that still operate under this framework and make long time series at a high frequency available. Thus, if we focus on the eight OECD countries that adopted IT earliest, we are left with three countries: Canada, Sweden, and the United Kingdom.[6] IT was adopted in Canada in February 1991 and was in its complete form at the end of 1995, when the decelerating path of inflation was transformed in a fixed target range. The same process took place in the United Kingdom: adoption in October 1992 and completion in May 1997, which corresponds to the independence of the Bank of England. In Sweden, IT was adopted in January 1993 with the objective of its being fully applied in January 1995, and the inflation target has remained the same since IT adoption: no decelerating path of inflation occurred during the implementation period.

We focus on the period from 1987:1 to 2007:12 in order to rule out the disinflation period of the early 1980s during which most central banks fought against high inflation. We consider a period of stable inflation over which potential changes in the conduct of monetary policy would be even more striking. We therefore escape the usual criticism that better inflation performance under IT is concomitant with disinflation policies that started being implemented all over the industrialized world in the early 1980s.[7] Beginning in 1987:1 makes it possible to assess whether the *institutional* adoption had an effect on the conduct of monetary policy over a stable sample with low inflation.

Our concern being the conduct of monetary policy, we focus on the three standard variables of the monetary policy rule: the nominal short-term interest

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rate, the officially targeted CPI index, and the output gap. We use monthly data. The interest rate is the central bank reference rate, as advertised by central banks themselves. The inflation rate is the measure of inflation targeted by central banks. For the United Kingdom, the series is extrapolated from RPIX, RPI, and CPI-H, the harmonized index of consumer prices. In Canada, the series is the CPI excluding eight of the most volatile components; and for Sweden, UND1X, a core CPI index, is used. Interest rates and price indices come from central banks' statistical databases. The output gap is the monthly interpolated OECD output gap whereas unemployment rates, which are used to check the robustness of our outcomes in place of output gap measures, are national measures taken from the Thomson Financial Datastream.[8] Inflation rates are expressed as the first difference of the log of the price index, and all variables are expressed as percentages. Figure 1 plots these series.[9] The gray bars represent the implementation period between the institutional adoption of IT and its completion.

3. HAS MONETARY POLICY CHANGED? A STRUCTURAL BREAK ANALYSIS

3.1. Model

The first step of our analysis is to assess whether the conduct of monetary policy has changed during the period considered. We characterize the monetary policy responses to inflation and output gap with a contemporaneous Taylor (1993)-type rule,

$$r_t = \alpha + \beta_\pi \cdot \pi_t + \beta_y \cdot y_t + \varepsilon_t, \quad (1)$$

where r_t is the central bank reference rate and π_t and y_t are the current inflation and output gap, β_i parameters (with $i = \pi, y$) are the weights attributed, respectively, to inflation and output gap, and ε is a disturbance shock. This contemporaneous Taylor rule, which may seem at odds with what has become the dominant paradigm in the academic literature during the last decade, nevertheless corresponds to the very specification of the interest rate rule in the FRB-US [Brayton and Tinsley (1996)] and SIGMA [Erceg et al. (2006)] models at the Federal Reserve and the ECB's NAWN model [Coenen et al. (2008)]. Moreover, because central bank inflation and output projections may be inaccurate and unexpected shocks may occur, the policy rate may have to respond to actual changes in current macroeconomic conditions. A contemporaneous Taylor rule is therefore useful in analyzing monetary policy [see, e.g., Christiano et al. (2005) and Campbell et al. (2012)]. In addition, it has two major advantages. First, it enables us to circumvent the endogeneity problem with forward-looking specifications of the monetary reaction function that make future realized inflation and output endogenous to interest rate changes through the transmission channels of monetary policy. Estimating a contemporaneous Taylor rule when monetary policy experiences transmission lags [as shown by Bernanke and Blinder (1992); Bernanke and Mihov (1998); and Goodhart (2001)] circumvents this endogeneity issue. If inflation and output

