The Impact of Monetary Strategies on Inflation Persistence*

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We analyze the impact of price-stability-oriented monetary strategies on inflation persistence by using a time-varying coefficients framework in a panel of sixty-eight countries over 1993–2013. It is shown that inflation targeting (IT) is effective even during and after the financial crisis and that explicit IT has a stronger effect on taming inflation persistence than implicit IT. It is shown that exchange regimes with the euro as a reserve currency are more effective than those using the U.S. dollar. On the other hand, U.S. inflation persistence exhibits a disproportionally lower effect on other countries' persistence than its German counterpart.

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1. Introduction and Motivation

As Fuhrer (2011, p. 431) states, "a key objective of recent inflation research has been to map observed or reduced-form persistence into the underlying economic structures that produce it." We contribute to this broad debate in this paper by assessing the impact of

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price-stability-oriented monetary strategies (inflation targeting and constraining exchange regimes) on inflation persistence. The topic is important to both macroeconomists and policymakers. Because of that, we analyze the issue in a comprehensive manner to circumvent some of the limitations in earlier studies and to provide less ambiguous results.

Aside from periods of hyperinflation, in normal times the inflation rate usually trails some reasonable steady-state level—an underlying trend inflation—from which it may deviate due to shocks (Ascari and Sbordone 2014). Subsequent adjustments towards its long-run level can be described by the speed it takes for inflation to return to the steady-state level. Inflation persistence (IP) is a measure of this convergence speed: the greater (lower) the speed, the less (more) persistent is inflation. A knowledge and quantification of inflation persistence is vital for monetary policy in its goal to maintain price stability. Higher persistence means (i) a smaller "policy space" to deal with temporary price shocks (Roache 2014) and (ii) a higher "sacrifice ratio," representing the output costs associated with lowering inflation (Fuhrer 1994; Ascari and Ropele 2012). In other words, less persistent inflation means it is easier for a central bank to maintain price stability.[1]

Essentially, two types of IP measure exist. Structural persistence is supposed to originate from known economic sources. Reduced-form persistence represents the empirical property without an economic interpretation.[2] Pivetta and Reis (2007), Stock and Watson (2007), and Cogley, Primiceri, and Sargent (2010) produced

[1]Primarily for these reasons, the issue of inflation persistence has been the subject of considerable research. Fuhrer (2011) provides a thorough review of inflation persistence and the relevant research. Pivetta and Reis (2007) review the debate on inflation persistence in the United States while Altissimo, Ehrmann, and Smets (2006) and Meller and Nautz (2012) cover the euro area; Watson (2014) analyzes its development after the Great Recession.

[2]Despite the fact that it is preferable to know the behavior of inflation persistence as well as its sources, the link between the two remains a considerable challenge. While we do not attempt to uncover the structural sources of IP in this paper, we analyze the link between specific monetary policy strategies and (reduced-form) inflation persistence. In the same way, we do not analyze the potential effect of a fiscal policy, but we acknowledge that coordinated monetary and fiscal policies are likely to produce lower inflation volatility after a shock as demonstrated by Greenwood-Nimmo (2014).

important contributions to inflation persistence dynamics in the United States, and empirical evidence from many developed economies shows that inflation was highly persistent from the 1960s until the mid-1980s, but evidence in later periods is mixed (Fuhrer 2011). Evidence on the sources of inflation persistence and its link to related monetary strategies remains controversial. However, the combined effects of past inflation rates (intrinsic persistence) are seen as a primary source of inflation persistence (Fuhrer 2006, 2011).

Gerlach and Tillman (2012, p. 361) argue that “any monetary policy strategy that attaches primary importance to price stability is likely to lead to a low level of inflation persistence.” Central banks choose various strategies, and inflation persistence is increasingly used as an indicator of monetary policy effectiveness (Meller and Nautz 2012). Two relevant policy strategies employed by monetary authorities are inflation targeting (Siklos 1999) and a constraining exchange rate arrangement (Alogoskoufis and Smith 1991). Despite the price-stability character of both strategies, empirical evidence on their links with inflation persistence (reviewed in section 2) does not point to unambiguous results. Such unclear results are possibly because (i) analyses are often performed on individual countries or small sets of countries, (ii) quite frequently the employed methods do not allow for the time-varying nature of inflation persistence,[3] and (iii) researchers often rely on only a few persistence measures.

In this paper we take a firmly comprehensive approach in order to contribute to the literature in two ways. First, we assess inflation persistence in a panel data framework by using a sizable data set of sixty-eight countries from all over the world that represent both developed and emerging economies. We analyze our data in a time-varying coefficients framework, which enables us to derive inflation persistence while accounting for structural breaks, which do exist in the IP of the majority of the countries in our sample. We employ four different IP measures, all established in the literature (see section 3), and cover more measurement issues. Second, we focus on links between inflation persistence and two types of price-stability-oriented monetary strategies. In doing so, we account

[3]Influential contributions (Levin and Piger 2004, Pivetta and Reis 2007, and Stock and Watson 2007, among others) document the importance of accounting for the time-varying nature of persistence during empirical analysis.

for the endogeneity of inflation targeting and the exchange rate arrangement with respect to inflation persistence itself. Based on our comprehensive approach, we show a contributing effect of inflation targeting with respect to inflation persistence and differences in the effect of the foreign exchange regime that depend on what reserve currency is used. The pattern of inflation persistence dynamics also shows that an IT strategy is effective even under financial crisis, as inflation persistence remains on a declining track during the crisis as well as afterwards.

2. Inflation Persistence, Monetary Strategies, and Structural Breaks: Context and Related Literature

Fuhrer (2011, p. 482) thoroughly analyzes the concept of inflation persistence in macroeconomic theory and argues that "it is unlikely that any change in persistence has arisen from a change in the persistence of the driving process." The argument suggests that an intrinsic factor rather than driving forces is the prevailing source of inflation persistence (Fuhrer 2006). While the above claims are thoughtful and are supported by meticulous analysis, a number of studies that we review below analyze various monetary policy factors as potentially relevant in explaining (reduced-form) inflation persistence.[4]

2.1 Inflation Targeting

A monetary policy framework designed to achieve a specific inflation target is known as inflation targeting (IT). According to Heenan, Peter, and Roger (2006) and Mishkin (2008), IT includes four key elements: (i) price stability as the explicit mandate and objective of the central bank, (ii) a quantified inflation target, (iii) the accountability and transparency of the central bank, and (iv) a forward-looking assessment of inflation pressures.

[4]For the sake of space, we refrain from reviewing the literature on inflation persistence in general. Rather, we review the related literature from the perspective of the IT and exchange rate regime strategies that exhibit a potential to affect inflation and its dynamics. Other parts of the inflation persistence literature are not reviewed.

IT was first adopted by New Zealand in 1990, followed by Canada in 1991. The basic ingredients of inflation targets in countries that adopted IT in the early 1990s are comprehensively presented in Siklos (1999, table 1), and a brief account of the experience over twenty-five years of IT is presented in Wheeler (2015). Approaches towards IT were discussed by Svensson (1997, 2002), Bernanke et al. (2001), Bofinger (2001), and the European Central Bank (2004). Explicit inflation targeting (EIT) requires a central bank to publicly recognize low inflation as its monetary policy priority along with announcing an official target for the inflation rate (Goodfriend 2004). EIT is further characterized by a large degree of transparency related to the central bank's monetary policy. Since low inflation might not be the key policy objective, some countries perform implicit inflation targeting (IIT). They declare their inflation objectives in broad terms but their "policy makers may have implicit inflation targets, which agents have to learn over time" (Ascari and Sbordone 2014, p. 680). A strong commitment to the formal adoption of IT is "neither a necessary nor a sufficient condition for a drop in inflation persistence" (Gerlach and Tillman 2012, p. 361). A similar assessment was made even earlier by Siklos (1999, p. 47) who, however, claims that "inflation targeting seemingly lacks some of the drawbacks of other policy regimes."

Empirical evidence on the link between inflation targeting and inflation persistence is not entirely unified. One segment of the literature documents that well-anchored inflation expectations in a credible IT regime correlate with lower inflation persistence (Mishkin and Schmidt-Hebel 2007). Benati (2008) shows that reduced-form persistence declines after the introduction of IT but is still present in countries without anchors (United States and Japan). Baxa, Horváth, and Vašíček (2014) provide evidence of a temporal coincidence between IT introduction and a drop in inflation persistence in countries that have long experience with an IT regime (Australia, Canada, New Zealand, Sweden, and the United Kingdom). On the other hand, Siklos (2008) finds that the introduction of IT resulted in reduced inflation persistence in only a few emerging countries. Filardo and Genberg (2010) in their survey show that persistence declined only in Australia, Korea, and New Zealand, while in other Asian countries it even increased when IT was adopted. Franta, Saxa, and Smídková (2010) show that some of the new EU member states exhibit persistence similar to that in the euro area but other countries suffer from high intrinsic and high expectations-based inflation persistence.

