Macroeconomic Dynamics, **26**, 2022, 1302–1337. Printed in the United States of America.
doi:10.1017/S1365100520000565

INFLATION TARGETING UNDER INFLATION UNCERTAINTY—MULTI-ECONOMY EVIDENCE FROM A STOCHASTIC VOLATILITY MODEL

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One of the most important advantages of an inflation target is that it helps to reduce uncertainty about future inflation. However, this confidence may be undermined if actual inflation continuously deviates from the target level. We examine how inflation uncertainty relates to the presence of an inflation target and deviations of inflation from the targeted level. Inflation uncertainty is quantified by means of an unobserved components stochastic volatility model that allows to distinguish between permanent and transitory inflation uncertainty. While long-term inflation appears largely stable in most economies, the short-term inflation uncertainty is found to be time-varying. Most notably, short-term inflation uncertainty is high if inflation rates are below the target level. This is particularly relevant for economies which are currently confronted with the presence of persistently low-inflation rates. Our findings suggest that announcing higher inflation targets as it is currently discussed may be costly in terms of provoking higher inflation uncertainty.

Keywords: Inflation Targeting, Inflation Uncertainty, Stochastic Volatility, Identification through Heteroscedasticity

1. INTRODUCTION

A recent debate among central bankers and macroeconomists centers on the optimal target rate of inflation. Prolonged periods of low inflation and interest rates that are close to zero are typically considered as undesirable for various reasons. For example, small or near-zero interest rates restrain the possibility of

We thank Geert Bekaert, Benjamin Born, Zeno Enders, Jan-Oliver Menz, Elmar Mertens and Henning Weber, the editor William A. Barnett, and two anonymous referees as well as conference participants at the SMYE 2017 Halle for helpful comments. Financial support from the Fritz-Thyssen Foundation is gratefully acknowledged. Address correspondence to: Maren Ulm, Department of Economics, Georg-August-University Göttingen, Humboldtallee 3, 37073 Göttingen, Germany. e-mail: mulm@uni-goettingen.de, maren.ulm@web.de.

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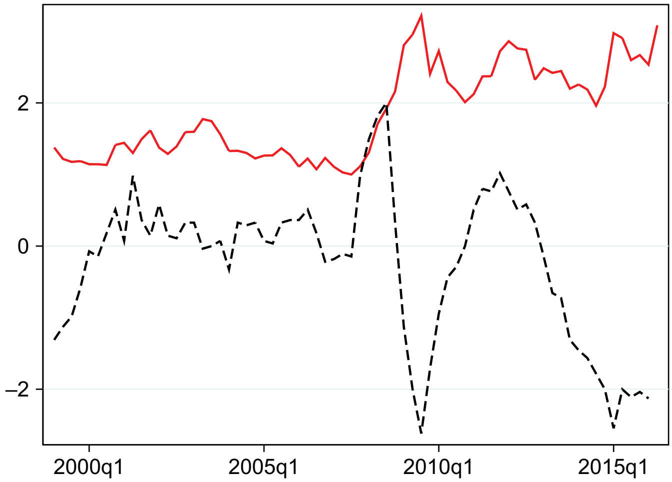

FIGURE 1. Survey-based inflation uncertainty in the Eurozone (1 year ahead, solid red line) and deviations of inflation from the target (dashed black line). Target deviations are obtained as annual Harmonised Consumer Price Index inflation minus approximately 2%, the officially announced target level of the ECB.

counteracting recessions by means of accommodative monetary policy. During recent decades, a large number of economies have adopted inflation targeting (henceforth, both "inflation targeting" and "inflation target" are abbreviated as IT) as a central part of their monetary policy framework. In many economies, central banks aim to stabilize inflation at a level close to 2%.

According to Henzel and Rengel (2017) and Coibion and Gorodnichenko (2012), however, it is not guaranteed that the adoption of an IT generates the intended outcomes. For example, the European Central Bank (ECB) has maintained an inflation target of slightly below 2% since the inception of the Euro in 1999. The evolution of inflation uncertainty (IU, henceforth) and the role of deviations of actual inflation from the target in the Eurozone provides an example for the relation that we investigate in this study. Each quarter, the ECB elicits density predictions for inflation from a panel of professional forecasters. An aggregate measure of inflation uncertainty is obtained from the survey data as the average variance across individual density forecasts. Figure 1 depicts average inflation uncertainty jointly with the deviation of actual inflation from the targeted level of approximately 2%. It can be seen that after 1999, the stable evolution of inflation close to the target has been accompanied by a similarly stable path of IU. However, around the beginning of the economic crisis, both deviations of inflation from the IT and IU have markedly increased. In particular, actual inflation has been deviating from the target for several years until the end of 2016. This may also help to explain why IU has been persistently high since about 2007, despite the recovery of economic conditions in the Euro area beginning in 2010, which would be rather associated with reductions in uncertainty. The evolution of the survey-based indicator of IU illustrates that an IT may contribute only weakly to the containment of IU if inflation deviates markedly from the IT.

Apart from the influence of inflation dynamics, gaps between inflation and the target might also arise or widen as a result of adjustments of the target level. Such changes have been implemented in various countries such as, for example, Canada or South Korea. Moreover, the decision to introduce an IT may in some cases reflect the intention to influence the future path of inflation by means of the IT. This could, for example, have been the case in Japan, which experienced a relatively long period of low inflation well below the level of 2%, before this value was introduced as IT in 2013. Aside from the potential benefits of such target introductions or adjustments, the example shown in Figure 1 highlights that such changes of the monetary policy framework might be costly in terms of increased IU. The aim of this paper is to examine how inflation and its deviation from an IT are related to IU.

Several developed economies have adopted IT only during recent years. Accordingly, economy-specific empirical analyses of IU may be constrained by a rather small number of (most) relevant observations. Thus, considering a cross section of economies is a natural means to strengthen the empirical conclusions. The analysis of IU in this study proceeds in two steps. First, we estimate IU for a large cross section of 26 advanced and emerging economies in the framework of the state-of-the art unobserved components stochastic volatility (UCSV) model as proposed by Stock and Watson (2007). This delivers a measure of IU which enables us to analyze a broad range of economies.[1] In the second step, we relate IU quantifications to a range of effects explanatory variables in a panel context. In particular, we jointly analyze the effects of macroeconomic variables and characteristics of the monetary policy framework. Considering a broad range of potential IU determinants allows us to accurately describe marginal effects that can be ascribed to the monetary conditions of interest. In this sense, we contribute to the literature by providing a more comprehensive examination of the sources of IU in comparison with other empirical studies that have mainly focused on specific transmission channels such as the effect of inflation on IU (Grier and Perry (1998), Conrad and Karanasos (2005), Hartmann and Herwartz (2012)). We also investigate to which extent the results are specific to developed economies as compared with emerging market economies. Since the latter are often characterized by higher inflation rates, the characteristics of IU might be distinct in such countries, for example, due to other priorities of the respective monetary authorities.

The UCSV specification flexibly separates the permanent and transitory components of IU. In this sense, the UCSV model distinguishes between uncertainty about long-term and short-term inflation. The importance of this separation has been emphasized by, for example, Stock and Watson (2007) or Cogley and Sbordone (2008). Long-term IU might be thought of as the uncertainty about the existence, the level, and the credibility of the central bank's inflation objective, while short-term IU may indicate uncertainty about the duration of potential deviations from it. The notion of separate uncertainty horizons has been formalized, for example, by Beechey et al. (2011) who employ a small-scale Dynamic Stochastic General Equilibrium (DSGE) model in which they distinguish between an uncertain IT on the one hand, and uncertainty about the persistence of deviations between inflation and the IT on the other hand. The former (latter) might be interpreted as permanent (transitory) IU in our framework. While the UCSV model matches important stylized facts of inflation processes (Wright (2011), Clements and Galvao (2014)), it has been noted that conditional variance series that are implied by the UCSV model can lack significant time variation. Hence, analyzing the determinants of IU by means of panel models as we do in the second step of our analysis might result in spurious conclusions if the cross section entails both trending and constant IU series. Moreover, an emerging strand of literature addresses its potential overparametrization (Chan (2016)). We account for these caveats by applying the Bayesian stochastic model specification search of Frühwirth-Schnatter and Wagner (2010) as a sensitive diagnostic device to test for time variation in the transitory and permanent component of IU.

Two further points need to be addressed when analyzing the relation between target deviations of inflation and IU. First, the effect has to be isolated from other potential influences on IU. Apparently, IU can be related to a range of distinct economic and other, potentially country-specific, circumstances. Moreover, it should also be taken into account that parameters might depend on distinct regimes. We deal with these issues by analyzing inflation deviations above and below the target separately. This framework accommodates both the current low-inflation environment as well as the inflation trajectories that characterize past decades. The second problem to be addressed when examining the linkage between IT, deviations from the target and IU is endogeneity. In many economies, monetary policy is at least partly insulated from political influences. Thus, central banks are able to condition the adoption of IT on economic circumstances, such that the inception of an IT may itself be driven by IU or factors that affect it, like the inflation rate. The potential dependence of successful IT on inflation is discussed, for example, by Lin and Ye (2007) or Lin (2010). To obtain valid orthogonality restrictions in this setting, we employ a method proposed by Lewbel (2012) that exploits heteroscedasticity in the disturbances. The issue of endogeneity, that is, an influence of IU on deviations of inflation from the target, is also highly relevant from the viewpoint of monetary policy. In particular, reverse causality may impair the success of an IT even further, if it increases the gap between actual inflation and the target.

We document that over the long-term inflation is predictable in the sense that the related permanent IU is diagnosed as constant in most economies. In contrast, transitory IU is found to be time-varying. Most importantly, IU is particularly high during periods when inflation falls below the target level. Given the current environment of persistently low inflation, such periods seem to be especially important from the viewpoint of economic policy. Moreover, comparing the results from fixed effects (FE) and the endogeneity-robust Generalized Method of Moments (GMM) estimation suggests that IU and the deviations of inflation from the target are jointly evolving. Thus, increases of IU during periods of negative target deviations might feed back to the inflation level and further increase the wedge between the actual and the targeted inflation rate. Hence, the attempts of central banks like the Bank of Japan to increase inflation in order to narrow the deviation from the target might turn out as difficult at present, in particular if the level of IU is high. Furthermore, a split-sample analysis suggests that this effect may be ascribed mainly to developed economies.

To summarize, our findings suggest that permanent IU is in most economies remarkably stable. This may reflect firm confidence in the capability of monetary policy to preserve the status quo. While a constant permanent IU may still be relatively high in comparison with the one in other economies, we regard constant IU as a salient feature of a well-anchored inflation process. The dampening of fluctuations in (permanent) IU increases the predictability of inflation fluctuations and thereby facilitates the task to insure oneself against risks of future losses of nominal income. For example, the pricing of securities that provide insurance against inflation risk (e.g., inflation-protected government bonds) is considerably facilitated in the absence of time variation in IU, as this should essentially eliminate the risk premium on comparable nominal assets.