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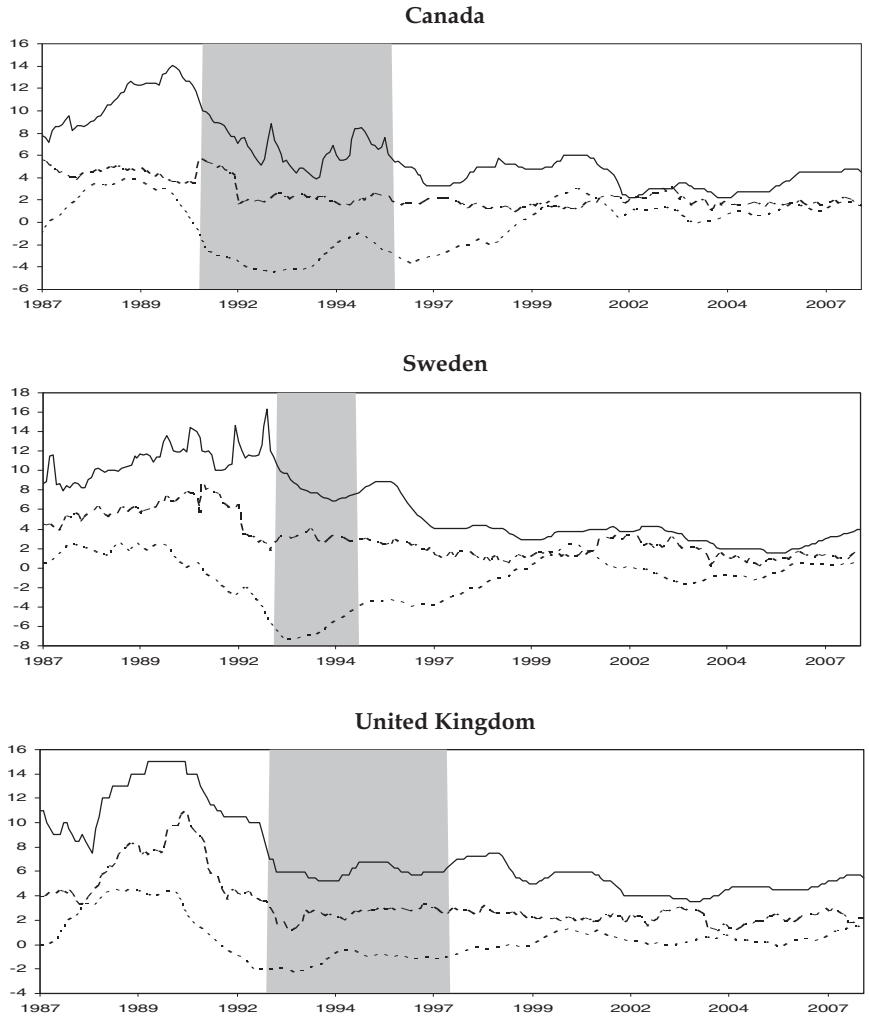

FIGURE 1. Data. The implementation period between the adoption of IT and its completion in final form has been represented by a gray area. The solid line is the central bank reference interest rate, the dashed line is the inflation rate targeted by the central bank, and the dotted line is the output gap.

respond with even one lag to changes in the policy instrument—and the literature shows that the real effects of monetary policy happen after 12 months for the GDP and between 18 and 24 months for inflation—then the current values of inflation and output should not be affected contemporaneously by ε_t, and are therefore not subject to this endogeneity issue. Second, it makes it possible to circumvent the issue of the partial availability of internal central bank forecasts along the sample.

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We apply the multivariate procedure of Qu and Perron (2007), which has been designed to estimate and test for multiple structural breaks that occur at unknown dates and allows for conditional heteroskedasticity. An advantage of this procedure is that the parameters, the covariance matrix of the errors, or both are allowed to change across regimes (i.e., periods between two structural breaks). The procedure tests the null hypothesis of no break against an unknown number of breaks up to a maximum of K; it then identifies the number and dates of breaks using a sequential approach. There are two steps in our estimation strategy. First, we identify the most significant and invariant break in the monetary policy reaction function after assuming the presence of two or three breaks over the sample. Second, based on these tests, we set the number of breaks to a fixed number $K = 1$ and assess whether the break date and the estimated parameters of the post-break regime can be associated with IT.[10]

3.2. Results

Table 1 summarizes the estimated break date and the parameters of the monetary rule. We perform three different tests: allowing breaks both in regression coefficients and in the covariance matrix of the errors, only in regression coefficients, and only in the covariance matrix of the errors. The second test seems more appropriate to assess a change in the institutional setting. However, one may also argue that the test would capture a break affecting only the covariance matrix of errors. For this reason, we compare the outcomes of the three tests. The Qu and Perron (2007) test reveals a break at the date 1999:9 for Canada with a narrow confidence interval at 90% from 1999:8 to 1999:10. In the United Kingdom, the estimated break occurred in 2001:1, with a confidence interval from 2000:12 to 2001:2. In Sweden, the break date evidenced is 1999:1 with a confidence interval from 1998:11 to 1999:3.

First, it is very interesting to note that monetary policy has changed over a sample (1987–2007) generally considered as stable. Most of the studies focusing on monetary policy changes postulate or find a change at the end of the 1970s or the beginning of the 1980s. The Great Moderation period is found or assumed to be stable. The present test evidences that monetary policy has changed in the three countries considered. Second, it appears that the structural break estimated for each country follows the end of the transition period to IT adoption and happens approximately four years after the full implementation of IT in the three countries. Third, Table 1 also provides the estimates of the policy coefficients of the two regimes before and after the break date. In Canada, the response to inflation, β_π, has decreased from 1.08 to –0.48, whereas the response to output, β_y, has risen from 0.49 to 1.28. In Sweden, the response to inflation has also been reduced from 1.25 to 0.72 and the response to output has increased from –0.22 to 0.34. Last, in the United Kingdom, the response to inflation was 1.18 before the break and is equal to –0.01 and not significant afterward, whereas the response to output increased from 0.14 to 1.13. To conclude, in the three IT countries, the pattern is identical and