2.2 Constraining Exchange Rate Arrangement

A constraining exchange rate regime linked to a reference currency is primarily used to stabilize a domestic currency, but a secondary role might be to control inflation. This is because domestic inflation is to a large extent determined by the inflation in the country of the reference currency (Alogoskoufis and Smith 1991; Edwards 2011). What is the mechanism linking the constraining foreign exchange regime and inflation persistence? The link depends on the degree of monetary accommodation. According to Dornbusch (1982), monetary policy responding to price shocks in a more accommodative manner is likely to produce more persistent inflation. For that reason, failure to accommodate inflation shocks is frequently perceived as a precondition for lower inflation persistence (Alogoskoufis and Smith 1991). Less monetary accommodation, which is linked with lower inflation persistence, can be achieved by credibly constraining the exchange rate arrangement (provided that such a regime truly delivers lower monetary accommodation). On the other hand, Galí and Monacelli (2005, p. 725) argue that the complete stabilization of the nominal exchange rate under a peg induces stationarity in domestic price levels and "in response to a shock, inflation initially falls but then rises persistently above the steady state."

The literature on the effect of a constraining exchange rate arrangement on inflation persistence does not provide unambiguous results. Alogoskoufis and Smith (1991) and Alogoskoufis (1992) analyze inflation dynamics in the United States, the United Kingdom, and twenty-one OECD countries during periods of fixed arrangements and also more flexible arrangements. They find that inflation persistence was markedly higher under the flexible arrangements. Obstfeld (1995) provides similar evidence for twelve OECD countries, with the exception of the United States. This result is questioned by Burdekin and Siklos (1999), who claim that other factors (notably oil price shocks and central bank reforms) could also be attributed to reduced inflation persistence instead of exchange rate arrangements alone.[5] Similarly, Anderton (1997) analyzes inflation dynamics among countries in and outside of the former Exchange Rate Mechanism (ERM) and shows that ERM was a key factor in inflation persistence reduction but it was neither necessary nor sufficient alone.[6] In an analysis of inflation in OECD countries from the 1950s to the early 1970s, Bleaney (2000) does not find differences in inflation persistence in connection to exchange rate regimes. Bleaney and Francisco (2005) show relatively high inflation persistence for both floating and pegged regimes in a large set of developing countries, but the results alter substantially when hard exchange rate pegs were distinguished from soft ones. On the other hand, more recent analyses from emerging markets do not show differences in inflation persistence across tight and flexible exchange rate arrangements (Jiranyakul 2014; Nguyen et al. 2014).

3. Inflation Persistence Measures

Fuhrer (2011, p. 431) points out that there is no definitive measure of reduced-form persistence and provides a list of the most common IP measures employed in the literature.[7] These measures have their pros and cons, though. Out of them, the sum of the autoregressive (AR) coefficients and the dominant root (or the largest AR root, LAR) represent more versatile measures that account for dynamics in inflation persistence and provide an opportunity to explore its potentially time-varying nature. Both measures were employed by Pivetta and Reis (2007) in their study of U.S. inflation persistence

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[5]This claim is in accord with the results of Beechey and Österholm (2012), who suggest that by placing emphasis on inflation stability in recent decades, the Federal Reserve succeeded in lowering U.S. inflation persistence.

[6]An exchange rate peg to a reserve currency serves as a disciplining device that enables a high-inflation economy to import monetary stability from a low-inflation reserve-currency country (Husain, Mody, and Rogoff 2005); this behavior is shown in Kočenda and Papell (1997) on the example of the members of the former European Monetary System (EMS). Lower inflation persistence can potentially be imported as well, if the persistence is low in the reserve country in the first place.

[7]These are (i) conventional unit-root tests, (ii) the autocorrelation function (ACF) of the inflation series, (iii) the first autocorrelation of the inflation series, (iv) the dominant root of the univariate autoregressive inflation process, (v) the sum of the coefficients from a univariate AR for inflation, and (vi) the unobserved-component decompositions of inflation proposed by Stock and Watson (2007).

along with the measure termed half-life (HLF) that they define as the number of periods in which inflation remains above 0.5 following a unit shock. Further, Cogley, Primiceri, and Sargent (2010, p. 44) recently define an R^2-based "measure of persistence in terms of inflation-gap predictability, in particular, as the fraction of total inflation-gap variation j quarters ahead that is due to past shocks" (henceforth RJT).

Therefore, following the methodological approaches outlined in Pivetta and Reis (2007), Cogley, Primiceri, and Sargent (2010), and Fuhrer (2011), we employ in our analysis the sum of the AR coefficients (SUM) as our primary inflation persistence measure that is complemented by the LAR, HLF, and RJT measures. All four measures are formally defined presently along with a description of how they fit into our estimation strategy.

3.1 The Time-Varying AR(n) Process as a Framework

Univariate AR modeling is an intuitively appealing approach because it can be easily linked to the simple central bank behavior model below (1a–1c). From a backward-looking perspective, change in inflation ($y_t - y_{t-1}$) in a simple Phillips-curve specification can be modeled as being positively dependent on an output gap g_t (1a). The output gap is then negatively linked to the central bank's key interest rate i_t (1b). Finally, the bank's policy interest rate is directly linked to the inflation rate y_t (1c). Substitution of (1c) and (1b) into (1a) yields exactly an AR(1) process (1d), as can been seen from the following equations:

$$y_t - y_{t-1} = \alpha g_t \tag{1a}$$

$$g_t = -\beta i_t \tag{1b}$$

$$i_t = \gamma y_t \tag{1c}$$

$$y_t = \phi y_{t-1} = \frac{1}{1 + \alpha\beta\gamma} y_{t-1}. \tag{1d}$$

A natural extension of an AR(1) process is a higher-order AR process in which intrinsic inflation persistence can be captured in a more subtle way. Specifically, we adopt an autoregression of order p and allow for time-varying coefficients:

$$y_t = \phi_{0t} + \phi_{1t} y_{t-1} + \phi_{2t} y_{t-2} + \ldots + \phi_{pt} y_{t-p} + \varepsilon_t \quad t = 1, 2, \ldots, T, \quad (2)$$

where y_t is the observed inflation variable, ϕ_{it} denotes the i-th order coefficient at time t, and ε_t is the error term.[8]

The derivation of persistence may come from a hypothetical setting where there is only a one-unit-sized shock at some point t in time and no shocks before or after. We define the j-th value of the impulse response function (IRF_j) as the derivative of y_{t+j} with respect to shock ε_t:

$$IRF_j = \frac{\partial y_{t+j}}{\partial \varepsilon_t}.$$

In a stable system the impulse response decays down to zero and persistence measures the speed of this decay. In all of our calculations we suppose that for every time point the actual AR parameters will stay in place indefinitely.

3.2 Sum of Autoregressive Coefficients (SUM)

Hence, following the exposition in section 3.1, our main measure of inflation persistence is the sum of AR parameters at a given time point t:

$$IP_t^{SUM} = \sum_{i=1}^{p} \phi_{it}. \quad (3)$$

Additional intuitive motivation for the SUM measure emerges if we take a steady state of the system and impose a sudden shock: the deterministic part of the response in the first period after the shock will be exactly the sum of the coefficients multiplied by the value of the steady state.