In contrast to permanent IU, the detected fluctuations in transitory IU emerge especially during periods when actual inflation deviates from the target. Importantly, we document that high IU and negative deviations from target are jointly determined. This finding provides a tentative explanation for the difficulties that some central banks face when trying to implement a departure from a low-inflation environment. Moreover, this finding seems to be most relevant for developed economies. The results from a comparison of estimates for the entire cross section of economies with the ones obtained for a cross section that comprises only developed economies shows that IU is even higher during low-inflation periods in countries which belong to the Organisation for Economic Co-operation and Development (OECD) countries.

In Section 2, we introduce the UCSV model for inflation and IU along with the model specification procedure and the design of the panel regressions formalizing the linkages between IU and its potential determinants. In Section 3, we first discuss the results of the model selection search. Second, we discuss the empirical determinants of IU with a particular focus on the marginal influence of IT. Third, we briefly comment on the robustness of our analysis with respect to several alternative specifications of the empirical setup. Section 4 concludes. Appendices A and B outline the employed Gibbs sampling procedure and provide an overview on introduction dates of inflation targeting regimes, respectively. Appendix C displays estimated IU trajectories for all sample economies.

2. EMPIRICAL FRAMEWORK

In this section, we first sketch the UCSV model (Stock and Watson (2007)) and its parametrization that allows a stochastic model selection procedure. A description of the main computational steps of the Markov Chain Monte Carlo (MCMC) algorithm can be found in Appendix A. Finally, we outline the specification of the regression equation for the second step analysis. In specific, we emphasize how periods of inflation targeting and deviations from the inflation target are defined.

2.1. The UCSV Model

In the UCSV model, inflation is decomposed into the sum of an unobserved permanent component and a transitory disturbance. The permanent component represents an underlying trend inflation and is assumed to follow a random walk. The transitory component captures fluctuations of inflation around its trend level. Both the innovations to inflation and to its trend are modeled by means of stochastic volatility processes to account for frequent changes in macroeconomic volatility. The UCSV model is specified as:

$$\pi_t = \tau_t + \exp\{h_t^{\pi}\}\, \xi_t^{\pi} \quad (1)$$

$$\tau_t = \tau_{t-1} + \exp\{h_t^{\tau}\}\, \xi_t^{\tau}, \quad (2)$$

where π_t and τ_t denote the observed inflation and the underlying trend inflation, respectively, and $\xi_t = \left(\xi_t^{\pi}, \xi_t^{\tau}\right)$ is assumed to be *i.i.d.* $N(\mathbf{0}, I_2)$. The stochastic volatility terms are governed by random walks:

$$h_t^{\pi} = h_{t-1}^{\pi} + \nu_t^{\pi}, \quad \nu_t^{\pi} \sim i.i.d.N(0, \omega_{\pi}^2) \quad (3)$$

$$h_t^{\tau} = h_{t-1}^{\tau} + \nu_t^{\tau}, \quad \nu_t^{\tau} \sim i.i.d.N(0, \omega_{\tau}^2), \quad (4)$$

where the innovations ν_t^{π} and ν_t^{τ} are assumed to be independent. In a widely cited study, Ball and Cecchetti (1990) find that for many economies inflation dynamics are well described by a model which incorporates transitory and permanent shocks to inflation. The distinguished conditional volatility processes for the transitory and the permanent innovations to inflation allow to extract inflation uncertainty measures for the two distinct horizons. Ball and Cecchetti (1990) emphasize the importance of this distinction as a means to reconcile inconsistent empirical results on the relation between inflation and inflation uncertainty. Similar to them, we presume that uncertainty about future inflation in the short run depends on the variance of the transitory shock and is measured by the standard deviation:

$$\sigma_t^{\pi} = \exp\{h_t^{\pi}\}. \quad (5)$$

Uncertainty about the long-run development of inflation is captured by the standard deviation of the shock affecting the trend inflation:

$$\sigma_t^{\tau} = \exp\{h_t^{\tau}\}. \quad (6)$$

While a number of studies, such as Dovern et al. (2012), employ a combination of the terms in (5) and (6) to measure IU at a given horizon, we focus on the distinction of IU at the short and the long run by considering σ_t^{π} and σ_t^{τ} separately. This distinction between short- and long-term IU reflects characteristics of a typical forecasting problem of economic agents who might employ a wide range of modern theory-based macroeconomic models such as DSGEs. Such specifications typically rely on a well-defined steady state. However, the short- to medium-term dynamics that describe the transition toward the steady state are often based on less stringent theoretical foundations and depend on various details such as numerical values of calibrated parameters and ad hoc mechanisms like price indexation. If a forecaster were to employ such a model, the long-term IU might vary to a lesser extent than the short-term IU, since available models provide little unambiguous guidance especially in the short run. A model which expresses the problem of an economic agent who seeks to learn both the long-term target inflation of the central bank and the duration of deviations between actual inflation and the target is discussed in Beechey et al. (2011).[2] In their small-scale DSGE model, it can be shown that the more persistent the deviations from the target are, the higher is the short-term IU. This result also holds if the targeted inflation level is known and agents only have to learn about the length of a spell of misalignment between actual and target inflation.

2.1.1. Stochastic model specification search. The majority of empirical approaches to quantify IU implement the UCSV model directly following the work of Stock and Watson (2007), among them Wright (2011) or Mertens (2016). In this study, the analysis of the relation between IU and IT requires a different empirical strategy. In the next section, the effect of IT on the components of IU will be analyzed by means of panel regression models with cross-sectionally constant slope coefficients. In such a framework, we have to be cautious to avoid spurious conclusions regarding the effects of IT, since the cross section might comprise both economies with trending and/or constant IU. Constant IU might arise, for example, if reductions in IU were accomplished already before the formal introduction of IT due to a steady accumulation of trust in the monetary policy. In other words, many economies might have pursued monetary policy strategies largely in line with IT before such policy principles were explicitly formulated in a legally binding way. As a case in point, one might regard the disinflation policy of the US-FED in the early 1980s under the chairman Paul Volcker. The US-FED policy during this time should have helped to anchor long-term inflation expectations and IU before the official announcement of an IT. Such developments, however, are hard to measure directly in our case owing to the lack of, for example, a broadly available metric of central bank credibility for large cross sections of countries. Without taking a stance a priori on whether IU should be regarded as constant or time-varying, testing for an appropriate specification of the IU processes seems reasonable prior to analyzing the filtered IU series in a panel framework. Moreover, a growing strand of literature addresses the potential overfitting of time-varying parameter models (Eisenstat et al. (2016), Chan (2016)). Besides the issue of safeguarding against spurious findings that has been discussed above, testing for an appropriate model specification seems also reasonable to reduce the risk of overparametrization. While the stochastic processes in both shock volatilities might well capture macroeconomic effects contributing to high and unstable inflation processes in some (emerging) economies, the data might favor a more parsimonious specification with constant variances for economies with relatively stable inflation. In the specification of Stock and Watson (2007) the a priori assumed stochastic processes for the conditional volatilities in (3) and (4) pass their time variability on to the suggested IU measures in (5) and (6). To draw conclusions on the time-varying properties of IU, we investigate the degree of time variation of h_t by means of a model selection search for the UCSV model as developed by Frühwirth-Schnatter and Wagner (2010). The stochastic model specification search has been applied, among others, in Grassi and Proietti (2014) to characterize trends in economic time series. Our approach is similar to Berger et al. (2016) who test for time variation in the parameters of a multivariate unobserved components model for the US economy. The application of the stochastic model specification builds upon a non-centered parametrization of the time series process under consideration. The next two paragraphs describe the non-centered parametrization for the volatility equations (3) and (4) and the model selection by means of stochastic binary indicators.

2.1.2. Non-centered parametrization. The non-centered parametrization for the stochastic volatilities h_t in equations (3) and (4) allows to decompose the dynamics of the log volatilities into an observation equation for h_t and a state component $\tilde{h}_t$, that is,

$$\begin{aligned} & h_t = h_0 + \omega \, \tilde{h}_t, \\ \text{with} \quad & \tilde{h}_t = \tilde{h}_{t-1} + \tilde{v}_t, \quad \tilde{h}_0 = 0 \quad \text{and} \quad \tilde{v}_t \sim N(0, 1). \end{aligned} \tag{7}$$

The square root of the shock variances, ω, in (7) corresponds to a regression coefficient in a linear state-space model. The non-centered parametrization in (7), however, is not identified, since the sign of all elements in $\{\tilde{h}_t\}_{t=1}^T$ and the parameter ω can be multiplied by -1 without affecting the distribution of $\{h_t\}_{t=1}^T$. As pointed out by Frühwirth-Schnatter and Wagner (2010), the corresponding likelihood function becomes symmetrically bimodal with modes close to ω and $-\omega$ for $\omega^2 > 0$. In contrast, there is only one mode at $\omega^2 = 0$ under a constant volatility h_0. Hence, the shape of the posterior distribution of ω gives the first indication if h_t is varying over time.

2.1.3. Binary model indicators. The choice of the variance ω^2 can be regarded as a variable selection problem for $\tilde{h}_t$ in (7). Therefore, we introduce a stochastic binary indicator δ in (7). If the indicator $\delta = 0$, $\tilde{h}_t$ is not selected for modeling h_t and, accordingly $h_t = h_0$. In contrast, if $\delta = 1$, the coefficient ω in (7) corresponds to an unknown parameter to be estimated in the course of the Gibbs sampling procedure. Introducing the indicator δ into the non-centered parametrization (7) obtains

$$h_t = h_0 + \delta \, \omega \, \tilde{h}_t. \tag{8}$$

We evaluate the posterior inclusion probability $P(\delta = 1)$ by means of the frequency at which the respective model specification is visited across the M Gibbs

https://doi.org/10.1017/S1365100520000565 Published online by Cambridge University Press

iterations, that is, $P(\delta = 1) = \frac{1}{M}\sum_{m=1}^{M} \mathbb{1}_{(\delta=1)}$ where $\mathbb{1}$ denotes an indicator function. If the posterior inclusion probability exceeds 0.5, the indicator takes a value of unity and, hence, the corresponding IU process is modeled as time-varying. In contrast, if the posterior inclusion probability remains below 0.5, IU is indicated to be constant.

2.1.4. Prior distributions. A priori, we regard both model specifications (constant vs. dynamic volatility) to be as equally likely for both types of volatility, transitory, and permanent. Therefore, we assume a uniform prior distribution for both indicators δ^{π} and δ^{τ}. For the initial states h_0^{π} and h_0^{τ}, we assume normal priors $N(0, 1)$ and $N(\ln(0.5), 1)$, respectively. With respect to the prior distribution for the variance of the SV processes, $\omega_{\bullet}$ with $\bullet \in \{\pi, \tau\}$, we follow Frühwirth-Schnatter and Wagner (2010) and employ a Gaussian prior, that is $\omega_{\bullet} \sim N(0, 1)$.