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TABLE 1. Testing for a structural break in monetary rules over 1987–2007

	Allowing break in regression coefficients and in the covariance matrix of the errors			Allowing break in regression coefficients			Allowing break in the covariance matrix of the errors		
Canada									
Estimated break date[a]	1999:9			1999:9			1991:2		
90% interval confidence	1999:9	1999:10		1999:8	1999:10		1989:11	1991:3	
	β_π	β_y	σ_ε	β_π	β_y	σ_ε	β_π	β_y	σ_ε
Sample prebreak	1.08***	0.49***	2.83	1.08***	0.49***	1.86	1.29***	−0.10*	15.43
Sample postbreak	−0.48***	1.28***	0.37	−0.48***	1.28***				2.34
Sweden									
Estimated break date	1999:1			1999:1			1993:1		
90% interval confidence	1999:1	1999:2		1998:11	1999:3		1991:8	1993:3	
	β_π	β_y	σ_ε	β_π	β_y	σ_ε	β_π	β_y	σ_ε
Sample prebreak	1.25***	−0.22***	3.49	1.25***	−0.22***	2.13	1.49***	−0.38***	7.96
Sample postbreak	0.72***	0.34***	0.28	0.72***	0.34***				1.48
United Kingdom									
Estimated break date	2001:1			2001:1			2001:11		
90% interval confidence	2001:1	2001:2		2000:12	2001:2		2000:12	2007:7	
	β_π	β_y	σ_ε	β_π	β_y	σ_ε	β_π	β_y	σ_ε
Sample prebreak	1.18***	0.14**	1.12	1.18***	0.14**	0.81	1.35***	0.01	1.26
Sample postbreak	−0.01	1.13***	0.18	−0.01	1.13***				2.51

[a]Given the minimal length criteria of a regime (set at 20% of the total length of the sample) and one break allowed.
Significance levels are based on OLS estimates. *,**,*** mean, respectively, significant at 10%, 5%, and 1%.

the outcome is straightforward: the response to inflation decreased after the break date. There is no evidence of a policy change toward a greater focus on inflation.

Our main result does not contradict Clarida et al. (2000) and the subsequent literature, but rather complements it. Most central banks have been proactive since the end of the 1970s in their response to inflation. On this stable and proactive-to-inflation sample of the Great Moderation (starting in 1987 in this study), we find that for the three IT central banks considered, the response to inflation decreased after the full implementation of IT.

4. HOW HAS MONETARY POLICY CHANGED? A TIME-VARYING ANALYSIS

Boivin (2006), Kim and Nelson (2006), Canova and Gambetti (2008), Koop et al. (2009), and Kishor (2012), among others, show that the conduct of monetary policy may change smoothly. Therefore we use the TVP estimation to assess possible gradual changes rather than a discrete break and to control for heteroskedasticity.

4.1. The Time-Varying Parameters Model

We estimate policy changes induced by IT through a contemporaneous Taylor rule augmented with time-varying coefficients. The TVP model includes stochastic volatility, as Primiceri (2005), Kim and Nelson (2006), and Sims and Zha (2006) argue that the time-varying variance of shocks may be important in modeling monetary policy. A generally accepted characterization of the monetary policy conduct hence takes the following form:

$$\begin{aligned} r_t &= \alpha_t + \beta_{\pi t} \cdot \pi_t + \beta_{yt} \cdot y_t + \varepsilon_t, \quad \varepsilon_t \sim N\left(0, \sigma_{\varepsilon t}^2\right) \\ &= \Psi_t \cdot Z_t + \varepsilon_t, \end{aligned} \tag{2}$$

where r_t is the central bank reference interest rate, and π_t and y_t are the inflation rate and the output gap. The vector $\mathbf{\Psi}_t$ denotes the collection of TVP and Z_t the corresponding variables. All parameters have a t subscript to denote their time-varying behavior. The TVP model assumes that all parameters in the measurement equation (the Taylor rule) follow a driftless random walk, called the transition equation:

$$\Psi_{t+1} = \Psi_t + \upsilon_t \quad \text{with} \ \ \upsilon_t \sim N(0, \Sigma). \tag{3}$$

Stochastic volatility, denoted h_t, is modeled in the following form:

$$\begin{aligned} \sigma_{\varepsilon,t}^2 &= \gamma \exp(h_t) \\ h_{t+1} &= \phi h_t + \eta_t, \quad \eta_t \sim N\left(0, \sigma_\eta^2\right). \end{aligned} \tag{4}$$

The parameters do not follow a stationary process but a random walk process. The random walk assumption allows both temporary and permanent shifts in the parameters, as shown by Nakajima (2011). Shocks to the innovations of the TVP

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are assumed to be uncorrelated with the parameters Ψ_t and h_t. This makes the estimation procedure easier and simpler. Evolution of coefficients therefore depends on the value of the noise-to-variance ratio, i.e., the ratio between the variance of the transition equation and the variance of the measurement equation ($\Sigma/\sigma_{\varepsilon t}^2$). A regression with constant coefficients would consist in fixing the diagonal of $\Sigma = 0$ in the transition equation, thus having a noise-to-variance ratio equal to zero. If parameters were time-invariant, the estimation would produce OLS results.