A more formal way to justify the SUM measure is to compute the convergence limit of the cumulated sum of the impulse response, which is naturally in a positive relationship with persistence. It is linked to our measure as follows:

[8] In our empirical analysis we use quarterly data; therefore, we allow for five lags in the autoregression. Another option would be using a lag selection criterion for each country. However, since later we aggregate the estimated coefficient sequences, we find it more appropriate to use the same lag length for all country series.

$$\sum_{j=0}^{\infty} \frac{\partial y_{t+j}}{\partial \varepsilon_t} = \frac{1}{1 - \sum_{i=1}^{p} \phi_{it}} = \frac{1}{1 - IP_t^{SUM}}. \quad (4)$$

3.3 Largest Autoregressive Root (LAR)

It can be shown easily with difference equations that the impulse response of an AR system always yields an exponential trajectory in time. More specifically, if we eliminate residuals, the solution to (4) takes the form

$$IRF_j = \sum_{i=1}^{p} c_i \lambda_i^j, \quad (5)$$

where $\lambda_1, \lambda_2, \ldots, \lambda_p$ are the roots of the inverse AR polynomial (which may be complex, but if so, they appear as conjugate pairs) and $c_1, c_2, \ldots, c_p$ are constants that sum to 1 and can be computed using the roots. This is a sum of exponentials that all diminish in time (stability assumed), and the one with the largest absolute base will dominate the sum. Therefore, the speed of decay will be determined by the largest root, which gives support to the LAR persistence measure defined as

$$IP_t^{LAR} = \max_i |\lambda_i| . \quad (6)$$

3.4 Half-Life (HLF)

Another approach to measuring the speed of decay is the number of periods needed to reach a certain threshold—for example, half of the initial shock size. In an AR(1) model where the AR coefficient is positive, the decay is strictly exponential and the half-life can be expressed explicitly as a function of the coefficient. However, with the introduction of negative coefficients and a higher order (multiple and complex roots), the impulse response may oscillate around the threshold. In our definition, the half-life is the number of periods after which the absolute value of the impulse response is indefinitely below 0.5. The HLF persistence measure is then defined as

$$IP_t^{HLF} = \min_k \{k \mid j \geqslant k \Longrightarrow |IRF_j| < 0.5\} . \quad (7)$$

3.5 Inflation Gap Predictability Measure (RJT)

Last, we adapt the persistence measure of Cogley, Primiceri, and Sargent (2010) in our univariate model. This involves converting our time-varying AR(n) model to a time-varying VAR(1) and then calculating the forecast variances. The idea of the RJT measure is to compare the variation due to shocks inherited from the past to the total forecast variance, thus producing a variance ratio that is an R^2-like measure. The first VAR conversion step is straightforward:

$$z_{t+1} = \mu_t + A_t z_t + \varepsilon_{z,t+1}, \tag{8}$$

where we stack up lags of y_t in vector z_t. Further, the A_t coefficient matrix contains the AR coefficients and ones and zeros. Finally, $\varepsilon_{z,t}$ contains the AR residual and zeros, thus indicating that the vector equation consists of one meaningful equation plus identities. The location of that meaningful equation within the vector z_t—which shows where we have y_t on the left-hand side—is shown by the selector vector e.

In the VAR model we are able to express the conditional forecast variance on a given horizon j and compare it with the total unconditional forecast variance. The R^2_{jt} measure is then defined as

$$IP_t^{RJT} = 1 - \frac{var_j\left(e\hat{z}_{t+j}\right)}{var\left(e\hat{z}_{t+j}\right)} \approx 1 - \frac{e\left[\sum_{k=0}^{j-1}\left(A_t^k\right) var\left(\varepsilon_{z,t+1}\right)\left(A_t^k\right)'\right]e'}{e\left[\sum_{k=0}^{\infty}\left(A_t^k\right) var\left(\varepsilon_{z,t+1}\right)\left(A_t^k\right)'\right]e'}. \tag{9}$$

Note that in our case the persistence measure is invariant on the residual variance $var\left(\varepsilon_{z,t+1}\right)$ which makes the measure computable even without estimating it. For the selection of the forecast horizon j we use the values 1, 4, and 8, similar to Cogley, Primiceri, and Sargent (2010).

4. Time-Varying Estimation Methodology and Hypotheses

4.1 Estimating Time-Varying Inflation Persistence

Analysis of inflation persistence is often complicated by potentially existing, but unaccounted for, structural breaks. Bleaney (2000) argues that estimates of inflation persistence are quite sensitive to shifts in mean and a larger (smaller) number of unaccounted-for shifts biases inflation persistence estimates upwards (downwards). Indeed, Levin and Piger (2004) and Cecchetti and Debelle (2006) show that estimates of inflation persistence are considerably lower when structural breaks are accounted for. To avoid this upward bias induced by unaccounted-for breaks, an adequate methodology has to be used.

In order to capture the truly time-varying nature of inflation persistence, we employ the maximum-likelihood estimation of a state-space model by using the flexible least squares (FLS) estimator introduced by Kalaba and Tesfatsion (1988) and estimate the time-varying coefficient autoregression (2). The most important advantage of this framework is that it eliminates the need to account for known and unknown structural breaks.[9] On the other hand, employing the time-varying coefficient method is only useful if the data support the hypothesis of no constancy. For that we later (in section 6.1) apply persistence-change tests to underpin the use of our time-varying coefficient model, and we note that the persistence-change tests confirm the correctness of our approach. Hence, with the above method both sudden and continuous changes are revealed, and so beyond the break dates we have the additional advantage of identifying the tendency of the persistence sequences. By using time-varying parameter models, we argue that only the deviations from the estimated time-varying mean should be taken into account when estimating persistence. Thus, with the FLS estimation we go one

[9]Cogley and Sargent (2002) were probably the first to estimate a model with continuously changing inflation persistence for the United States using Bayesian analysis in a VAR framework. Pivetta and Reis (2007) summed up the univariate changing persistence measures also in a Bayesian setting and concluded that U.S. inflation persistence is constantly high and not changing. They based this result mainly on two facts: (i) although the estimated persistence sequence did show signs of change, the broad confidence intervals allowed for constant persistence and (ii) formal tests from Banerjee, Lumsdaine, and Stock (1992) signaled no change. However, these tests have been later overridden in terms of size and power by a test proposed by Kim (2000) that was corrected by Kim, Belaire-Franch, and Amador (2002), extended by Busetti and Taylor (2004), and operationalized by Harvey, Leybourne, and Taylor (2006). Based on this approach Noriega, Capistrán, and Ramos-Francia (2013) and Darvas and Varga (2014) detected changes in inflation persistence in a number of countries.

step further than studies that employ a multiple structural breaks approach.

We now formally introduce the flexible least squares methodology.[10] The main advantage of the FLS algorithm is that it does not require any distributional assumptions. Suppose y_t is the time-t realization of a time series for which a time-varying coefficient model is to be fitted,

$$y_t = \beta_t' x_t + \varepsilon_t \quad t = 1, 2, \ldots, T. \tag{10}$$

In (10) we compress our regressors into the $k \times 1$ coefficient vector x_t which in our specific case contains a constant and the lagged values of y_t. The time-varying $k \times 1$ vector of unknown coefficients to be estimated is denoted by β_t. Finally, ε_t is the approximation error.

The two main assumptions of the method are formulated without any distributional requisites:

$$y_t - \beta_t' x_t \approx 0 \quad t = 1, 2, \ldots, T \tag{11a}$$

$$\beta_{t+1} - \beta_t \approx 0^{k \times 1} \quad t = 1, 2, \ldots, T - 1. \tag{11b}$$

That is, the prior measurement specification (11a) states that the residual errors of the regression are small, and the prior dynamic specification (11b) declares that the vector of coefficients evolves slowly over time.

The idea of the FLS method is to assign two types of residual error to each possible coefficient sequence estimate. A quadratic cost function is assumed to be

$$C(\beta_1, \ldots, \beta_T, \mu, T) = \sum_{t=1}^{T} (y_t - \beta_t' x_t)^2 + \mu \sum_{t=1}^{T-1} (\beta_{t+1} - \beta_t)' (\beta_{t+1} - \beta_t), \tag{12}$$

where μ is the weighting parameter. The minimization of this cost function for $\beta_1, \ldots, \beta_T$, given any $\mu > 0$, leads to a unique estimate for $\beta_1, \ldots, \beta_T$. Consequently, there is a continuum of numbers of FLS solutions for a given set of observations, depending on the weighting

[10]The flexible least squares methodology is in some respects similar to Kalman filtering but better suits our purpose. A detailed introduction of FLS and a comparison to Kalman filtering can be found in Montana, Triantafyllopoulous, and Tsagaris (2009).

parameter. We use an FLS smoother with a weighing parameter of 100, which conforms to the simulation experiments conducted by Darvas and Varga (2012).

4.2 Inflation Persistence and Monetary Strategies

Once the FLS-smoothed inflation persistence estimates are available for each country, we use panel regression techniques to explore the effects of exchange rate and inflation-targeting strategies. Formally, we estimate the following specification:

$$\widehat{IP}_{ct} = \alpha_0 + \alpha_1 ER_{ct}^{USD} + \alpha_2 ER_{ct}^{EUR} + \alpha_3 IT_{ct}^{IMP} + \alpha_{4a} IT_{ct}^{EXP} + \alpha_5 ZLB_{ct} + CFE_c + TFE_t + u_{ct}. \tag{13a}$$

Using c as the country and t as the time subscript, $\widehat{IP}_{ct}$ is the smoothed estimate of the inflation persistence of country c at time t, CFE_c is a country fixed effect, TFE_t is a time (period) fixed effect, and u_{ct} denotes the unobserved error. All five regressors are dummy variables formed based on our reasoning in section 1 and further detailed in section 5. They have the following meaning: ER_{ct}^{USD} equals one when the constraining exchange regime of a domestic currency uses the U.S. dollar as a reserve currency and zero otherwise; ER_{ct}^{EUR} is defined in the same way when the reserve currency is the euro (or deutsche mark before 1999); IT_{ct}^{EXP} equals one when the country follows an explicitly stated IT regime and zero otherwise; IT_{ct}^{IMP} equals one when the country practices implicit targeting and zero otherwise (IT_{ct}^{IMP} and IT_{ct}^{EXP} are mutually exclusive dummy variables; for more details see section 5).