2.2. Determinants of IU

After estimating the UCSV model in the selected specifications for the 26 economies by means of the Gibbs sampler, measures of IU are available for the cross section of economies. We employ a panel data framework to examine the link between IU and its institutional and macroeconomic determinants in the second part of the analysis. While the precision of volatility estimates based on the UCSV model benefits from using intra-quarterly data series, monthly variations might be less informative from the viewpoint of macroeconomic modeling. The decision-taking process in fiscal or monetary policy institutions is characterized by various frictions that impair a swift response to changing circumstances. For example, central banks usually do not adjust short-term interest rates at the monthly frequency. Hence, if the aim is to explain variations in macroeconomic series by means of institutional characteristics, monthly fluctuations might be regarded as unnecessarily noisy. To extract the most meaningful fluctuations for macroeconomic analysis, we aggregate the available monthly observations, that is,

$$\sigma_{jq} = \frac{1}{3}\sum_{t\in q} \sigma_{jt}$$

with q indicating the quarter and relate them to the realized volatilities of macroeconomic variables.

After temporal aggregation, the panel observations cover the period from 1973Q4 to 2015Q4. In the following, we describe the employed panel regression set up with a focus on how we identify periods of IT and the deviations from the target. Furthermore, we give details on how we compute realized volatilities of the macroeconomic aggregates.[3]

2.2.1. Inflation targeting and target deviations. Our primary interest is to uncover if and how inflation targets and deviations of observed inflation rates from

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the targets relate to IU. We model the adoption of an inflation target in economy j and quarter q by means of a dummy variable IT_{jq}, that is,

$$IT_{jq} = \begin{cases} 1 & \text{if monetary authorities in economy } j \text{ maintain IT in quarter } q \\ 0 & \text{otherwise.} \end{cases}$$

Following Bernanke et al. (1999) and Schaechter et al. (2000), we define the start of IT as the point in time when targets had been first announced by the central banks. A quarter is characterized by IT if the monetary authorities maintain an IT for at least 1 month in that quarter.[4] Moreover, we examine how deviations of observed inflation from the target affect IU. In particular, we distinguish how IU reacts to positive deviations, that is, periods when actual inflation is above the target $\mathcal{T}_{jq}$, and negative deviations when inflation remains below the target level. To this end, we set up the two variables:

$$d_{jq}^{(+)} = \max\big(0, (\pi_{jq} - \mathcal{T}_{jq}) \times IT_{jq}\big) \qquad \textbf{(9)}$$

and

$$d_{jq}^{(-)} = \max\big(0, (\mathcal{T}_{jq} - \pi_{jq}) \times IT_{jq}\big). \qquad \textbf{(10)}$$

For economies in which no IT is adopted throughout the considered sample period, the variables for the target deviations remain zero. Furthermore, for economies that maintain a target range instead of a point target, we use the central value of the range for $\mathcal{T}_{jq}$. The distinction between positive and negative target deviations is supported by results in Gregoriou and Kontonikas (2009) indicating that the speed of adjustment toward the target differs according to the sign of the deviation. Despite of the symmetry of the target, their study on OECD countries reveals that monetary policy reacts more aggressively toward an undershooting. Consequently, also IU might react differently to the deviations. A theoretical model which is based on similar preconditions is described in Ruge-Murcia (2003). This paper proposes a game-theoretical model of monetary policy where central bankers have asymmetric preferences and, hence, allocate distinct weights to positive and negative deviations from the inflation target. The frequencies of positive and negative deviations from the target are listed in Table 1. Overall, positive and negative deviations are balanced across different groupings of economies and over time. For member states of the Economic and Monetary Union (EMU), we observe slightly more negative than positive deviations. The same holds when considering all economies that are members of the OECD. Over time, there is a slight increase in the number of target deviations, since the monetary authorities in Japan, the USA, and Turkey have adopted IT during the time period 2005–2015. After initializing an IT strategy, during 1999–2009, economies mostly recorded inflation rates in excess of the targeted levels. For the period 2010–2015, in contrast, we can observe more negative than positive deviations from the targets.

Moreover, the magnitude and the distribution of the target deviations are of interest for examining their effect on IU. From the histogram in Figure 2, we see

TABLE 1. Frequencies of target deviations

	$d^{(-)} > 0$	$d^{(+)} > 0$	$\sum$
Groups of economies			
EMU	363	312	675
OECD	657	572	1229
Emerging market economies	104	101	205
Time			
1999–2004	151	173	324
2005–2009	187	230	417
2010–2015	323	209	532

Notes: The group of OECD economies contains members of the EMU but excludes Chile and Israel that joined the OECD in 2010. The time period for this table starts in 1999, since by then the majority of economies implemented IT. The rightmost column provides row-wise sums.

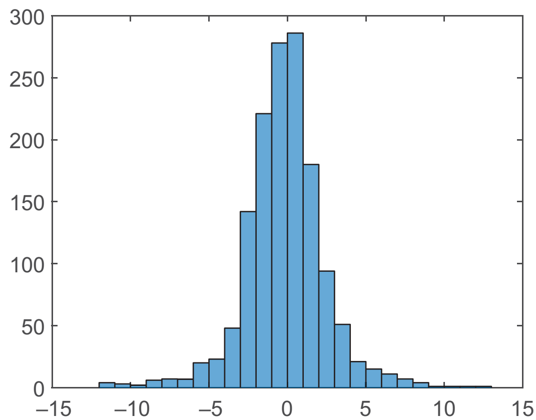

FIGURE 2. Deviations from inflation targets in percentage points calculated as $\pi_{jq} - \mathcal{T}_{jq}$.

that most target deviations are located in an interval between −3 and 3 percentage points (pp). There is a small number of deviations larger than 5 pp, and only a few extreme deviations. Overall, the descriptive information on the target deviations suggests that potential effects on IU are neither due to specific time periods or economies nor extreme deviations.

2.2.2. Macroeconomic determinants. To single out the impact of IT and the target deviations on IU, we consider a set of country-specific macroeconomic determinants of IU. In particular, we include the country-specific realized volatilities of FX rates against the US dollar and the MSCI stock market indices. Moreover, the set of lagged explanatory variables comprises the economies' inflation rates and growth rates of the industrial production indices. We follow Engle et al. (2013) to estimate realized volatilities of the quarterly macroeconomic

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series. Accordingly, we employ the squared residuals $(\hat{\zeta}_q)^2$ from fitting an autoregressive model with four quarterly dummy variables D_{nq} to the growth rate z_q of each macroeconomic series:

$$z_q = \sum_{n=1}^{4} \rho_n D_{nq} + \sum_{i=1}^{4} \phi_i z_{q-i} + \zeta_q. \tag{11}$$

Overall, the set of macroeconomic variables employed to explain IU is

$$\mathbf{x}_{jq-1} = (\pi_{jq-1}, \Delta IP_{jq-1}, RV^{FX}_{jq-1}, RV^{MSCI}_{jq-1})', \tag{12}$$

where $RV^{\bullet}$, with $\bullet \in \{FX, MSCI\}$, denotes the estimated realized volatility $(\hat{\zeta}^{\bullet}_q)^2$ for the corresponding macroeconomic variable. During the last two decades, the importance of global trends in inflation dynamics and the international synchronization of IU has increased as documented, for example, by Berger and Grabert (2018) and Henzel and Wieland (2017). To account for global trends, we incorporate a factor f^{global}_{q-1} that captures common movements of IU over time. We extract f^{global}_{q-1} as the first principal component from the panel of the 26 estimated IU processes.[5]

Further adding country-fixed effects, μ_j, obtains the following regression equation for IU:

$$\sigma^{\bullet}_{jq} = \mu_j + \lambda_1 IT_{jq} + \lambda_2 d^{(-)}_{jq} + \lambda_3 d^{(+)}_{jq} + \mathbf{x}'_{jq-1}\boldsymbol{\beta} + \gamma f^{global}_{q-1} + \varepsilon_{jq}, \ \bullet \in \{\pi, \tau\}. \tag{13}$$

The regression model in (13) might suffer from endogeneity due to a potential interrelation between IU, the introduction of IT, and subsequent target deviations. For instance, central banks of economies with high and variable inflation rates, such as the Bank of Chile, have been among the first to adopt inflation targeting as the primacy of monetary policy. With inflation in excess of 20%, the Bank of Chile had started announcing inflation projections in 1990 to gradually phase in IT which was then formally adopted one decade later (Mishkin (2000)). Hence, high inflation and increased levels of IU potentially influenced monetary authorities in their decision to introduce IT. To address the potential simultaneity bias arising for IT and the target deviations $d^{(-)}$ and $d^{(+)}$, we employ the heteroscedasticity-based identification method proposed by Lewbel (2012) as a robustness check. This technique facilitates the identification of the model parameters when regressors are endogenous and informative external instrumental variables are hardly available. To generate internal instruments for the potentially endogenous regressors $IT_{jq}, d^{(-)}_{jq}, d^{(+)}_{jq}$, we impose the assumption:

$$Cov\left(\mathbf{x}_{jq-1}, \eta^2_{jqi}\right) \neq 0 \quad \text{for } i \in \{IT, d^{(-)}, d^{(+)}\}, \tag{14}$$

where η_{jqi} denotes the disturbances in regressions of the respective endogenous regressor $IT_{jq}, d^{(-)}_{jq}, d^{(+)}_{jq}$ on the exogenous regressors $\mathbf{x}_{jq-1}$ and $\sigma^{\bullet}_{jq}$. Valid instruments for the endogenous variable are generated by means of the product of the error terms η_{jqi} and (a subset of) the centered observable variables, that is, $\left[\mathbf{x}_{jq-1} - E(\mathbf{x}_{jq-1})\right]\eta_{jqi}$. The strength of the instruments, therein, relies on the degree of heteroscedasticity of the error term η_{jqi} with respect to $\mathbf{x}_{jq-1}$. The validity of the instruments can be tested by means of a Hansen-type test for overidentification, a Lagrange-Multiplier (LM)-type test for underidentification, and tests for weak identification. The respective results are provided in Table 4.[6]

3. EMPIRICAL RESULTS

After a short data description, the following section successively provides the results and the interpretation from the first step of the analysis, that is, the model specification search for the UCSV model and the estimated country-specific IU processes. Results from the panel data analysis on the determinants of IU and their discussion follow.

3.1. Data

For the calculation of the IU processes, we employ annualized monthly inflation rates evaluated as $\pi_t = 1200 \times \ln(CPI_t/CPI_{t-1})$ with CPI denoting seasonally adjusted consumer price indices. The observation period is from June 1973 to December 2015 and covers a cross section of 26 industrialized and emerging market economies, namely Austria, Belgium, Canada, Chile, Denmark, Finland, France, Germany, Greece, India, Ireland, Israel, Italy, Japan, South Korea, Malaysia, Mexico, the Netherlands, Norway, Portugal, South Africa, Spain, Sweden, Turkey, the UK, and the USA. In the subsequent analysis, further macroeconomic variables include monthly observations on the seasonally adjusted industrial production index IP_q and the nominal exchange rate against the US dollar FX_q. Information on the economies' stock market performance are included as country-specific MSCI indices. We gathered the information on the implementation dates of IT regimes from the corresponding central banks' homepages and press releases.