4.2. Estimation Method

We implement a Bayesian analysis of equations (2) to (4) using a Markov chain Monte Carlo (MCMC) algorithm to generate the joint posterior distribution of parameters of interest under the assumption of a certain prior probability density [see, e.g., Chib and Greenberg (1996) and Chib (2001)].

The Bayesian approach using the MCMC method plays an important role in estimating the TVP model with stochastic volatility [Primiceri (2005) and Nakajima (2011)] because the latter has parameters and state variables in both linear and nonlinear forms. β_t coefficients and stochastic volatility are state variables, and they form the state-space model. Because the TVP model forms a nonlinear state-space model, the maximum likelihood (ML) estimation is intractable and requires heavy computation to reiterate the filtering and evaluate the likelihood function for all parameters until it reaches a maximum. Moreover, with the ML estimation, when the variance of the transition equation is small, the "pile-up" issue arises: the estimate is biased in the direction of 0, because the ML function has a large point mass at this value. Alternatively, a Bayesian approach using the MCMC method provides an efficient estimate of the TVP model.

The MCMC algorithm follows Nakajima (2011) and is mainly similar to the algorithms of the original TVP-VAR model developed by Primiceri (2005). We assume that $\Psi_0 = 0$, $v_0 \sim N(0, \Sigma_0)$, $\gamma > 0$, and $h_0 = 0$, and set the following priors, which can be considered to be diffuse and uninformative:

$$\Psi_t \sim N(0, I), \Sigma \sim \text{IW}(0, 40 \times I),$$
$$(\phi + 1)/2 \sim \text{Beta}(20, 1.5), \sigma_\eta^2 \sim \text{IG}(2, 0.02), \gamma \sim \text{IG}(2, 0.02).$$

To compute the posterior estimates, we generate $L = 30{,}000$ draws after the initial 6,000 draws are discarded. The convergence diagnostics (CD) and inefficiency factor of Geweke (1992) are computed to check the convergence of the MCMC algorithm and to ensure that the iteration size is sufficient and that the MCMC produces posterior draws efficiently.

4.3. Results

Figure 2 reports the evolution across time of posterior estimates (posterior medians and two- and one-standard-deviation bands) of the responses of the central bank

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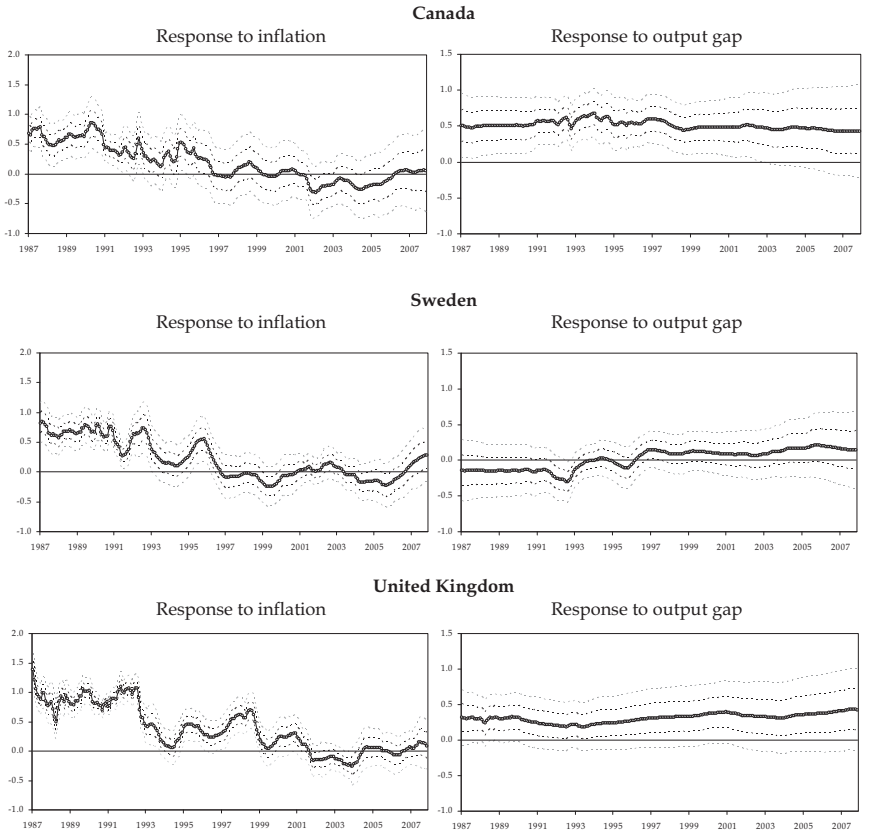