The zero lower bound (ZLB) or zero interest rate policy has been analyzed as an important factor affecting inflation persistence because it constrains conventional monetary policy (Buiter 2009; Swanson and Williams 2014). In order to explicitly control for the ZLB, we also incorporated a ZLB dummy in (13a) that takes a value of one when a country has hit the ZLB during the sample period and zero otherwise.

In the next step we modify (13a) to account for the effect of imperfections in explicit inflation targeting. Despite a strong commitment, a central bank might deviate from the inflation target. We account for this formally in specification (13b):

$$\begin{aligned}\widehat{IP}_{ct} = {} & \alpha_0 + \alpha_1 ER_{ct}^{USD} + \alpha_2 ER_{ct}^{EUR} + \alpha_3 IT_{ct}^{IMP} \\ & + \alpha_{4b} IT_{ct}^{EXP} \cdot Abs(Inflation - Target)_{ct} \\ & + \alpha_5 ZLB_{ct} + CFE_c + TFE_t + z_{ct}. \end{aligned} \tag{13b}$$

In (13b) the variable $IT_{ct}^{EXP} \cdot Abs(Inflation - Target)_{ct}$ captures deviations of the inflation rate from the central bank's target when a country follows explicit IT. The construction of the variable allows for deviations above as well as below the policy-intended level of the inflation rate.

In terms of estimation, by using cross-section fixed effects, we account for any level differences between the countries, and in doing so we eliminate any possible time-invariant endogeneity (Wooldridge 2002, p. 248; Greene 2003, p. 291). By applying period fixed effects we also account for any common trend among the persistence series (Wooldridge 2002, p. 278). We acknowledge that there still can be an omitted variable which is time varying and not common in all countries, though. However, a country-specific and time-period fixed-effects approach ensures to a large extent that the effects associated with the dummy variables for monetary strategies are not spurious and the potential endogeneity of monetary strategies with respect to inflation persistence is accounted for. To check for any excess kurtosis or skewness in the residuals that might be caused by inflation targeting, we apply a bootstrap test to the residuals of the regression and verify whether the coefficients remain statistically significant.[11]

4.3 Testable Hypotheses

Our methodological approach accounts for time-varying inflation persistence and potential structural breaks. We use breakpoint tests (Chow test, Quandt-Andrews test) to analyze the stability of the estimated inflation-persistence equation within the class of I(0)

[11] As an alternative, the entire estimation of (2) and (13) could be done in one step via maximum likelihood, but that would induce two significant drawbacks: (i) we would be obliged to impose distributional assumptions and (ii) the numerical optimization would involve an enormous number of dimensions, which could lead to false local optima and produce practical difficulties. For those reasons we prefer the well-established and distribution-free two-stage methodology.

series. We assess a null hypothesis of no break at the 5 percent significance level and report the results in section 6.1.

Further, we assess the link between the exchange rate regime and inflation persistence. Our working hypothesis is that there is no such link. We specify two possibilities of reserve currency in a constraining exchange arrangement (U.S. dollar and euro, or deutsche mark before 1999) and assess the coefficients α_1 and α_2 in specification (13). We formally test two null hypotheses, H_0: $\alpha_1 = 0$ for USD and H_0: $\alpha_2 = 0$ for EUR, against the respective alternative hypotheses H_A: $\alpha_1 \neq 0$ and H_A: $\alpha_2 \neq 0$. If the null hypothesis is rejected, a negative (positive) coefficient indicates the existence of a link between the exchange rate regime and a decrease (increase) in inflation persistence. The results are reported in section 6.2.

Finally, we uncover the link between two degrees of inflation targeting and inflation persistence via an assessment of coefficients α_3 and α_4 in specification (13). Here again we formally test two null hypotheses depending on the type of IT strategy. Specifically, we test H_0: $\alpha_3 = 0$ for implicit IT and H_0: $\alpha_4 = 0$ for explicit IT against their respective alternatives H_A: $\alpha_3 \neq 0$ and H_A: $\alpha_4 \neq 0$. Similarly as above, when the null hypothesis is rejected, a negative (positive) coefficient points to a decrease (increase) in inflation persistence with respect to the inflation-targeting strategy. The results are reported in section 6.3.

5. Data

Our sample covers sixty-eight countries that are listed in the appendix, table 3. The set contains both developed countries and emerging markets according to the Dow Jones list. We use quarterly inflation rates computed as changes in the consumer price index (CPI). CPI values were obtained from International Financial Statistics (IFS) of the International Monetary Fund (IMF) for two decades from 1993:Q1 to 2013:Q4. In addition, the data were cross-checked or augmented with the information provided by the statistical offices or central banks of the countries under research.

Further, in order to analyze the effect of monetary strategies, we form a data set indicating the date when implicit inflation targeting (IIT) and explicit inflation targeting (EIT) were adopted (table 3). Dummy variables for IIT or EIT take values of one when a country exercises IIT or EIT and zero otherwise. Since both classifications are mutually exclusive, the estimated effects of both IT regimes are net effects. The classification strategy follows Carare and Stone (2006) and is based on the information obtained from the individual central banks and numerous studies in the academic literature.[12]

In addition, we form a set of ZLB dummies that take a value of one for those countries in our sample that have hit the ZLB during the sample period and zero otherwise. The ZLB is represented by a 0.5 percent or lower value of a central policy rate that corresponds to empirically observed values associated with the ZLB-related monetary policy of major central banks in the United States, United Kingdom, euro area, Canada, etc. (Buiter 2009; Swanson and Williams 2014). Eleven countries plus the euro area in our sample that have hit a ZLB during the sample period are listed in the appendix, table 3, with starting and ending dates when the central bank policy rate was at or below 0.5 percent. If there is no ending date, the ZLB was maintained until the end of our sample period.

Further, we form the variable $IT^{EXP}_{ct} \cdot Abs(Inflation - Target)_{ct}$ to capture absolute deviations of the inflation rate from the central bank's explicit inflation target. The changes in target levels over time are accounted for. If a central bank has a target interval, we use a midpoint as a reference value. In table 3 we provide information on countries' inflation target rates as well as the timing of their adoption.

Finally, we employ a de facto exchange rate regime classification of Reinhart and Rogoff (2004) that is available until 2001. For the later period (2002–13) a de facto regime classification is based on their approach and checked against information obtained from the literature. We distinguish constraining exchange rate arrangements with respect to the U.S. dollar and the euro (or the deutsche

[12] Euro-area countries are primarily classified as explicitly targeting because of the declared commitment of the European Central Bank (ECB) to keep the annual inflation rate close to or below 2 percent. However, the classification of individual euro-area member states as explicit inflation targeters can certainly be debated, as the ECB is not expected to stabilize inflation at close to 2 percent for the individual member states but for the euro area as a whole. In this sense the IMF classifies the monetary policy regime in euro-area member states as "other," instead of "inflation targeting." Therefore, as an alternative and robustness check we classify the euro-area member states as having floating exchange rates but without an inflation-targeting regime.

mark before 1999); on one occasion we also account for a peg to the British pound.[13] The dummy variable for the exchange rate regime with respect to a specific currency takes a value of one during periods when such a regime was in power and zero otherwise (table 3). We account for a peg to a reserve currency along with constraining intermediate regimes. In the case of a currency basket peg or its crawling version, the dummy variables are coded to reflect a link to more reserve currencies.