3.2. UCSV Model Specification

The model selection procedure provides clear evidence for country-specific UCSV models. Based on the results for posterior inclusion probabilities, we re-estimate all UCSV models in their suggested specification to quantify IU. The posterior inclusion probabilities of the binary indicators δ^{π} and δ^{τ} are summarized in Table 2. We model the innovation variance as being time-varying if the inclusion probability exceeds 0.5. Accordingly, we obtain time-varying estimates of transitory IU, denoted σ_t^{π}, for all economies.

In contrast, permanent IU σ_t^{τ} is indicated to be constant for the majority of economies. As displayed in the lower lines of Table 2, the posterior inclusion probabilities of δ^{τ} are mostly small. Exceptions include Italy, Belgium, and economies that became members of the OECD more recently such as Chile, Mexico, or Israel. Those countries were struggling with high and variable inflation

TABLE 2. Posterior inclusion probabilities for stochastic indicators δ^{π} and δ^{τ}

	Economies						
	Austria	Belgium	Canada	Chile	Denmark	Finland	France
$P(\delta^{\pi}=1)$	1	1	1	1	1	1	1
$P(\delta^{\tau}=1)$	0.0311	0.7268	0.0708	1	0.0832	0.0345	0.3880
	Germany	Greece	India	Ireland	Israel	Italy	Japan
$P(\delta^{\pi}=1)$	1	1	1	1	1	1	1
$P(\delta^{\tau}=1)$	0.0145	0.0268	1	0.2017	1	1	0.0796
	Korea	Malaysia	Mexico	The Netherlands	Norway	Portugal	South Africa
$P(\delta^{\pi}=1)$	1	1	1	1	1	1	1
$P(\delta^{\tau}=1)$	0.6557	0.2714	1	0.1707	0.0301	0.1807	0.6868
	Spain	Sweden	Turkey	UK	USA		
$P(\delta^{\pi}=1)$	1	1	1	1	1		
$P(\delta^{\tau}=1)$	0.0227	0.0257	0.2080	0.4089	0.2075		

Notes: The posterior inclusion probabilities are calculated as $P(\delta^{\bullet}=1)=\frac{1}{M}\sum_{m=1}^{M}\mathbb{1}_{(\delta^{\bullet}=1)}$ for $\bullet \in \{\pi, \tau\}$. The number of Gibbs sampling iterations is $M=8000$.

rates until the mid-1990s. Hence, the variance of shocks to the trend inflation is indicated to be time-varying only for a subset of the considered economies. For the remaining economies, constant variances of shocks express the uncertainty surrounding the trend inflation. The levels of the estimated variances, however, differ substantially across economies.

The shape of the posterior distributions of the non-centered parameters ω_{π} and ω_{τ} displayed in Figure 3 confirm the results from the model specification search. From the symmetric posterior distributions for all economies, we see that the distributions have two modes, and no probability mass at $\omega_{\pi}=0$. Hence, we conclude that the innovation variance ω_{π}^{2} is different from 0. The second row of Figure 3, similarly, illustrates the posterior distributions for ω_{τ}. For the majority of economies, the probability mass concentrates at $\omega_{\tau}=0$, which suggests a model specification with a constant variance for shocks affecting trend inflation. In contrast, for some (former) emerging market economies, such as Chile and India, the model specification search indicates time-varying trend variances. This does not necessarily imply, however, that IT had not been beneficial in anchoring long-term IU. As noted before, the finding from the specification search procedure which suggests that permanent IU is constant in many economies could reflect that implicit targets have possibly been already in place prior to official IT announcements. Against this background, finding a constant permanent IU may suggest that monetary policy schemes that are predictable in general can

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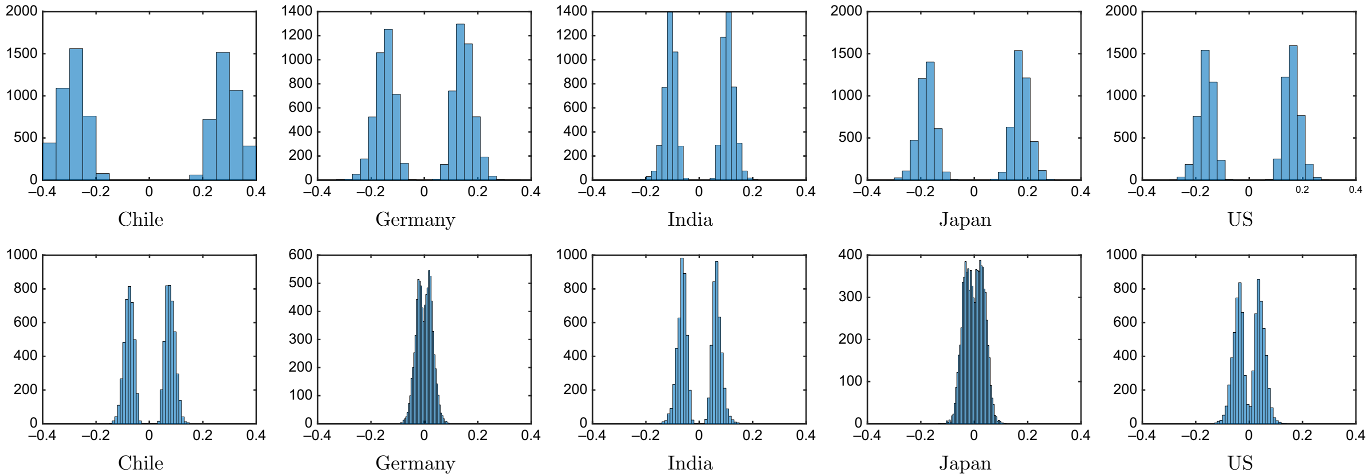

FIGURE 3. Posterior densities of ω_π (first row) and ω_τ (second row) in the non-centered parametrisation for selected economies. The estimates are obtained by fixing the stochastic indicators δ^π and δ^τ to unity throughout the sampling procedure. The bimodality of the posterior density of ω_π supports the time variation of h_t^π for all economies. The shape of the posterior densities of ω_τ suggests that h_t^τ is time-varying for Chile and India. Due to space constraints the figure is limited to five exemplary economies. Figures for all economies are available upon request.

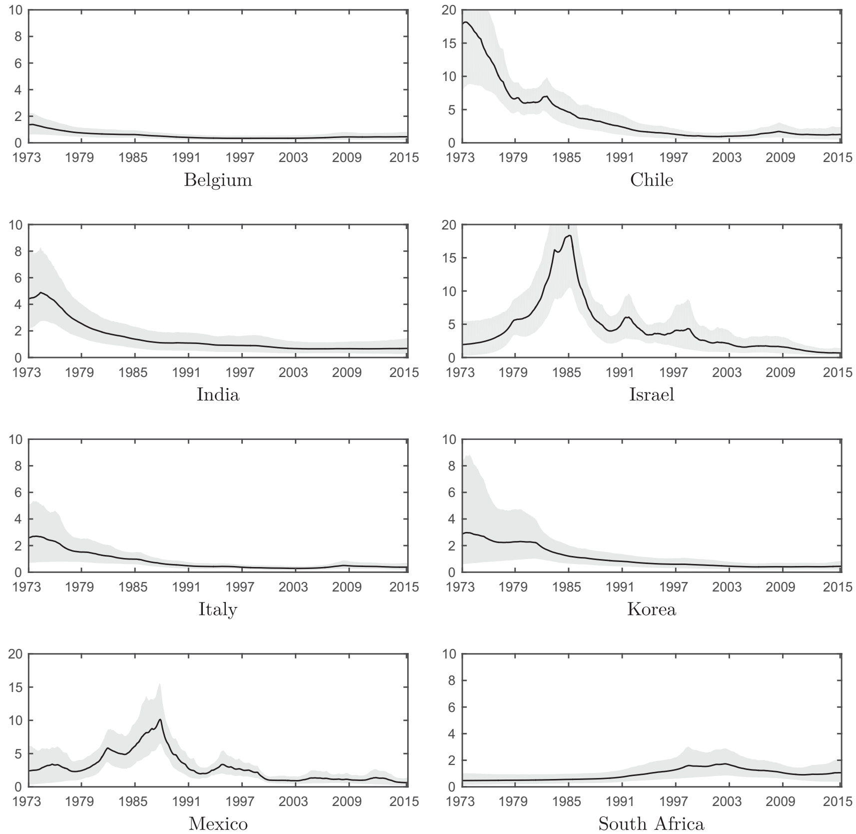

FIGURE 4. The graphs display the IU trajectories for the economies with time-varying permanent IU for the time period 1973M6–2015M12. The solid line represents the posterior mean of σ_t^τ. The shaded area indicates the corresponding 5th and 95th percentiles of the posterior sample.

be beneficial also in the absence of formal targets, although this is not directly testable in our framework. In any case, it seems that the commitment of monetary policy to establish price stability is less uncertain than it used to be before the 1980s, when the stimulation of economic activity might have featured more prominently among central banks' aims.

3.3. Estimated Permanent and Transitory IU Processes

The evidence from the stochastic model selection search supports dynamic permanent IU processes for Belgium, Chile, India, Israel, Italy, Korea, and Mexico. Figure 4 shows the corresponding trajectories. For Chile, Italy, and India, uncertainty about trend inflation drops substantially at the beginning of the sample and continues to be very smooth throughout the remaining sample period. In contrast,

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TABLE 3. Estimated permanent IU σ^τ

	Economies					
	Austria	Canada	Denmark	Finland	France	Germany
σ_0^τ	0.313 [0.24 0.39]	0.375 [0.29 0.48]	0.307 [0.24 0.40]	0.448 [0.35 0.56]	0.372 [0.30 0.46]	0.324 [0.25 0.40]
	Greece	Ireland	Japan	Malaysia	The Netherlands	Norway
σ_0^τ	0.593 [0.44 0.78]	0.449 [0.36 0.56]	0.336 [0.25 0.44]	0.402 [0.28 0.58]	0.369 [0.29 0.46]	0.354 [0.26 0.46]
	Portugal	Spain	Sweden	Turkey	UK	USA
σ_0^τ	0.574 [0.43 0.76]	0.415 [0.32 0.54]	0.386 [0.29 0.49]	2.833 [2.08 3.76]	0.695 [0.53 0.89]	0.494 [0.37 0.63]

Notes: The constant permanent IU σ_0^τ is evaluated as the posterior mean of $M = 8000$ Gibbs sampling iterations. The corresponding 5th and 95th percentiles of the posterior sample are given in brackets.

permanent IU experiences pronounced peaks in Israel in 1985 and in Mexico shortly afterward. With the introduction of an IT policy in Israel at the end of the 1990s, permanent IU evolves more smoothly. Similarly, permanent IU in Mexico is reduced at the beginning of the 2000s. Table 3 reports the estimated levels of permanent IU for the economies with constant permanent IU. The estimates differ across the economies. For EMU members, the estimates of permanent IU range in a similar magnitude, only Greece and Portugal display a slightly larger level of permanent IU. For Turkey, we diagnose a particularly large constant long-run uncertainty.