FIGURE 2. Time-varying responses to inflation and output gap. Median posterior with 1- and 2-S.D. bands.

interest rate, respectively to inflation and to the output gap.[11] The response to inflation has decreased in Canada, Sweden, and the United Kingdom. In the three countries considered, the response to inflation converges toward zero and evolves around this value after 1999. The response to output gap has not significantly changed across the sample and is rather stable for the three countries. All in all, estimates for Canada, Sweden, and the United Kingdom testify for a lower monetary reaction toward inflation over the sample. Time-varying estimates for the three countries clearly reject the hypothesis of a stronger response to inflation in the monetary reaction function with the adoption of IT and show that the conduct of monetary policy since IT adoption has not changed in the direction usually assumed, consistently with Baxa et al. (in press). Moreover, IT adoption did not lead to a decrease in the policy response to output.

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4.4. Robustness

To assess the robustness of the previous results, we estimate the TVP model based on two different sets of diffuse and uninformative priors, focusing our changes on the random walk process of parameters. The first alternative prior set has an alternative distribution of the parameters Ψ_t, whereas the second alternative set of priors has an alternative prior for Σ, the variance of the disturbance term of the random walk process:

$$\Psi_t \sim N(0, 1/2 \times I), \Sigma \sim \text{IW}(0, 40 \times I) \text{ and } \Psi_t \sim N(0, I), \Sigma \sim \text{IW}(0, 4 \times I).$$

Figure A in the Online Appendix plots the time-varying responses to inflation and output with an alternative prior for Ψ_t, whereas Figure B in the Online Appendix plots the responses with an alternative prior for Σ. Both series of estimates strongly confirm the downward trend of the response to inflation for all three central banks, whereas the response to output gap has remained constant. Both robustness tests evolve in a manner consistent with the baseline TVP estimates and suggest rejecting the hypothesis that the conduct of monetary policy has focused more strongly on inflation since IT adoption. This is also consistent with the outcome of the first empirical approach.

5. A COMPLEMENTARY ANALYSIS WITH MARKOV-SWITCHING VECTOR AUTOREGRESSION

In order to complement the two previous empirical approaches, we now assess whether the break in the policy coefficients can be related to the occurrence of a new regime or whether the break has consisted in a return to a previously existing regime. For this, we adopt the nonlinear stochastic dynamic simultaneous equations model of Assenmacher-Wesche (2006) and Sims and Zha (2006). The Markov-switching method allows us to test for the presence of a break and to assess the properties of each regime.

This analysis departs from the rest of the paper, as the procedure does not involve a contemporaneous Taylor rule but a backward-looking specification, and estimates are based on a three-equation VAR rather than the single equation of a monetary rule. First, although a contemporaneous (or forward-looking) monetary rule is certainly more representative of the behavior of central banks, its identification may be fragile [Sims and Zha (2006)]. The consistency of results using a backward-looking rule makes it possible to ensure the validity of the former identification. Moreover, it has been standard in dynamic stochastic general equilibrium models to assume that the monetary authority responds to lagged variables [Sahuc and Smets (2008)]. Second, the rationale for using a VAR is to identify the changes in the macroeconomic environment considered in its entirety compared to changes in the Taylor rule only. Thus we investigate whether changes in inflation and output processes occurred with changes in the conduct of monetary policy.

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5.1. Method

The MSVAR, as proposed by Hamilton (1989, 1994), allows the structural coefficients and the covariance matrix to be dependent on an unobserved state variable S_t, which is assumed to follow a first-order Markov chain. The joint distribution of the shocks can be nonconstant across the sample periods. The general framework is described by the equation

$$\begin{cases} y_t = x_t \cdot \beta_{S_t} + u_t & t = 1, \ldots, T \\ u_t | S_t \sim N(0, \Sigma_{S_t}) & S_t = \{1, \ldots, M\} \end{cases}, \tag{5}$$

where $y_t = (y_{1,t}, \ldots, y_{n,t})$ is a $1 \times n$ vector of endogenous variables, with n the number of variables of interest, namely the central bank interest rate, the inflation rate, and the output gap, x_t is a $1 \times np$ vector of p lagged endogenous variables, S_t is an unobserved state, β_{St} is an $np \times 1$ vector of parameters, T is the sample size, and M the number of states (or regimes). The covariance matrix Σ_{S_t} takes the form

$$\Sigma_{S_t} = \sigma^2(S_t) \cdot I_p. \tag{6}$$

The transition probabilities matrix, denoted P, is

$$P = \begin{pmatrix} p_{11} & \cdots & p_{M1} \\ p_{12} & \cdots & p_{M2} \\ \vdots & \cdots & \vdots \\ p_{1M} & \cdots & p_{MM} \end{pmatrix} \tag{7}$$

with $\sum_{j=1}^{M} p_{kj} = 1$ and $p_{kj} \geq 0$, $\forall k, j \in \{1 \ldots M\}$.