6. Empirical Results

6.1 Inflation Persistence Dynamics

First, we assess the stability of the estimated inflation-persistence equation within the class of I(0) series by using two breakpoint tests: the Chow test and the Quandt-Andrews test (at the 5 percent statistical significance level and under 10 percent trimming). For the Chow test we assume the break point to be exogenous because the date of IT adoption is known. Depending on the type of statistics used (indicated in parentheses), the Chow test rejects the null of no change in three (F-stat.), five (LR-stat.), and nine (Wald-type) cases out of thirty-one countries that adopted EIT during our sample period. With the Quandt-Andrews test we tested for stability changes at unknown break points to account for potential instabilities due to reasons other than IT adoption. The test rejects the null of no change in six to thirty-nine cases, depending on the type of statistics used.[14] When comparing the results of both tests, we

[13] Euro-area countries are classified as floaters because, since its introduction, the euro freely floats. This is in line with the IMF exchange rate classification (AREAER) that classifies the euro-area member states as having freely floating exchange rate regimes. During our sample period only Israel used the British pound as a reserve currency in its constraining exchange rate regime, when the British pound was part of a basket with the U.S. dollar.

[14] The Quandt-Andrews test provides maximum (MaxF), exponential average (ExpF), and average (AveF) test statistics with non-standard distributions. The true distribution was developed by Andrews (1993) and the approximate asymptotic p-values were provided by Hansen (1997). In our analysis, there are $3 \times 2 = 6$ potential results (MaxF/ExpF/AveF $\times$ LR/Wald) on rejecting the null of no break. The specific numbers of rejections are twenty-nine, ten, four, thirty-nine, six, and twenty-five (observing the order of the test statistics list in parentheses).

conclude that instabilities in the persistence equation exist and a number of them materialize for reasons additional to IT adoption.

Second, we describe the essential facts related to the panel estimation.[15] The key results are obtained based on the SUM persistence measure (table 1). Supplementary results are obtained based on alternative measures: LAR (table 1), HLF (table 1), and RJT (table 2). Since all four IP measures are constructed differently, the persistence estimates derived from the measures are not directly comparable.

In our panel setup a constant is the same for all countries and represents the average persistence of all countries under the condition that the exchange rate and IT regime-dependent dummies do not exhibit any effect. Based on the constant coefficient (α_0) value, the average persistence is rather low. In our estimations we also account for country-specific and time fixed effects. The country-specific effect is basically an added constant for every given country, and its sum with the global constant above (α_0) represents the average country persistence (again, under the condition that the exchange-rate-dependent and IT-regime-dependent dummies do not exhibit any effect). Based on the SUM measure, the values of country-specific effects range from 0 to about $|0.7|$; this means that inflation persistence is strongly country dependent. Since we have sixty-eight countries, the individual fixed-effect coefficients are not reported.

Time fixed effects account for a common trend in inflation persistence among countries. In figure 1 we present a plot of those estimated period fixed effects; they are obtained from the panel specification (13a) estimated with the different IP measures defined in (3), (6), (7), and (9). Through period fixed effects we control for the downward trend in the IP dynamics that changed into a general increase after 2001 and culminated with the financial crisis in 2008. Later this pattern is characterized by a mild decline. These features were well captured by period-specific effects, as advocated in section 4.2.

Further, in figure 2, we present plots of the averages of the FLS-smoothed inflation persistence based on the SUM persistence

[15]The panel regression results largely stay the same when applying a bootstrap test to the residuals, as none of the estimated coefficients' significance levels change when looking at the bootstrap distribution.

Table 1. Panel Least Squares Estimation Results with SUM, LAR, and HLF Persistence Measures

Dependent Variable ⟶		**SUM Persistence Estimate**		**LAR Persistence Estimate**		**HLF Persistence Estimate**	
Equation Setup		**With ITEXP Dummy**	**With IT Difference**	**With ITEXP Dummy**	**With IT Difference**	**With ITEXP Dummy**	**With IT Difference**
Constant	α_0	0.289***	0.147***	0.859***	0.855***	6.621***	5.122***
		(18.46)	(14.35)	(243.54)	(371.91)	(10.50)	(12.45)
U.S. Dollar Regime (ERUSD)	α_1	−0.060***	−0.041**	0.004	0.004	0.137	0.339
		(−3.20)	(−2.20)	(0.85)	(0.98)	(0.18)	(0.45)
Euro (Deutsche Mark) Regime (EREUR)	α_2	−0.405***	−0.251***	−0.019***	−0.016***	−4.082***	−2.812***
		(−19.29)	(−13.77)	(−4.00)	(−3.97)	(−4.83)	(−3.85)
Implicit Inflation Targeting (ITIMP)	α_3	−0.215***	−0.130***	−0.024***	−0.020***	−6.925***	−5.597***
		(−9.01)	(−5.87)	(−4.43)	(−3.97)	(−7.21)	(−6.28)
Explicit Inflation Targeting (ITEXP)	α_{4a}	−0.443***		−0.005		−2.865***	
		(−18.84)		(−0.85)		(−3.02)	
ITEXP * ABS(Inflation – IT Midpoint)	α_{4b}		−0.122***		0.001		−0.168
			(−17.14)		(0.80)		(−0.59)
Zero Lower Bound Dummy (DZLB50BP)	α_5	−0.031	−0.029	−0.014**	−0.013**	−1.713	−1.553
		(−1.06)	(−1.00)	(−2.10)	(−2.00)	(−1.46)	(−1.33)
R-squared		60.9%	60.5%	59.0%	59.0%	21.5%	21.4%

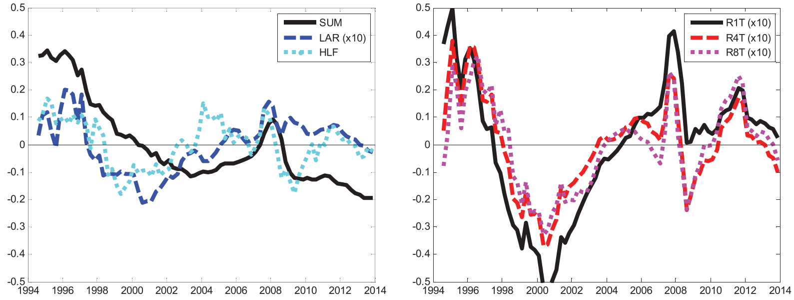
Notes: The persistence measures are the sum of autoregressive coefficients (SUM), largest autoregressive root (LAR), and half-life in quarters (HLF). The table shows regression coefficients with *t*-statistics in parentheses. *, **, and *** indicate a rejection of insignificance at the 10, 5, and 1 percent level, respectively. Cross-section and period fixed effects (dummy variables) are included in all specifications, the number of periods is seventy-eight, and the number of cross-sections is sixty-eight.

Table 2. Panel Least Squares Estimation Results with RJT Persistence Measures

Dependent Variable ⟶		R1T Persistence Estimate		R4T Persistence Estimate		R8T Persistence Estimate	
Equation Setup		**With ITEXP Dummy**	**With IT Difference**	**With ITEXP Dummy**	**With IT Difference**	**With ITEXP Dummy**	**With IT Difference**
Constant	α_0	0.350***	0.344***	0.256***	0.244***	0.156***	0.145***
		(49.54)	(74.74)	(34.33)	(50.31)	(20.99)	(29.99)
U.S. Dollar Regime (ERUSD)	α_1	0.025***	0.025***	0.015	0.016*	0.009	0.011
		(2.93)	(3.04)	(1.64)	(1.81)	(1.06)	(1.22)
Euro (Deutsche Mark) Regime (EREUR)	α_2	0.000	0.006	−0.004	0.006	−0.026***	−0.017**
		(0.03)	(0.75)	(−0.41)	(0.75)	(−2.66)	(−2.02)
Implicit Inflation Targeting(ITIMP)	α_3	−0.132***	−0.128***	−0.115***	−0.106***	−0.115***	−0.106***
		(−12.22)	(−12.79)	(−10.14)	(−10.10)	(−10.22)	(−10.15)
Explicit Inflation Targeting(ITEXP)	α_{4a}	−0.016		−0.027**		−0.021*	
		(−1.48)		(−2.38)		(−1.89)	
ITEXP * ABS(Inflation – IT Midpoint)	α_{4b}		−0.004		−0.004		−0.002
			(−1.12)		(−1.29)		(−0.50)
Zero Lower Bound Dummy (DZLB50BP)	α_5	−0.046***	−0.045***	−0.053***	−0.052***	−0.043***	−0.042***
		(−3.48)	(−3.46)	(−3.81)	(−3.75)	(−3.15)	(−3.07)
R-squared		56.7%	56.7%	56.2%	56.1%	47.8%	47.8%

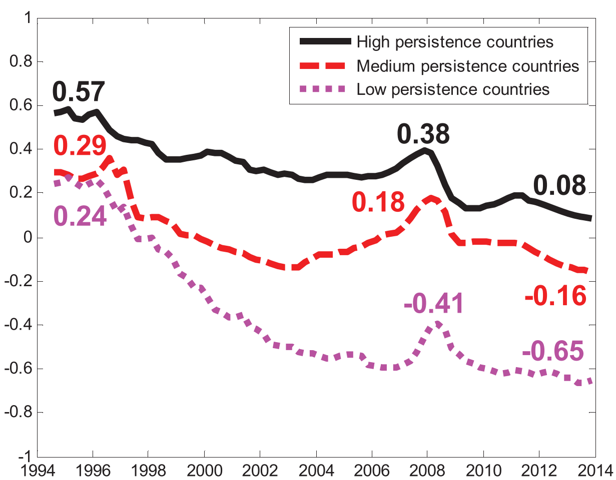
Notes: The persistence measures are the R^2_{jt} statistics for $j = 1$ (R1T), $j = 4$ (R4T), and $j = 8$ periods (R8T). The table shows regression coefficients with t-statistics in parentheses. *, **, and *** indicate a rejection of insignificance at the 10, 5, and 1 percent level, respectively. Cross-section and period fixed effects (dummy variables) are included in all specifications, the number of periods is seventy-eight, and the number of cross-sections is sixty-eight.