Figure 5 displays the estimated measures of transitory IU for a subset of the considered economies. Uncertainty measures for the remaining economies can be found in Figures C1–C3 in Appendix C. Overall, the IU trajectories reflect both common and country- or region-specific components. Moreover, for the majority of economies, IU remains on a moderate level with less variability during the period of the Great Moderation. During the onset of the global financial crisis, in contrast, uncertainty increases considerably in all economies. The most remarkable peaks are observable for economies outside the EMU, such as Chile, the UK and the USA. Moreover, Canada and the USA show elevated levels of uncertainty beginning around 1997 which continue to increase with short interruptions. Around 2010, uncertainty starts to decrease in both economies. The picture is slightly different for member economies of the EMU. While they likewise display elevated levels of uncertainty around the breakout of the global financial crisis, the increases are less pronounced in comparison with economies outside the EMU. In particular, IU in Southern European economies such as Italy, Spain, or Portugal and the Northern European economies such as Denmark and Finland decreases substantially during the 1980s and retains a low level and variance

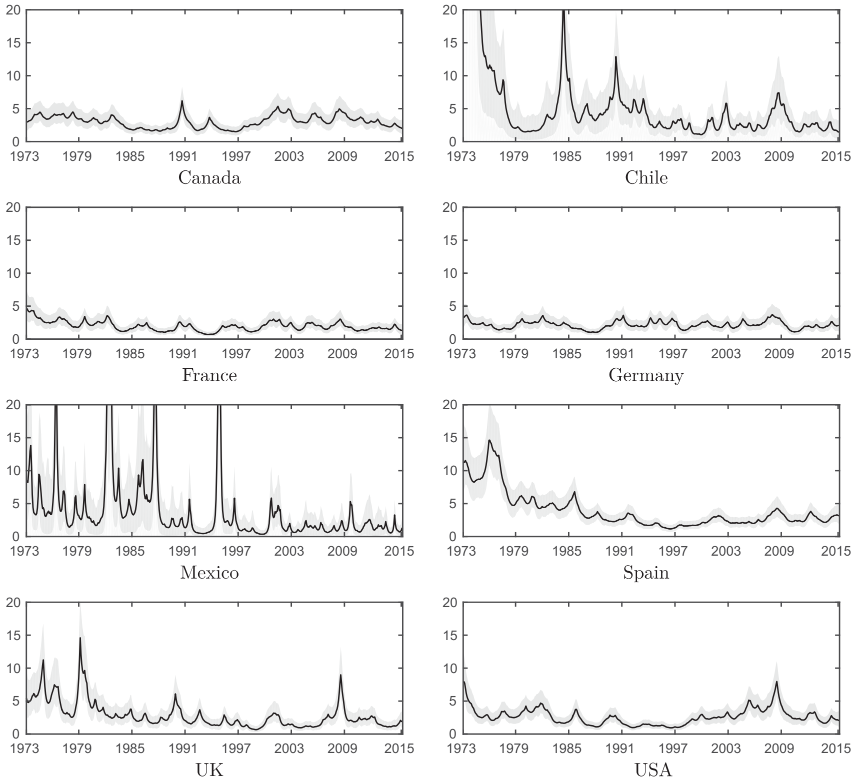

FIGURE 5. The graphs display the transitory IU for the time period 1973M6–2015M12. The solid line represents the posterior mean of σ_t^π. The shaded area indicates the corresponding 5th and 95th percentiles of the posterior sample.

until the outbreak of the global financial crisis. Japan and South Korea experience increases in short-run uncertainty during the outbreak of the Asian crisis in 1997. India and Malaysia, which plummeted into a recession shortly afterward, are likewise characterized by larger and more volatile IU. The considered Latin-American economies display remarkable peaks and high fluctuations of IU around 1985, the peak of the Latin-American debt crisis. Substantial capital outflows caused strong depreciations in most Latin-American currencies followed by a rise of inflation. In summary, the evolution of transitory IU reflects periods of global or region-specific excess macroeconomic volatility. The fluctuations of IU over time and differences across economies further motivate the assessment of potential determinants of IU.

3.4. Macroeconomic and Institutional Determinants of IU

In this section, we give a short overview of empirical studies on IU first. Next, we examine the effects of distinct groups of explanatory variables on IU. We start

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from a baseline specification that includes only macroeconomic and global influences (model "I"). In the next step, this model is augmented with variables that relate to the monetary policy environment (model "II"). Third, estimation results that are obtained by means of FE estimation are compared with outcomes from an estimation method that accounts for the potential endogeneity of a country's decision to announce an IT (model "III"). Fourth, we examine developed and emerging economies separately. To this end, we reestimate model "II" and model "III" for the subset of OECD economies. Finally, we comment on the robustness of core findings.

3.4.1. Analysis of IU in the related literature. The macroeconomic literature highlights several distinct transmission channels to determine aggregate IU. Friedman (1977) provides an intuitive explanation for the relation between inflation and IU. According to Friedman, increases in inflation induce erratic policy responses which have implications for future inflation that are not entirely predictable. Ball (1992) formalized this idea in a model with asymmetric information, in which agents are uncertain about the reaction of monetary policy to increasing inflation. The concept of a (positive) causal linkage between inflation and IU that is described in these two studies has become known as the "Friedman-Ball hypothesis."

Empirical studies of the determinants of IU include Caporale and Kontonikas (2009) or Hartmann and Herwartz (2014). Batchelor and Orr (1991) investigate the effect of IT on IU and find that the level of IU depends on the degree of inflation aversion of monetary authorities. In this study, we take these various potential influences into account and, primarily, examine the role of policy indicators such as the adoption of an IT. The examination of the linkage between IU and IT is closely connected to the debate about the sources of the Great Moderation. Besides the reduction in the level of inflation over the last decades, the Great Moderation also refers to the lower variability of inflation. It is currently still controversial if these stylized facts should be ascribed to a lower size and frequency of inflationary shocks ("good luck"), or to the successful conduct of monetary policy ("good policy"). For example, Bernanke et al. (1999) argue that an IT strategy helps to anchor inflation expectations. Similarly, findings by Cornand and M'baye (2018) show that communicating an IT contributes to reducing the volatility of inflation, interest rates, and output gap. In contrast, Primiceri (2005) or Sims and Zha (2006) associate the decline of inflation and inflation fluctuations to the reduction of both the frequency and the magnitude of shocks. Moreover, Taylor (2000) considers a theoretical model where a lowered market power of firms reduces their capability to pass through increases in input prices to the prices of final goods. This mechanism explains why a secular reduction in inflation can occur even in situations where both frequency and magnitude of cost shocks are unchanged.

In the following, we examine the sources of declining IU by separating global influences from economy-specific determinants. While the effects of monetary policy on IU are in most economies country-specific, the dampening of inflationary shocks can, at least partly, be associated with global factors. The latter might comprise, for instance, reductions in energy prices or unit labor costs. In this sense, it is a relevant observation that the decline of IU is found across a range of economies. Graphical displays of IU in Figure 5 and Figures C1–C3 show that, for the majority of economies, IU has been higher at the beginning of the sample period than at the end. Hence, it is unlikely that this global trend in IU is the result of idiosyncratic determinants such as monetary policy alone. This can be seen by relating the IU trajectories to the dates when IT has been first announced. As it is shown in Table B1, the first announcements of target levels have been made in the early 2000s in many economies. For most economies, a reduction of IU is already visible prior to 2000. To quantify how global influences may transmit to IU in individual economies, we consider the common inflation (uncertainty) dynamics that are captured by the global component (f_{q-1}^{global}), and a number of other covariates such as the fluctuations in FX rates or equity prices. A detailed description of all considered variables is contained in Section 2.2.2. The estimation results are documented in Table 4.[7]

3.4.2. IU and its relation to macroeconomic conditions. In the baseline model (column I of Table 4), the level of inflation exerts a positive effect on transitory IU, which is in line with the theoretical arguments of Friedman (1977) and Ball (1992). Similarly, as it is hypothesized in the so-called "Friedman hypothesis," the influence of the growth rate of the industrial production index on IU is negative, that is, IU tends to be higher during recessions. This effect, however, lacks significance. A negative relationship between real activity and more general indicators of uncertainty has been also documented by Bloom (2009), Henzel and Rengel (2017), or Jurado et al. (2015). Regarding the volatility indicators, we find positive spillover effects from the variation of stock and FX market returns. Complementing similar findings for the level of inflation in Ciccarelli and Mojon (2010), the global factor f_{q-1}^{global} contributes to IU.

3.4.3. IU and the role of monetary policy. The results documented in column II of Table 4 correspond to a regression specification that includes an IT dummy variable and two variables which express how inflation and the presence of an IT jointly affect IU. In particular, this specification allows to examine the importance of the "good policy" hypothesis, that is, how important monetary policy has been for governing IU besides the influence of global factors. It turns out that IU is only slightly and insignificantly smaller during periods when an officially announced IT is in place. In contrast, the results indicate that the global factor f_{q-1}^{global} governs IU. This first impression suggests that recent reductions of IU may have been accomplished mainly through an externally driven reduction of shocks. This finding is not surprising given that the correlation between IT_{jq} and f_{q-1}^{global} is relatively large, as it is shown in Table 5. However, it is interesting to examine the potential role of monetary policy in the process of anchoring inflation expectations in more detail.

TABLE 4. Estimation results

	Full sample			OECD economies	
	FE		Generated IV	FE	Generated IV
	(I)	(II)	(III)	(IV)	(V)
	σ^{π}_{jq}	σ^{π}_{jq}	σ^{π}_{jq}	σ^{π}_{jq}	σ^{π}_{jq}
π_{jq-1}	0.115	0.126	0.197	0.128	0.136
	(0.0173)	(0.0168)	(0.0119)	(0.0182)	(0.00513)
ΔIP_{jq-1}	−0.00581	−0.00381	−0.00203	−0.00347	0.00173
	(0.00425)	(0.00404)	(0.00205)	(0.00477)	(0.00205)
RV^{MSCI}_{jq-1}	2.00e-05	1.49e-05	4.50e-06	1.46e-05	4.46e-06
	(1.05e-05)	(8.31e-06)	(2.56e-06)	(8.64e-06)	(2.51e-06)
RV^{FX}_{jq-1}	0.000225	0.000205	0.000193	0.000206	0.000185
	(8.10e-05)	(8.53e-05)	(1.12e-05)	(9.26e-05)	(1.02e-05)
f^{global}_{q-1}	0.158	0.156	0.141	0.151	0.177
	(0.0408)	(0.0389)	(0.0315)	(0.0395)	(0.0227)
$d^{(-)}_{jq}$		0.201	0.289	0.272	0.422
		(0.0707)	(0.0384)	(0.0665)	(0.0365)
$d^{(+)}_{jq}$		0.0945	0.200	0.121	0.0169
		(0.0601)	(0.0548)	(0.0778)	(0.0167)
IT_{jq}		−0.0303	0.168	−0.0796	−0.108
		(0.163)	(0.184)	(0.164)	(0.153)
Constant	2.462	2.322	−0.324	2.175	−0.238
	(0.0577)	(0.100)	(0.0949)	(0.0998)	(0.0872)
Country FE	Yes	Yes	Yes	Yes	Yes
Observations	3418	3418	3418	2957	2957
R^2	0.319	0.329	0.444	0.353	0.355
Overidentification			0.397		0.198
Underidentification			0.018		0.08
Weak identification			70.82		51.40

Notes: Standard errors given in parentheses are robust and clustered at the country level. Models III and V are estimated by efficient two-step GMM based on the instrumental variables (IV) (Lewbel (2012)). The overidentification test is based on the Hansen J test with the null hypothesis of validity of the overidentifying restrictions. Underidentification of the model is the null hypothesis of the LM test by means of the Kleibergen-Paap statistic. P-values are reported for both diagnostics. Testing for the null hypothesis of weak identification with robust, clustered covariance estimates is based on the Kleibergen-Paap rk F-statistic. The Corresponding critical value for the reported test statistic is the Stock–Yogo IV critical value 18.73 for a 5% maximal IV bias.