Initial values of the vector of parameters are calculated. A conditional probability density function is defined according to the information set in $t - 1$. The model is recursively estimated through the ML Expectation-Maximization "EM" algorithm, starting from the unconditional density of y_t, which is calculated by summing conditional densities over possible values for S_t. The ML estimates are finally obtained by maximizing the log-likelihood function and make it possible to obtain the final matrix of parameters. Our approach is close to that of Assenmacher-Wesche (2006). The baseline equation of the model is free of restrictions. The ad hoc nature of restrictions is opposed to the motivation of our methodology: because we do not know ex ante the possible changes of monetary policy effects implied by IT and because the empirical approach is data-driven (i.e., we are looking for what data tell us about this framework, setting aside any preconceived conclusions), we do not impose any restrictions on the parameters.

The MSVAR estimation is performed with three-equation VAR with four lags, and we focus specifically on the interest rate equation for the interpretation of results. The estimation is performed with changes in both coefficients and disturbance terms. We can emphasize different regimes with different monetary policy coefficients. We test for two or three different states (or regimes); because results

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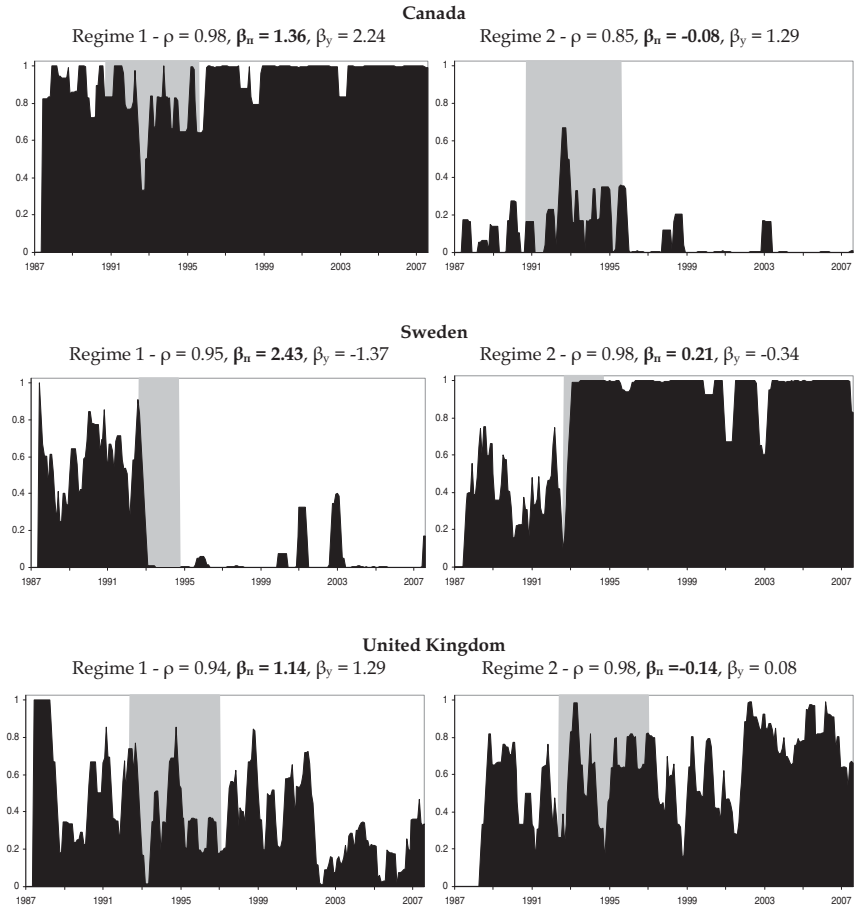

FIGURE 3. Regimes' probabilities over time for the three-equation VAR with output gap.

are consistent and robust, we only present the two-state specification, which fits well into the issue of whether, during a relatively short and stable sample (1987–2007), IT has constituted a regime with a stronger response to inflation.

5.2. Results

Results are reported in Figure 3.[12] They show for each country the implied state probabilities over time and the estimated coefficients of the interest equation that characterize each regime: the degree of persistence ρ and the respective long-run responses of the interest rate to inflation β_π and to the output gap β_y. By the long-run response, we mean the estimated parameter divided by one minus the persistence. The degree of persistence ρ is the sum of the coefficients on the lagged

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TABLE 2. Matrix of Markovian transition probabilities $P[i, j]$

Canada		Sweden		United Kingdom	
3-equation VAR with output gap					
0.93	0.73	0.61	0.10	0.51	0.32
0.07	0.27	0.39	0.90	0.49	0.68
3-equation VAR with unemployment					
0.95	0.40	0.73	0.07	0.62	0.27
0.05	0.60	0.27	0.93	0.38	0.73

interest rates.[13] To facilitate reading, we label the regime with higher response to inflation "regime 1." "Regime 2" stands for the regime with lower response to inflation. Matrices of transition probabilities are presented in Table 2.