Figure 1. Estimated Period Fixed Effects of the Panel Equations



Notes: The graphs show the time fixed effects for the FLS-smoothed persistence equations, with all six persistence measures. Some measures are multiplied by a factor of 10 to make a similar range.

Figure 2. Average FLS-Smoothed Inflation Persistence of Three Country Groups



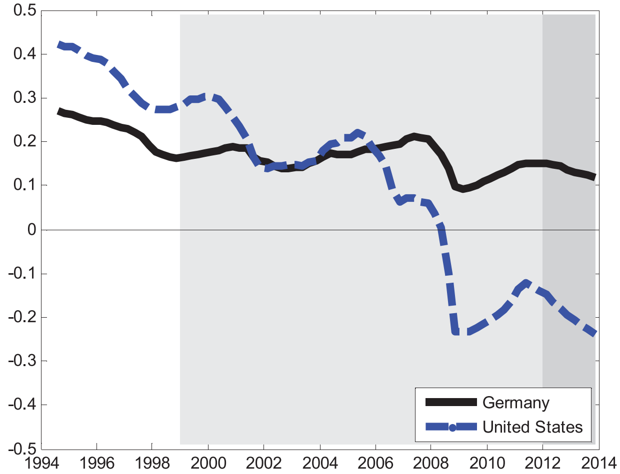
Notes: The three lines show the estimated FLS-smoothed sum-of-AR-coefficients (SUM) persistence series for the three country groups based on average persistence throughout the sample. High persistence means the highest one-third of the countries, low persistence means the lowest one-third of the countries, while medium means the middle one-third. The numbers show the values of the series at the beginning of sample (1994:Q3), the financial crisis (2008:Q1), and the end of sample (2013:Q4).

measure for three country groups: low-, middle-, and high-persistence countries. The plots show (i) ample evidence of a common pattern in inflation persistence among countries, albeit at different IP levels, (ii) existence of structural breaks, and (iii) a uniform effect of the financial crisis as IP was rising in all three groups during 2007–08.[16] In addition, low-persistence countries even exhibit negative inflation persistence. This finding could partly be a consequence of the time-varying steady-state level of the inflation rate, but it is not unusual, as it is reported in other studies as well (see, among others, Benati 2008; Meller and Nautz 2012; and Darvas and Varga 2014). This phenomenon can be explained with the help of microeconomic price-setting models that often imply that "high persistence in the price level ... translates into very low or even negative persistence in inflation" (Cecchetti and Debelle 2006, p. 317). For example, in the canonical time-dependent price-setting model of Taylor (1980), positive persistence in the price level implies negative inflation persistence. Hence, price-level stickiness yields a plausible interpretation of the negative inflation persistence observed in some countries in our sample. From a technical point of view it is also worth considering that state-space models, like the Kalman filter or FLS, compute the optimal increment of the state variable (in our example, the AR coefficients which are directly linked to persistence), holding the variance of this increment constant (or given, as in the FLS case). This can more easily lead to negative persistence values. The key takeaway from this is to look more at the development of IP than the exact levels of IP.

Finally, in figure 3 we present the persistence series for the United States and Germany (as a proxy for the euro area). The IP series is based on the estimated FLS-smoothed sum of AR coefficients (SUM). Their evolution is quite similar, as, in most cases, they seem to change direction at the same time, although the German series is smoother than the U.S. series.

[16]Principal components analysis (PCA) of the SUM-based IP series reveals that the first two principal components explain 76 percent of the total variance (58 percent and 18 percent, respectively); the influence of the remaining components is negligible. The PCA result hints at the existence of a factor structure in inflation persistence across countries, possibly due to policy factors as argued by Benati and Surico (2008) and Cogley, Primiceri, and Sargent (2010).

Figure 3. FLS-Smoothed Inflation Persistence



Notes: The two lines show the estimated FLS-smoothed sum-of-AR-coefficients (SUM) persistence series for the United States and Germany. The beginning of the light gray background shows when the euro was adopted. The dark gray background depicts when the United States adopted explicit inflation targeting.

6.2 Exchange Rate Regime and Inflation Persistence

The link between a constraining exchange arrangement and IP is captured by the coefficients α_1 and α_2, which represent the marginal effects of dummy variables ER^{USD} and ER^{EUR} on inflation persistence as an average for all countries. Relatively small and negative values of the α_1 coefficient based on the SUM measure (table 1) suggest that the USD-based constraining regime is mildly linked to persistence decrease. Results based on the LAR and HLF persistence measures are not available, as the estimate coefficients are statistically insignificant (table 1). Results based on the RJT measure produce very small positive coefficients, but half of them are statistically insignificant (table 2). All of the results, taken together, indicate a limited but contributing link between the U.S.-dollar-based constraining exchange regime and inflation persistence.

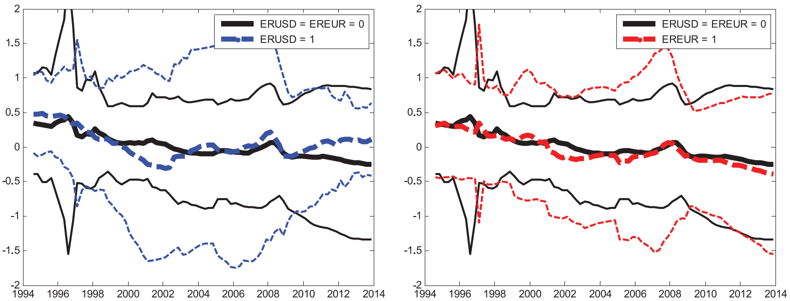
Regimes using the euro (or deutsche mark) exhibit an order of magnitude larger effect that contributes to lower persistence since the SUM-based α_2 coefficients are negative and relatively large (table 1). Results obtained by using three other measures of inflation persistence are also negative and proportionally similar (tables 1 and 2), given the differences in measure construction. Low German inflation and reasonably low inflation pursued by the ECB under the Maastricht stability criterion along with the prudent monetary policies of both institutions have led to low or moderate inflation persistence (Altissimo, Ehrmann, and Smets 2006; Meller and Nautz 2012), as documented for much of the span of our sample. Based on such IP dynamics, the negative α_2 coefficients come as a sensible outcome and the estimates provide consistent findings: the effect of constraining exchange regimes using the euro (or deutsche mark) is relatively strong and uniformly points at a link to a decrease in inflation persistence. The effect is also in accord with the dramatic decrease in inflation persistence following the euro introduction that is documented by Lopez and Papell (2012), and progressive inflation convergence documented by Brož and Kočenda (2018).

The above results indicate some difference between the effects of exchange rate regimes using different reserve currencies. Such dissimilarity materialized despite the strong constraints on domestic policy actions imposed by a commitment to a constraining exchange rate regime and limitations on how the monetary authorities can react to the persistence of inflation shocks (Bleaney 2000). As a complement, in figure 3 we provide a plot of inflation persistence for the United States and Germany. Inflation persistence in the United States was relatively high for the initial two-thirds of the period under research and, in fact, was rising prior to the financial crisis. Then it experienced a marked decline during 2006–08. This pattern is quite different from the global picture (figure 2), where a major increase in IP coincides with the crisis period in 2008. The sharpest decline in U.S. inflation persistence occurs from mid-2007 and correlates with the sequence of cuts to the federal funds rate initiated in August 2007. An increase in the post-crisis IP is soon transformed into a subsequent decline that coincides with the adoption of explicit inflation targeting by the Federal Reserve in 2012. The German IP exhibits a different pattern: it is low for most of the period and declines in a stable manner. A notable difference between U.S. and German inflation persistence is visible with respect to the 2008 crisis, though. During the crisis, German IP rises, albeit marginally, then declines and levels off. On the other hand, after the crisis U.S. inflation persistence has been remarkably low. The difference between the patterns in the U.S. and German IP likely stems from the fact that post-crisis ECB interest rate cuts were less pronounced than those of the Federal Reserve.