The establishment of a low level of IU is considered in most economies as one of the primary aims of monetary policy. Until recently, central banks primarily aimed to reduce uncertainty about the eventual emergence of high-inflation periods. Since the unfolding of the financial and sovereign debt crisis, IU may also indicate uncertainty about deflation scenarios or the eventual end of a prolonged

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TABLE 5. Pairwise correlation matrix of covariates

Variables	σ_q^{π}	IT_q	$d_q^{(-)}$	$d_q^{(+)}$	π_{q-1}	ΔIP_{q-1}	RV_{q-1}^{MSCI}	RV_{q-1}^{FX}	f_{q-1}^{global}
IT_q	−0.166	1.000							
$d_q^{(-)}$	−0.067	0.435	1.000						
$d_q^{(+)}$	−0.050	0.404	−0.086	1.000					
π_{q-1}	0.698	−0.256	−0.161	−0.035	1.000				
ΔIP_{q-1}	0.011	−0.083	−0.087	−0.042	0.004	1.000			
RV_{q-1}^{MSCI}	0.230	−0.021	0.041	0.006	0.270	−0.044	1.000		
RV_{q-1}^{FX}	0.363	−0.056	−0.015	−0.000	0.559	−0.110	0.164	1.000	
f_{q-1}^{global}	0.373	−0.399	−0.148	−0.139	0.309	−0.054	0.001	0.087	1.000

period of very low inflation. Ball (1992) discusses theoretically how the emergence of IU can depend on both the level of inflation and the preferences of the central bank. Giordani and Söderlind (2003) associate IU with (a lack of) credibility of a monetary policy. In the following, we consider the deviation of inflation from the target as an explanatory variable of IU. In general, differences between inflation and the target can arise due to target adjustments or inflation dynamics. It can be seen from Table 1 that positive and negative deviations have been recorded for a comparable number of time periods (i.e. quarters). However, deviations on either side of the target may not contribute equally to the emergence of IU. Inflation rates have been reduced in most industrial and emerging economies during the last decades. This trend might have fostered the public's confidence in the determination and ability of monetary authorities to reduce emerging inflation pressures, that is, to cope with inflation rates above the target level. In contrast, inflation rates that fall below the target seem to be a problem which is challenging at present. Hence, it might be less clear if inflation can be easily realigned with an existing target if it deviates from below.

By separately examining positive and negative target deviations, $d_{jq}^{(-)}$ and $d_{jq}^{(+)}$, we find that during periods when inflation is below the targeted level, IU is significantly higher than otherwise. In contrast, positive deviations have no significant effect on IU. This might reflect the larger credibility that has been gathered by many central banks during the last years of the Great Moderation. The finding that IU does not increase when inflation is above the target might be interpreted as a sign of good policy in the sense that central banks have been successful to insulate their economies against IU shocks during these periods.

3.4.4. Endogeneity of IT and deviations from target. The implications of the results regarding the relation between IU, inflation, and IT for monetary policy are still subject to the caveat that the announcement of an IT might be a result of the inflationary environment. Moreover, endogeneity in the sense that deviations of inflation from the target depend on IU could imply that agents are uncertain about the success of an IT or the time that it may take until inflation converges toward the target. In the following, we examine the role of potential endogeneity

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of the explanatory variables by means of an endogeneity-robust GMM estimation method. Comparing coefficient estimates obtained under the endogeneity-robust approach with the FE estimates should reveal if simultaneity is likely to disturb the empirical assessment of the effects from macroeconomic influences and monetary policy. We find to that several of the FE estimates from models “I” and “II” are relatively close the ones from the simultaneity robust GMM estimates of model “III.” In particular, the findings regarding the fluctuations in equity or FX markets discussed above remain essentially unchanged. The estimated effect of $d_{jq}^{(-)}$ documented in column III of Table 4, however, shows that the relation between negative target deviations and IU changes after we control for endogeneity. While the sign and significance of the corresponding coefficient estimate remain unchanged, the size of the effect is considerably larger in model “III.’ Hence, IU may influence to which extent actual inflation deviates from the target.

The presence of such a relation has important implications for monetary policy. Low IU helps to anchor inflation just as the alignment of inflation with the announced target reduces IU. Hence, the most promising way to establish an IT is to announce the target when inflation expectations are already well anchored. This is most likely the case if inflation is close to an already existing, well-established target. The finding regarding positive deviations from the IT is in line with this reasoning if the endogeneity-robust GMM approach is employed. The respective coefficient estimate suggests that IU is increasing when inflation has been exceeding the target level, though increases in IU are not very pronounced. The smaller coefficient estimates that are obtained might be interpreted as the result of a successful implementation of monetary policy during the Great Moderation. Our findings nevertheless indicate that the potential of “good monetary policy” is currently more limited than it might have been in the wake of the Great Moderation. This is in line with official statements from central banks during the last years which have emphasized the restrictions that monetary policy faces if the aim is to counteract excessively low inflation.

However, it has been noted that inflation rates are typically lower in developed than in emerging economies (Fraga et al. (2003)). The influence of the considered covariates on IU might emerge in distinct ways, depending on various conditions like, for example, the institutional framework of an economy, the long-term average of inflation, or the success of monetary policy strategies during earlier periods. Such conditions might differ particularly strongly between developed and emerging economies. Thus, we next examine if the findings documented so far are dependent on the particular characteristics of developed and emerging economies in the considered sample.

3.4.5. Distrust in inflation targets in a global context. It has been documented that adopting an IT might have different implications for developed than for emerging economies (Gonçalves and Salles (2008), Lin and Ye (2009)). In contrast to developed economies, the primary threat which monetary policymakers in emerging economies face might still be inflation rates that exceed the targeted

TABLE 6. Average durations of deviations from IT

	OECD		EME	
	$d^{(-)} > 0$	$d^{(+)} > 0$	$d^{(-)} > 0$	$d^{(+)} > 0$
Full sample	3.17	2.79	3.27	3.34
After 2005	3.33	3.01	2.54	3.38
After 2005, >1 pp.	2.31	2.08	1.80	2.84

Notes: The table reports the average length of periods with continuously negative ('$d^{(-)} > 0$'), respectively, positive ('$d^{(+)} > 0$') deviations of inflation from target. In the third row, we consider the time period after 2005 and disregard target deviations that are smaller than one percentage point. "EME" indicates "emerging market economies."

level. As a means to highlight the differences between developed and emerging economies, we next investigate the average number of quarters it takes until positive and negative deviations of inflation from the IT are realigned with the target. Table 6 reports such average durations (i) separately for OECD and emerging market economies and (ii) with a focus on more recent observations (> 2005). As it turns out, developed economies experienced longer periods of inflation falling short of the target than respective episodes during which inflation was above the target. The opposite holds in emerging market economies, where it takes longer to realign positive deviations with the IT.

The contrast is even more pronounced if only observations after 2005 are considered and it is further strengthened if the subsample only includes cases when inflation has been exceeding the target by more than one percentage point after the year 2005. In the latter case, positive target deviations last about one-quarter longer in emerging market economies than negative deviations on average. As a consequence, the way IU evolves within the two groups of economies could also be rather distinct. In contrast to the low-inflation environment that prevails in most developed economies, the high-inflation rates in emerging economies might influence IU more in accordance with the mechanism that is described by the model in Ball (1992), where IU emerges due to uncertainty about the timing and size of an eventual disinflation. To investigate potentially distinct effects in developed economies on the one hand and emerging economies on the other hand, we carry out the estimation "II" and "III" separately for the cross section of OECD economies. Respective results are documented in columns IV and V of Table 4. Several estimates are largely equivalent in both the full and the restricted sample. The influences of the inflation level and the growth rate of industrial production, for example, as documented for model "IV" are in line with those obtained for the full cross section. The same holds for the influence of stock market and FX rate fluctuations. Turning to policy-related variables, it is remarkable that all estimates of the effect of $d_{jq}^{(-)}$ remain affected by endogeneity. It turns out that negative deviations of inflation from the target seem to increase IU also for the subsample of developed economies. The size of the effect of $d_{jq}^{(-)}$ is even larger than the one that is found for the entire sample. This suggests that the relation between IU and $d_{jq}^{(-)}$ may be less pronounced for the emerging economies in the

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sample. Moreover, the coefficient estimate of $d_{jq}^{(+)}$ lacks significance in the OECD sample, in contrast to the full sample estimate. This suggests that the increase in IU that is associated with $d_{jq}^{(+)}$ stems primarily from emerging economies, where large positive inflation rates might still be a problem.[8]

3.5. Robustness Analysis

Unlike the sole presence of an IT, target deviations are seemingly of prime importance in explaining short-term IU. To address in particular if this core outcome of the cross-sectional analysis is robust, we consider a set of modified regressions.

In the first place, we exclude sample observations dating after 2007 to infer if regression outcomes change when focussing on the period prior to the Great Recession and the associated quantitative easing policies adopted by many central banks. Results documented in Table 7 show that the conclusions from the main analysis remain unaffected. For the implementation of inflation targeting regimes, we observe an even more pronounced negative effect for the shortened time period. Concerning the target deviations, we see a slight change in the relative magnitude between positive and negative target deviations compared with the full sample regression. Conditional on the full cross section of economies, positive target deviations have a higher impact on IU than negative deviations.

In the second place, we check if the consideration of a phase-in period after the first communication of an inflation target comes with modified effects of target deviations on IU. Defining target deviations to start 3 years after the adoption of the IT regime, both direction and magnitude of the estimated coefficients remain unchanged (see Table 8).

In the third place, noticing that the adoption of IT and (subsequent) target adjustments might trigger similar directional effects on IU, we include an additional dummy variable capturing the effect of target changes. Regression results displayed in columns 2 and 3 of Table 8 show that the estimated impact of a target change on IU is positive, and its magnitude being similar to the one of the target deviations. The effect is, however, not significant. In our sample, it is mainly the emerging economies that experienced target changes in the context of their disinflation policies. If we estimate the effect of target changes exclusively for OECD economies, the impact is positive but the magnitude is smaller.