Canada has not experienced a regime shift over the sample. There has only been a break during the transition period, but no emergence of a new monetary policy regime. Regime 1 has been prominent over the whole sample and is characterized by a response to inflation satisfying the Taylor principle in the long run, as well as by a relatively high response to the output gap. Canada experienced only a transitory period of adaptation between the announcement and completion of IT, during which regime 2 shows weak responses to inflation and the output gap. One can note the difference from both previous empirical approaches, possibly because of the backward-looking specification and the three-equation estimation rather than the monetary policy rule only. However, the hypothesis that IT led to a strong focus on inflation is still rejected. Moreover, the responses of monetary authorities to both policy objectives—inflation and the output gap—under regime 1 are not biased in favor of an excessive focus on inflation: the coefficient on the output gap is higher. This is consistent with Demers and Rodriguez (2002), and it complements Shih and Giles (2009), who model the duration analysis of the Bank of Canada's interest rate changes over the IT period and conclude that the conduct of monetary policy can be described by a standard rule which respects the Taylor principle.

In the United Kingdom, the MSVAR estimation does not underline a precise break but rather a progressive transition from regime 1 to regime 2. Because, by definition, the response to inflation of the gradually more frequent regime 2 is smaller than the one in regime 1, the gradual prominence of regime 2 goes hand in hand with a lesser focus of the Bank of England on inflation deviations from target. This latter result is in line with the TVP ones and may complement those reported in Assenmacher-Wesche (2006): during her so-called "low inflation" state, beginning in 1992 and ending in 2004, the Bank of England had a higher reactivity to inflation deviations and the output gap than under "high inflation." In our analysis, the "low inflation" state sample has been partitioned into two different

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regimes, where the second one, with a smaller policy response to inflation, has gained momentum over the years and mostly after 2002.

In Sweden, the adoption of IT has constituted a regime shift: regimes 1 and 2 were intertwined before IT adoption. Regime 1 has almost fully disappeared since IT announcement in 1993. This is a clear-cut result for Sweden and it corresponds to the usual assessment by Swedish central bankers that monetary policy entered into a new era after "flexible inflation targeting" was adopted [see Svensson (2009)]. The hypothesis of a greater response to inflation is clearly challenged by the dominance of regime 2 since IT adoption, consistently with estimates in Sections 3 and 4.

5.3. Robustness

The validity of the previous results is assessed in two ways. First, estimated monetary reaction functions are in line with former characterizations of Taylor rules by Kuttner (2004), Muscatelli et al. (2002), and Valente (2003) for these three countries (see Table D in the Online Appendix). Second, to assess the robustness of baseline MSVAR results, we ran new estimations with unemployment data, rather than output gaps, in the three-equation VAR. The unemployment rate can be considered as a proxy for the output gap, via Okun's law; moreover, it is a good measure of real activity at a monthly frequency [see Orphanides and Wieland (2008)]. One, four, and three lags have been used for these three-equation VARs respectively for Canada, Sweden, and the United Kingdom, according to the Schwarz information criterion.

Regime probabilities are reported in Figure C in the Online Appendix. In this alternative setting, Canadian outcomes are similar: the second regime occurred only during the transition period to full completion of IT, and the monetary regime always remained the same before IT announcement and after IT completion. This confirms that IT adoption has not led to a stronger response to inflation in the monetary reaction function. This result is also reinforced in the case of the United Kingdom: the gradual prominence of regime 2 (with a lesser focus on inflation) across time is in accordance with TVP estimates. In Sweden, the regime shift after IT adoption is also confirmed and consistent with TVP and structural break estimates. Estimates of monetary reaction functions, including the unemployment rate (see Tables 2 and C in the Online Appendix), first, confirm the initial results, and second, improve initial outcomes in that all reported coefficients show the expected signs.

6. CONCLUDING REMARKS

The central contribution of this paper is to provide an empirical assessment of the changes in the conduct of monetary policy induced by the adoption of IT without assuming the date and the nature of potential breaks. The analysis is carried out with structural break and TVP estimates of a contemporaneous Taylor rule and complemented with an estimation of a MSVAR.

The three econometric models show that the official adoption of IT in Canada, Sweden, and the United Kingdom has not led to stronger responses to inflation in the monetary reaction functions. Two intertwined mechanisms may explain this result. First, IT is meant to help anchor private inflation expectations, which will enable a central bank to control inflation without pursuing aggressive action toward inflation variations. Second, the central bank's decision to lower inflation may have led to low and stable inflation and hence to a lower response to inflation. The credibility of the monetary policy framework change may thus have led to changes in inflation expectations and the inflation process.

Our main result, linked to evidence on the stability of private expectations in IT countries, suggests that the IT framework does not constitute a binding commitment to inflation, but makes it possible to implement a flexible strategy, in which central banks need not be tough on short-term inflation provided the IT framework is credible and long-term inflation expectations are anchored.