Despite some differences in the effects, the results can be reasonably explained. Bleaney (2000, p. 393) develops a model of inflation persistence under a constraining exchange rate regime and argues that a "more constraining exchange rate regime tends to reduce the variance of inflation persistence across countries, because all countries take on the inflation persistence of the reserve currency in proportion to the degree of exchange rate constraint." However, inflation persistence is not necessarily lower in a more constraining arrangement. According to his model, the coincidence of low inflation persistence under a more constraining regime would emerge "if the exchange rate regime constrains the reserve currency to have low inflation persistence, or if it happened to have low inflation persistence by chance." The above arguments imply that under a constraining exchange rate regime—linked to a specific reserve currency—lower inflation persistence can be potentially imported under the condition that in the reserve-currency country persistence is low and its dynamics is stable. Pivetta and Reis (2007) provide evidence of high U.S. inflation from the end of World War II to the late 1990s. Beechey and Österholm (2012) argue that U.S. inflation persistence decreased during recent decades (partly thanks to the Federal Reserve accentuating price stability in its monetary policy). This claim resonates well with our evidence on high U.S. persistence before the crisis and particularly low IP afterwards (figure 3). The above theoretical arguments along with the empirical evidence help to explain that a constraining exchange arrangement with the U.S. dollar as a reserve currency might suppress inflation persistence somewhat less than one based on the euro (deutsche mark).

The above findings and interpretation are further complemented by testing the exchange rate channel of IP. We proceed by including the IP of Germany and the United States separately in the regression ((13a); not shown formally) and at the same time we remove the IP of each country from a panel of dependent variables. Statistically significant results are limited to the SUM measure and positive coefficients amount to 0.4 for U.S. IP and 2.6 for German IP (details not reported, available upon request). These marginal effects from

Figure 4. Aggregated FLS-Smoothed SUM Persistence Estimates by Exchange Rate Regime



Notes: The solid lines show the mean of IP (and bands of two standard errors) in countries that did not have any exchange rate arrangement at a given time. The dashed lines on the left show the same for countries that exercised a USD regime at given time; the dashed lines on the right show the same with EUR (and DEM earlier). Because ER^{USD} and ER^{EUR} are not mutually exclusive dummies by our definition, the three groups do have intersections.

the IP of the reserve country mean that an increase in U.S. inflation persistence is associated with a disproportionally lower increase of IP in a country using the U.S. dollar as a reserve currency. On the other hand, an increase in German inflation persistence is associated with a disproportionally larger increase of IP in country using the euro deutsche mark) as a reserve currency. We have to note that including the persistence of reserve countries in equation (13a) did not change the statistical significance of the key coefficients. Hence, our original inference remains the same. The strong positive coefficients associated with IP of the United States and Germany also show that there is a common factor in the persistence series of individual countries (see footnote 16).

We complement our regression results with a graphical presentation in figure 4, where we show the persistence dynamics in countries with and without constraining exchange regimes. Figure 4 is divided into two panels. The *solid lines* show the mean and two-standard-error bands of inflation persistence in countries that did not have any exchange rate arrangement at a given time. As the FLS estimator is distribution free, the error bands are calculated using the distribution of the by-country FLS point-estimate sequences. The *dashed* *lines* in both left and right panels show the same information for countries that exercised dollar-based or euro-based/deutsche-mark-based arrangements at a given time. The persistence in countries using a dollar-based regime was decreasing until 2002 and increased afterwards, reaching the highest value during the 2008 crisis (figure 4, left panel). Increasing persistence before the world financial crisis signals worsening monetary conditions in countries with tight exchange arrangements potentially transferred via the USD. A temporal drop in persistence after 2008 was quickly replaced by an increase of persistence to a new level, slightly higher than prior to the crisis. Inflation persistence in countries with floating exchange rates was mostly somewhat lower than that of those with dollar-based regimes and exhibits a more stable decreasing pattern. Persistence in countries using the euro (deutsche mark) as a reserve currency experienced a continuous decrease until 2000 and, after stabilization, began to marginally rise during the 2005–08 period (figure 4, right panel). After the financial crisis, inflation persistence began to decrease. In general, IP was also slightly lower and exhibited a more stable pattern than persistence in floating countries. The dynamics of persistence in both panels indirectly supports our quantitative results presented in table 2 about the contribution a constraining exchange rate regime makes in pacifying inflation persistence.

6.3 Inflation Targeting and Inflation Persistence

Coefficients α_3 and $\alpha_{4\mathrm{a}}$ exhibit the marginal effects of two forms of IT on inflation persistence. The negative values of the coefficients in tables 1 and 2 represent consistent outcomes, indicating a decrease in inflation persistence. The coefficients (table 1; SUM) associated with explicit IT ($\alpha_{4\mathrm{a}}$) are almost two times as large as the coefficients of implicit IT (α_3). This is quite a strong result, as our sample contains sixty-eight countries, out of which forty-two have practiced some type of IT during the time span. First, it shows that inflation targeting contributes to lower inflation persistence. Second, it shows that even its less strict version (IIT) possesses the power to tame persistence.

The results based on the LAR persistence measure also show a contributing effect to lower inflation persistence (table 1), but the estimate for the EIT is statistically insignificant. The values of the coefficients associated with the HLF measure indicate that implicit IT is more contributive than explicit IT (table 1). This finding might stem from differences in the construction of the persistence measures. Recall that the HLF measure represents the number of periods after which the absolute value of the impulse response is indefinitely below 0.5. Since inflation is usually higher under implicit IT than under explicit IT, it is more likely that the impulse response of the individual IP will be above the 0.5 threshold longer under implicit IT. In this sense, implicit IT provides more room for potential improvement of the HLF measure as the coefficient values attest.

Further, the results based on RJT measures (table 2) also show that the effect of implicit IT on inflation persistence seems to be larger than that of explicit IT. However, the coefficients show that the effect of explicit IT is rather stable but that of implicit IT diminishes with the time over which the specific RJT measure is computed. Thus, after all, results from the SUM measure (table 1) and those based on the HLF (table 1) and RJT measures (table 2) provide a qualitatively similar inference.

Our results also contribute to the debate on how the zero lower bound (ZLB) has affected inflation persistence due to the constraint it imposes on conventional monetary policy (Buiter 2009; Swanson and Williams 2014). The coefficients of the ZLB dummy (α_5) are relatively small, negative, and statistically significant when measured by the LAR (table 1) and RJT (table 2) measures; they are also negative but statistically insignificant in the case of the SUM and HLF measures (table 1). The negative marginal effect of the ZLB means that, ceteris paribus, once a country hits the ZLB its inflation persistence mildly decreases. This result should not be taken as advice to lower the interest rate to achieve lower IP, though. Under the ZLB, inflation is low anyway. Plus, the limited fraction of our research time span, during which some countries entered the ZLB, suggests that we take the ZLB effect with a grain of salt.

Further, we show how deviations of the inflation rate from the central bank's explicit inflation target affect inflation persistence. The results are limited to the SUM measure (table 1) delivering a statistically significant coefficient (α_{4b}) associated with the deviation-from-the-target variable ($IT_{ct}^{EXP} \cdot Abs(Inflation - Target)_{ct}$); other measures produce statistically insignificant coefficients. A negative coefficient ($\alpha_{4\text{b}}$) means that, ceteris paribus, there exists a pull to return to the inflation persistence mean as a central bank moves from its inflation target. However, the extent of this impact should not be overstated: when inflation is 1 percent from its target, the average marginal effect of the pull causes lower persistence of about 0.1 percent.[17]

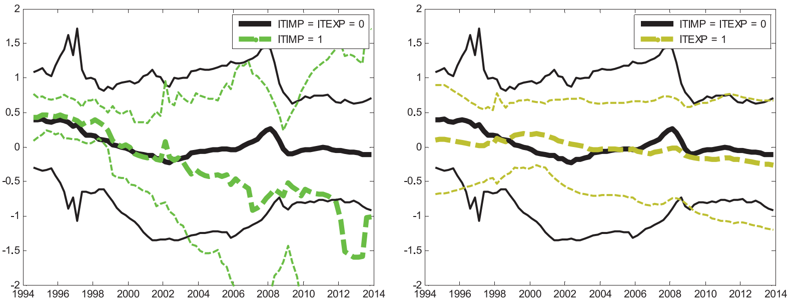
Finally, in figure 5 we bring forth a graphical presentation of the persistence dynamics. The *solid lines* show the mean and two-standard-error bands of inflation persistence in countries that did not practice any form of IT. The *dashed lines* in the left panel show the same information for countries that implicitly (and only implicitly) exercised inflation targeting at any given time. The *dashed lines* in the right panel show the inflation persistence in countries with explicit inflation targeting. Inflation persistence in countries practicing any form of IT shows a very stable pattern of gradual decline that is not interrupted even by the 2008 financial crisis. The key difference between the two panels is the dramatically larger decrease in persistence for countries with implicit IT. After 2002, the paths of the persistence of implicitly IT and non-IT countries even diverge. During most of the period under research, the persistence in explicitly

[17]As a complementary check we performed a formal test for the statistical significance of the difference between explicit and implicit inflation targeters. For all IP measures, the effects of the EIT and IIT were found to be statistically different at the 1 percent significance level (not reported but available upon request).