One might argue intuitively that the relation between IT and IU differs if fixed-number targets or target corridors are employed as a nominal anchor, since the latter provide more room for the definition of a critical target deviation. Therefore, finally, we included an additional dummy variable that accounts for sample economies where the central banks target inflation by means of a target corridor. As shown in the last two columns of Table 8, the estimated coefficients for the positive and negative target deviations remain unchanged, that is missing the target increases inflation uncertainty. As an interesting additional result, we can conclude that inflation uncertainty is lower for economies that maintain an inflation band instead of a fixed-number target. Fixed-number targets are more difficult to maintain than keeping inflation rates inside a defined inflation band.

TABLE 7. Results after excluding Great Recession

	Full sample		OECD economies
	FE	Generated IV	FE
	σ^{π}_{jq}	σ^{π}_{jq}	σ^{π}_{jq}
π_{jq-1}	0.121	0.175	0.122
	(0.0210)	(0.0140)	(0.0231)
ΔIP_{jq-1}	−0.00480	0.00285	−0.00415
	(0.00575)	(0.00258)	(0.00667)
RV^{MSCI}_{jq-1}	7.93e-06	−1.07e-05	9.09e-06
	(5.86e-06)	(5.99e-06)	(6.57e-06)
RV^{FX}_{jq-1}	0.000220	0.000216	0.000220
	(9.88e-05)	(1.13e-05)	(0.000105)
f^{global}_{q-1}	0.150	0.153	0.149
	(0.0436)	(0.0353)	(0.0443)
$d^{(-)}_{jq}$	0.0979	0.0521	0.198
	(0.0819)	(0.0222)	(0.0489)
$d^{(+)}_{jq}$	0.0993	0.287	0.137
	(0.0855)	(0.0437)	(0.109)
IT_{jq}	−0.0711	−0.213	−0.160
	(0.204)	(0.106)	(0.208)
Constant	2.338	−0.208	2.212
	(0.119)	(0.0769)	(0.126)
Country FE	Yes	Yes	Yes
Observations	2587	2587	2285
R^2	0.305	0.397	0.320
Overidentification		0.665	
Underidentification		0.022	
Weak identification		98.95	

For notes see Table 4.

Inflation expectations of economic agents might react faster and stronger to deviations from a point target than to fluctuating inflation rates that remain within the targeted range. Further pursued directions of robustness analysis include (i) the use of time FE to replace f^{global}_{q-1}, and the effect analysis of (ii) asymmetric target corridors or (iii) durations of target deviations. Moreover, we have additionally controlled (i) for the influence of fluctuations in oil prices and commodity prices, and (ii) potential business cycle effects. In general, the results documented in this study remain robust in quantitative terms under all these modifications of regression designs. For space considerations, we refrain from documenting detailed results that are available upon request.

TABLE 8. Robust analysis

	3 years lag		Target change		IT range	
	Full sample σ^{π}_{jq}	OECD σ^{π}_{jq}	Full sample σ^{π}_{jq}	OECD σ^{π}_{jq}	Full sample σ^{π}_{jq}	OECD σ^{π}_{jq}
π_{jq-1}	0.127	0.126	0.127	0.129	0.118	0.118
	(0.0163)	(0.0177)	(0.0168)	(0.0181)	(0.0159)	(0.0177)
ΔIP_{jq-1}	−0.00306	−0.00316	−0.00374	−0.00335	−0.00332	−0.00282
	(0.0042)	(0.0049)	(0.00401)	(0.00473)	(0.00394)	(0.00460)
RV^{MSCI}_{jq-1}	1.44e-05	1.6e-05	1.47e-05	1.46e-05	1.34e-05	1.27e-05
	(8.46e-06)	(9.73e-06)	(8.30e-06)	(8.70e-06)	(8.72e-06)	(9.13e-06)
RV^{FX}_{jq-1}	0.000207	0.000214	0.000205	0.000206	0.000212	0.000214
	(8.49e-05)	(9.11e-05)	(8.58e-05)	(9.29e-05)	(8.30e-05)	(8.94e-05)
f^{global}_{q-1}	0.140	0.137	0.159	0.155	0.158	0.151
	(0.0312)	(0.0315)	(0.0386)	(0.0392)	(0.0374)	(0.0378)
$d^{(-)}_{jq}$	0.257	0.257	0.194	0.264	0.203	0.277
	(0.0716)	(0.0913)	(0.0709)	(0.0685)	(0.0719)	(0.0626)
$d^{(+)}_{jq}$	0.067	0.070	0.0847	0.109	0.108	0.137
	(0.0364)	(0.0384)	(0.0557)	(0.0706)	(0.0519)	(0.0625)
IT_{jq+12}	0.036	0.044				
	(0.170)	(0.173)				
IT_{jq}			0.0195	−0.0212	0.186	0.135
			(0.165)	(0.167)	(0.137)	(0.141)
IT^{change}_{jq}			0.225	0.0846		
			(0.319)	(0.265)		
IT^{range}_{jq}					−0.960	−1.123
					(0.617)	(0.722)
Constant	2.269	2.133	2.298	2.149	2.380	2.233
	(0.103)	(0.104)	(0.105)	(0.104)	(0.135)	(0.144)
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3418	2957	3418	2957	3418	2957
R^2	0.334	0.353	0.330	0.353	0.339	0.365

Notes: Columns 1 and 2 indicate the results when accounting for a lag of 3 years between the actual implementation of an IT and the start of modeling its impact on IU. The results in column 3 and 4 were obtained when additionally controlling for the impact of a target change on IU. The last two columns contain the estimation results for including the variable IT^{range}_{jq} which separates the economies having an inflation target range from those that have a point target for inflation. All regression equations are estimated by means of FE to account for country-specific effects. Robust clustered standard errors are in parentheses.

4. CONCLUSION

This study contributes to the debate on the adjustment of inflation targets. We find that the feasibility, potential merits, and drawbacks of inflation targeting might depend on whether inflation is below or above the target. In particular, we investigate both how the presence of an inflation target and the deviations from the target relate to the uncertainty about future inflation. A central finding is that

https://doi.org/10.1017/S1365100520000565 Published online by Cambridge University Press

periods when inflation is below the target are associated with increasing inflation uncertainty. We employ the UCSV model of Stock and Watson (2007) to estimate measures of inflation uncertainty (IU) for a set of 26 developed and emerging economies. Thereby, we distinguish short and permanent IU. To assess the stability of short- and long-term inflation expectations, we examined how strongly IU varies over time by means of a stochastic model specification search. For most developed economies, the results of the specification search indicate that IU is constant in the long term. This might be interpreted as an indication of anchored long-term inflation expectations. In contrast, we find that transitory IU is varying over time for all economies.

Based upon our estimated IU measures for the different economies, we examine the linkages between inflation uncertainty and its macroeconomic and policy-related determinants in a panel data framework. While the mere presence of an inflation target lacks a significant effect on short-term inflation uncertainty, we find that deviations from the target substantially impact on the stability of inflation expectations. In particular, we document a significant increase in IU when inflation deviates from the target from below. A sample split analysis suggests that this is particularly important for the developed economies experiencing prolonged periods of low inflation. Hence, we conclude that currently discussed policy measures to increase inflation in several developed economies are challenged by an environment of increased uncertainty. The evidence we find suggests that the adoption or presence of an inflation target faces the risk to destabilize inflation expectations if inflation continuously falls short of the target.

NOTES

1. In contrast, survey-based uncertainty forecasts based on predicted densities are only available for the USA and the Eurozone.

2. The IT has to be determined in a learning process, since it may not be officially announced or inaccurately communicated.

3. Note that the UCSV framework as it has been proposed by Stock and Watson (2007) can be regarded as a reduced form specification. This means that the shock processes in this model encompass a wide range of structural relations. This allows us to derive IU series by means of a widely used specification in the first step and analyze the resulting IU series by means of an empirical model that allows for panel relations in the second step.

4. Table B1 in Appendix B gives an overview of the introduction dates and the level of the targets for all economies in the sample. Furthermore, we also account for the gradual changes in the targets employed by some central banks. For an alternative variable definition with respect to the timing of IT, see also the robustness analysis in Section 3.5.

5. The first principal component captures around 47% of the variation in the IU processes.

6. We use the Stata module ivreg2h that implements Lewbel's method (Baum and Schaffer (2012)).

7. The IU measure in Table 4 is quantified as the mean of the posterior distribution of σ_t^π. The availability of the posterior distribution allows to account for the uncertainty attached to any point estimate. As a robustness check, we employ the 5th and the 95th percentiles of the posterior distribution, respectively, as IU measures in equation (17). Additionally, we estimate (13) separately for samples of IU statistics that are below or above the country-specific median of the IU statistics. The sign and

the magnitude of the estimated coefficients essentially remain the same. Respective regression results are available from the authors upon request.

8. A direct test of this hypothesis is not possible due to the limited number of emerging economies in the sample, which precludes the implementation of the endogeneity-robust GMM estimation method.

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APPENDIX A: GIBBS SAMPLING ALGORITHM

The UCSV model requires the estimation of four model parameters, two stochastic binary indicators, and the three latent time series processes τ_t, h_t^π, and h_t^τ. The T latent states τ_t, h_t^π, and h_t^τ give rise to a high-dimensional parameter space such that an analytical form of the likelihood function is not available. In a linear Gaussian state-space model, latent states are estimated by means of the Kalman filter, which could be used to construct a likelihood function. However, the nonlinearities introduced by the stochastic volatilities and the stochastic model selection procedure lead to a highly nonlinear estimation problem. Hence to address these impediments, we use the auxiliary mixture sampling approach by Kim et al. (1998) and the Gibbs sampler to obtain a sample from the joint posterior density of the model parameters and the states conditional on the observed data for the inflation rate π_t. A sample from the joint distribution is simulated by iteratively drawing from the tractable full conditional densities of the parameters. The sampling is performed blockwise, such that the draws for the parameters and the states in the current iteration are conditioned on the most recent draws of the remaining parameters. The scheme of the Gibbs sampling procedure is as follows:

1. Sample the trend inflation $\{\tau_t\}_{t=1}^T$ from the state-space form (1) by means of the forward-filtering backward-smoothing procedure (Carter and Kohn (1994)).
2. Sample the binary indicators δ, the initial values h_0, and the variance parameters ω. The unrestricted variance parameters are sampled from the posterior normal distribution, while the restricted variances are set equal to 0.
3. Sample the time-varying components $\{\tilde{h}_t\}_{t=1}^T$ from the state-space form for the non-centered parametrisation for $\delta = 1$. Otherwise, for $\delta = 0$ draw $\tilde{h}_0$ from its prior distribution.
4. Perform a random sign switch for ω and $\{\tilde{h}_t\}_{t=1}^T$ leaving the parameters unchanged or replacing them by $-\omega$ and $-\{\tilde{h}_t\}_{t=1}^T$ with probability 0.5.

We execute these steps for 60.000 iterations and discard the first 20.000 draws as a burn-in sample. To reduce autocorrelation within the Markov chain, we thin the remaining 40.000 draws for each parameter. For posterior inference, we consider only every 5th draw such that we obtain a posterior sample of $M = 8000$ values for each model parameter and the latent states.