NOTES

1. See, e.g., Bullard (2009), Taylor (2009), and Frappa and Mésonnier (2010).

2. Most of the empirical papers dedicated to IT can be split into two categories: the anchoring of private expectations and inflation performance. Evidence points to lower and better-anchored inflation expectations with IT adoption [Johnson (2002); Levin et al. (2004); Fregert and Jonung (2008); and Gürkaynak et al. (2010)], whereas there is no significant effect on inflation performance [Cecchetti et al. (2002); Ball and Sheridan (2005); Angeriz and Arestis (2007); Lin and Ye (2007); Cecchetti and Hakkio (2009); and Genc (2009)]. These papers are all confronted by the control group problem enlightened by Gertler (2005) and magnified by the exceptional stability of inflation during the last decade. Because of the Great Moderation, it is difficult in a comparative setting to evidence a change either in inflation expectations or in inflation performance that can be attributed solely to a change in institutions.

3. The use of TVP to assess monetary policy in the United States has been abundant: Canova (1993), Stock and Watson (1996), Cogley and Sargent (2001), and Primiceri (2005) use TVP to estimate VARs with drifting coefficients, whereas Kim et al. (2005), Boivin (2006), and Kim and Nelson (2006) focus on monetary rules. Tillmann (2011) provides theoretical and empirical evidence that the interest rate setting of the Federal Reserve is nonlinear.

4. It is important to acknowledge that this paper does not assess the effectiveness of monetary policy. Hence, our tests do not address the debate on the Great Moderation. The latter is usually associated with the great decline in output, employment, and inflation volatility and attributed to more efficient monetary policy, increased globalization, better inventory policies, and/or "good luck" [see Davis and Kahn (2008) for a critical empirical review of these arguments]. It remains the case that our results are not blurred by the debate around the Great Moderation. We do not investigate the reasons for the decline in inflation, but rather focus on the relationship between the inflation rate and the policy instrument, without any judgment on its effectiveness over time. We focus on the changes in monetary policy that have occurred since IT adoption.

5. See recently on this point Blanchard et al. (2010).

6. We drop New Zealand and Australia because of the multiple modifications of their IT framework; Israel, an emerging country without long time series; and Finland and Spain because of their accession to the Eurozone in 1999. In Sweden and Canada, no change in the target has occurred since the completion of IT. In the United Kingdom, the target changed once: in December 2003, the target moved from 2.5% per year (for the RPIX) to 2% per year (for the CPI). It is generally admitted that because the RPIX and the CPI are not measured similarly, a 2% target for the CPI amounts to a

2.5% target for the RPIX [cf. King (2004); Cukierman and Muscatelli (2008)]. With respect to the motivations of our study, the fact that changes in targets have been nonexistent or scarce is important in that it helps to escape finding a change of monetary regime that would ensue solely from a change in the target, and not from a change in the conduct of monetary policy.

7. All countries have experienced a common strong disinflation. For this reason, our focus is not on the inflation performance of IT versus non-IT countries, but solely on changes in monetary preferences within IT countries. Moreover, many authors [see, e.g., Boivin (2006) or Sims and Zha (2006)] have shown for the United States, a non-IT country, that changes in the reaction function of the Federal Reserve happened when P. Volcker started his mandate and that the monetary preferences of the Fed have been stable since then (i.e., in our sample). Our own MSVAR checks on U.S. data confirm this result. This suggests that evidence presented in this paper is not due to factors that would also have affected non-IT central banks.

8. The output gap is the difference between actual and estimated potential GDP in percent of potential GDP. OECD estimation of potential GDP follows a production function approach, taking into account the capital stock, changes in labor supply, factor productivities, and underlying "non-accelerating inflation rates of unemployment" (NAIRU). A more detailed account of the methods for estimating potential and output gaps at the OECD is given by Giorno et al. (1995) and Beffy et al. (2006).

9. Stationary tests are provided in Table A of the Online Appendix. Supplementary materials are available at the Journal webpage.

10. We set the trimming parameter to 0.2, which determines the minimal length of a regime in proportion to the total sample size. This parameter has to be chosen large enough for tests to have approximately correct size and small enough for them to have decent power. Moreover, when the errors are autocorrelated and/or heteroskedastic, it has to be larger than when these features are absent.

11. The computational results are generated using Nakajima (2011)'s codes, available at http://sites.google.com/site/jnakajimaweb/program. Table B in the Online Appendix gives the estimates for posterior means, standard deviations, the 95% credible intervals, the convergence diagnostics (CD) of Geweke (1992), and inefficiency factors, which are computed using the MCMC sample. The Z-score of the CD statistic confirms that the convergence to the posterior distribution is satisfactory, and the inefficiency factors are quite low except for σ_η, which indicates efficient sampling for the parameters and state variables. Even for the σ_η, the inefficiency factor is about 208, which implies that we obtain about $L/208 = 144$ uncorrelated samples. This is considered to be large enough for the posterior inference.

12. Figures depict at each date the average probability to stand in the corresponding regime over the last 6 months. Coefficients of response are "artificial long-run responses" of the policy rate to both objectives of monetary policy, and they are computed as in Sims and Zha (2006), using the same confidence interval at 68%

13. See Table C in the Online Appendix for a complete presentation of point estimates and standard errors of the interest rate equation.

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