APPENDIX B: OVERVIEW OF INFLATION TARGETS

TABLE B1. Adoption dates and levels of inflation targets (IT)

	Date of adoption or target revision	Target
IT: Euro Zone		
Austria	January 2002	below 2%
Belgium	January 2002	below 2%
Finland	January 1994–December 1998	2%
	January 2002	2%
France	January 2002	below 2%
Germany	January 2002	below 2%
Greece	January 2002	below 2%
Ireland	January 2002	below 2%
Italy	January 2002	below 2%
The Netherlands	January 2002	below 2%
Portugal	January 2002	below 2 %
Spain	April 1995	3.5%–4.5 %
	January 1997	0%–3%
	January 2002	below 2 %
IT: European economies		
Norway	March 2001	2.5%
Sweden	Since January 1993	2% ± 1
United Kingdom	Since October 1992	2%
IT: Non-european countries		
Canada	February 1991	3%–5%
	Since 1993	1%–3%
Chile	September 1999	13%
	September 2000	10%
	September 2001	6.5%
	September 2002	4.5%
	September 2003	3%
Israel	June 1997	7%–10%
	August 1998	4%
	September 1999	3%–4%
	October 2000	2.5%–3.5%
	February 2002	2%–3%
	Since August 2002	1%–3%
Japan	January 2013	2%
Mexico	January 1999	13%

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TABLE B1. Continued

	Date of adoption or target revision	Target
	September 1999	10%
	January 2001	6.5%
	January 2002	4.5%
	January 2003	3%
South Africa	February 2000	3%–6%
South Korea	January 1998	9% ± 1%
	1999	3% ± 1%
	2000	2.5% ± 1%
	2001	3% ± 1%
	2002	2.5%
	Since 2003	2.5%–3.5%
Turkey	December 2005	5% ± 2%
	December 2006	4%
	December 2008	7.5%
	December 2009	6.5%
	December 2010	5.5%
	Since December 2011	5%
USA	January 2012	2%
Non-IT countries		
Denmark		
India		
Malaysia		

Notes: The dates in column 2 refer to the first announcement of central banks to adopt IT or revise the existing targets, respectively. Dates and target levels are mainly obtained from the periodic central banks' press releases on the stance of future monetary policy published on the banks' webpages. Dates and targets in this table are largely consistent with those used by Roger and Stone (2005) and Hammond (2012). Moreover, we also take into account the time-varying targets, employed especially by central banks in emerging market economies.

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APPENDIX C: TRANSITORY IU FOR ALL ECONOMIES

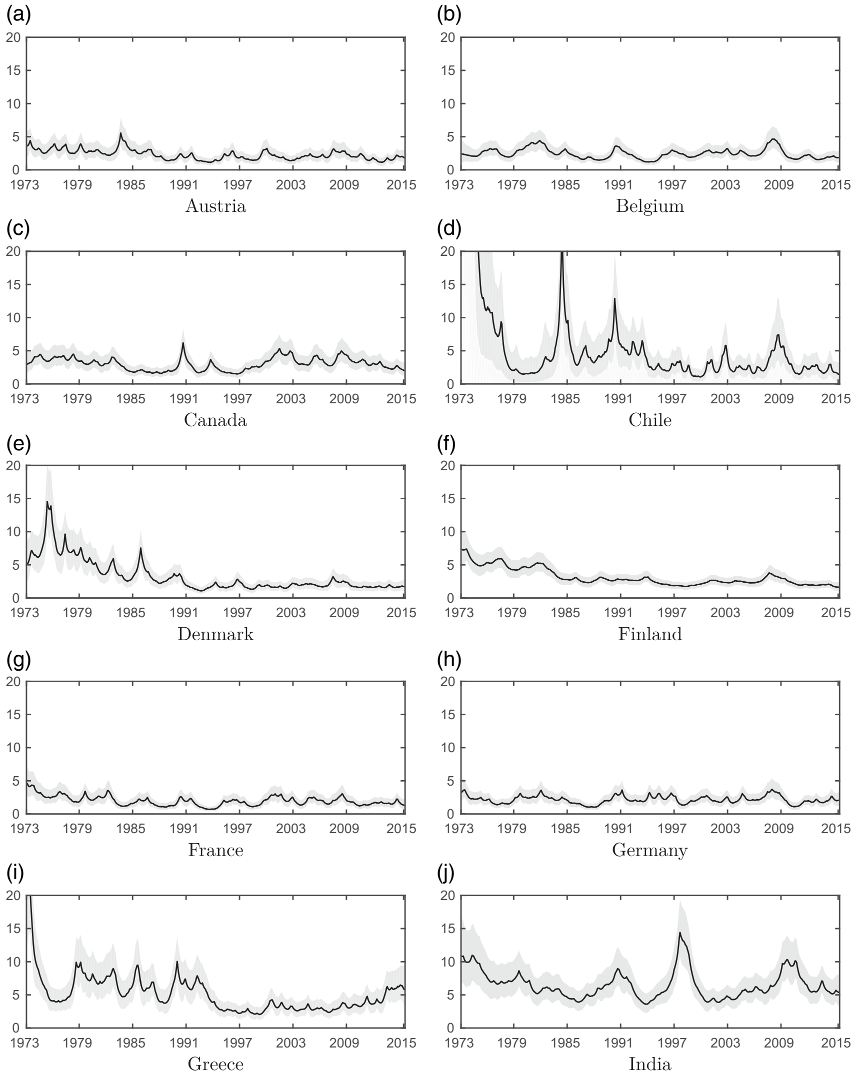

FIGURE C1. The graphs display the estimated measure of transitory IU for the time period 1973M6–2015M12. The solid line represents the posterior mean of σ_t^{π}. The shaded area indicates the corresponding 5th and 95th percentiles of the posterior sample.

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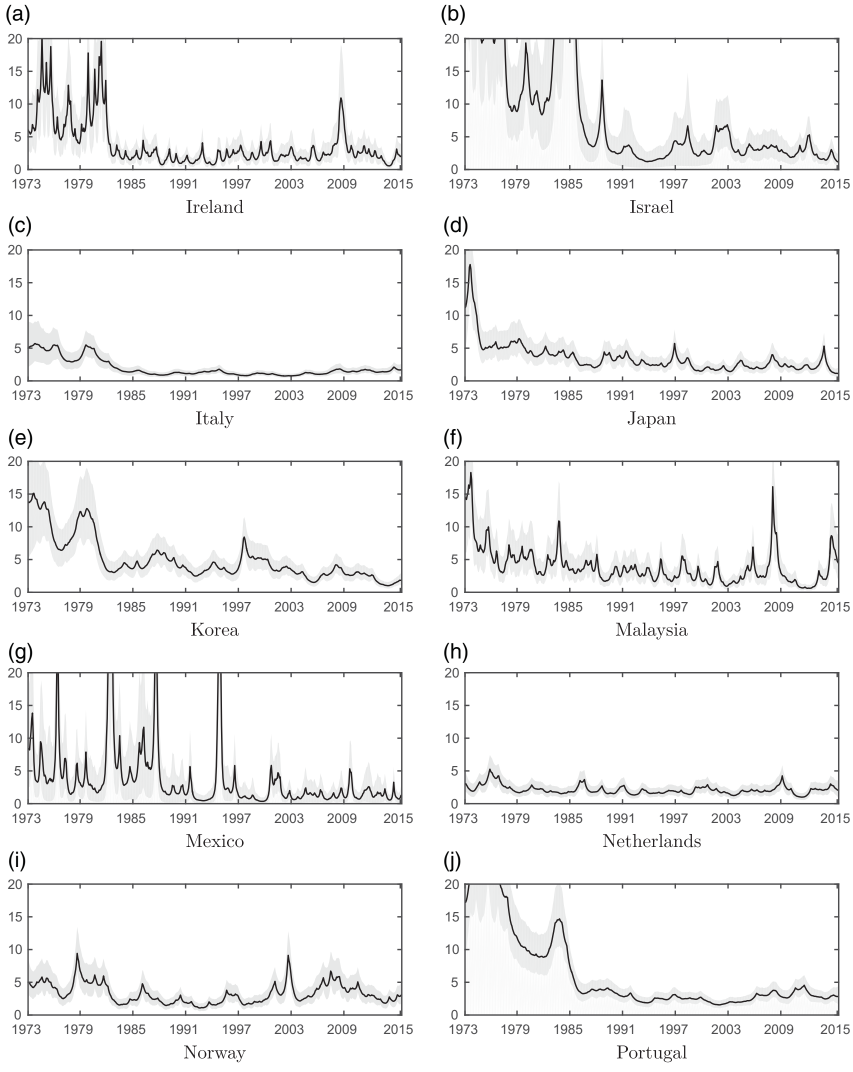

FIGURE C2. The graphs display the estimated measure of transitory IU for the time period 1973M6–2015M12. The solid line represents the posterior mean of σ_t^{π}. The shaded area indicates the corresponding 5th and 95th percentiles of the posterior sample.

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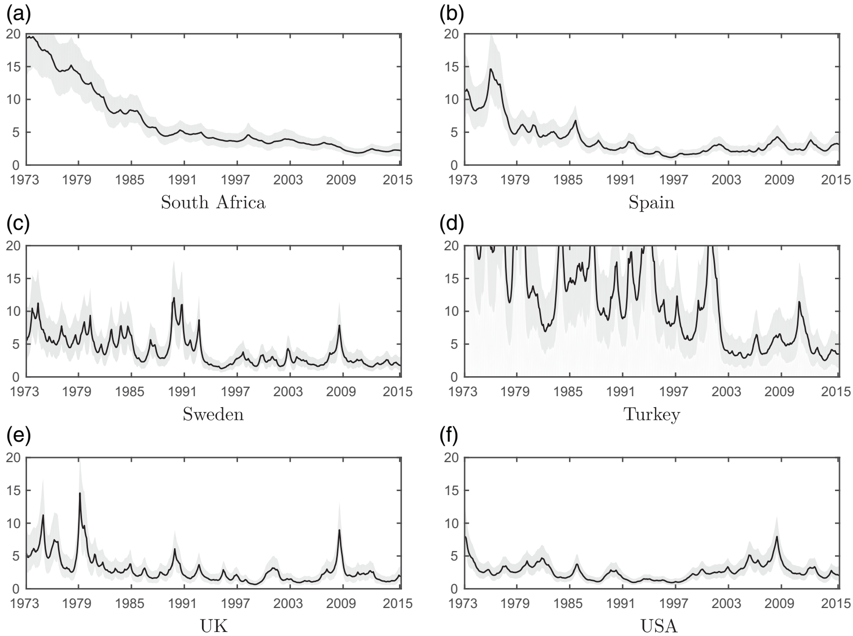

FIGURE C3. The graphs display the estimated measure of transitory IU for the time period 1973M6–2015M12. The solid line represents the posterior mean of σ_t^{π}. The shaded area indicates the corresponding 5th and 95th percentiles of the posterior sample.

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