Further, since the ECB is not expected to stabilize inflation at close to 2 percent for the individual member states but for the euro area as a whole, we performed a robustness check. We ran our panel regressions again under an alternative classification of the euro-area member states: floating exchange rates but without an inflation-targeting regime. In terms of the signs and statistical significance of the coefficients, the results did not materially change (not reported but available upon request). The single notable change was a statistical significance gain (under the alternative classification) of the coefficient capturing absolute deviations of the inflation rate from the central bank's explicit inflation target ($\alpha_{4\mathrm{b}}$) when using the RJT measure (lag 1 and 4). Hence, the results reported in tables 1 and 2 are robust with respect to the alternative classification of the euro-area member states.

Finally, one has to note that the number of countries practicing any form of IT has been growing. Consequently, from our IP estimates we witness a mostly decreasing pattern of IP over time (figure 5). These two phenomena might produce an inverse relationship. In order to rule out the possibility of such a spurious link, we repeated the estimation with the difference of IP as our explanatory variable in (13). This robustness check produced negative and statistically significant coefficients (α_3 and α_4; not reported, available upon request) and confirmed the contributive effect of IT on inflation persistence.

Figure 5. Aggregated FLS-Smoothed SUM Persistence Estimates by Inflation Targeting



Notes: The solid lines show the mean of IP (and bands of two standard errors) in countries that did not have inflation targeting at a given time. The dashed lines on the left show the same for countries that implicitly (and only implicitly) exercised inflation targeting at a given time; the dashed lines on the right show the same with explicit inflation targeting. Because IT^{IMP} and IT^{EXP} are mutually exclusive dummies by our definition, the three groups are disjunctive and their union gives all the countries at every time point.

targeting countries is low and stable, and exhibits a mild decreasing pattern that is interrupted only by temporary and marginal increases around 2000 and in 2008. Further, confidence bands around the persistence of the explicit-IT countries are visibly narrower that those related to the persistence of non-IT countries. The IP pattern in countries without IT is quite different. A gradual decline during the 1990s is replaced in 2002 by an upward trend and IP sharply rises prior to and during the 2008 financial crisis. A post-crisis drop is then replaced by an increase in IP to a new level that is higher than the low IP in 2002. In general, persistence dynamics is in line with our quantitative results and supports the favorable effect of IT with respect to inflation persistence, even during the financial crisis.

7. Conclusions

We provide a comprehensive analysis of the link between price-stability-oriented monetary strategies and inflation persistence. We analyze the dynamics of inflation persistence in a panel of sixty-eight countries by employing quarterly inflation rates for the period from

1993:Q1 to 2013:Q4. The panel data set contains both developed countries and emerging markets. This exceptionally wide coverage enables us to provide a truly "big picture" of the analyzed phenomenon. In our analysis we first use the time-varying coefficients approach to derive four different measures of inflation persistence for each individual country. The time-varying persistence approach helps us to account for structural breaks in persistence that in fact exist in a majority of the countries in our sample. In the second stage, we estimate links between inflation persistence and two policy strategies that possess potential to affect inflation persistence. The strategies are inflation targeting and a constraining exchange rate arrangement. We distinguish between implicit and explicit inflation-targeting strategies of central banks, and also identify constraining exchange rate arrangements with respect to the U.S. dollar and euro (or deutsche mark).

Based on our results, we show a contributing effect of inflation targeting with respect to inflation persistence. The effect of explicit IT is stronger than that of implicit targeting. However, even the less strict version (IIT) possesses the power to tame persistence. The link between inflation persistence and constraining exchange rate regimes is, in general, less pronounced than that of IT and the effect is statistically significant across all IP measures. Our results also contribute to the debate on how the zero lower bound has affected inflation persistence due to the constraint that it imposes on conventional monetary policy. We show that once a country hits the ZLB, its inflation persistence mildly decreases. Finally, we assess how deviations of the inflation rate from the central bank's explicit inflation target impact inflation persistence. We show that there exists a mild pull to return to the inflation persistence mean once a central bank moves away from its inflation target.

Further, regimes with the U.S. dollar as a reserve currency seem to be less effective in taming inflation persistence than those using the euro (deutsche mark). On the other hand, U.S. inflation persistence exhibits a disproportionally lower effect on other countries' persistence than its German counterpart. Our evidence shows that the effect of the exchange rate regime on inflation persistence depends on the reserve currency and correlates with the characteristics of inflation persistence in the country of the reserve currency.

Our findings show that price-stability-oriented policy strategies seem to possess the ability to help reduce inflation persistence. In this respect, both monetary strategies provide central banks with an enlarged "policy space" to deal with temporary price shocks, albeit to different extents. This result is in line with the argument voiced by Siklos (2017, p. 42) that "low and stable inflation continues to represent an essential ingredient of good practice in monetary policy." We conclude that IT seems to be an effective monetary strategy, as inflation persistence in countries practicing any form of IT exhibits a stable pattern of gradual decline, which is not interrupted even by the 2008 financial crisis.

Appendix

Table 3. Timings of Inflation Targeting, Exchange Rate, and Zero Lower Bound Regimes

No.	Country	IIT Start	EIT Start	IT Value	ZLB Start (End)	ER Intervals	ER Types
1	Argentina					1964–1971	USD
						1985–1986	USD
						1991:Q2–2002:Q3	USD
2	Australia	Jan. 1990	Apr. 1993	2.50±0.50		1972–1987	USD
3	Austria		Jan. 1999	1.75±0.25	May 2013	1954–1959	USD
						1960–1998	DEM
4	Bangladesh	Jul. 2013				(1972)–1982	GBP
						1983–2002	USD
5	Belgium		Jan. 1999	1.75±0.25	May 2013	1954–1955	USD
						1956–1998	DEM
6	Brazil		Jun. 1999	4.50±2.00		(1945)–1950	USD
						1967–1998	USD
7	Bulgaria				Jan. 2010	(1945)–1989	USD
						1997–	DEM/EUR
8	Canada		Mar. 1991	2.00±1.00	Mar. 2009	(1945)–1950	USD
					(Jul. 2010)	1963–1969	USD
9	Chile	Sep. 1990	Sep. 1999	4.00±0.00		1960–1962	USD
			Jan. 2001	3.00±1.00		1973:Q2–1999:Q3	USD
						1982–1983	DEM
10	China	Jan. 2003				1994–	USD
11	Colombia	Jan. 1991	Sep. 1999	3.00±1.00		(1945)–1983	USD
						1985–1998	USD
12	Czech Republic		Dec. 1997	2.00±1.00	Jul. 2012	(1991)–1997:Q2	USD
						(1991)–1997:Q2	DEM

(*continued*)

Table 3. (Continued)

No.	Country	IIT Start	EIT Start	IT Value	ZLB Start (End)	ER Intervals	ER Types
13	Denmark				Jun. 2012	(1945)–1951	USD
						1952–	DEM/EUR
14	Egypt					(1945)–1950	GBP
						1963–2002	USD
15	Estonia		Jan. 2011	1.75±0.25	May 2013	1992–2010	DEM/EUR
16	Finland		Feb. 1993	2.00±0.00	May 2013	1949–1972	USD
			Jan. 1999	1.75±0.00		1973–1998	DEM
17	France		Jan. 1999	1.75±0.25	May 2013	1949–1971	USD
						1972–1998	DEM
18	Germany	Jan. 1975	Jan. 1999	1.75±0.25	May 2013	(1945)–1970	USD
						1971	(DEM)
						1972	USD
						1973–1998	(DEM)
19	Greece		Jan. 2001	1.75±0.25	May 2013	1950–1981	USD
						1985–2000	DEM/EUR
20	Hong Kong				Dec. 2008	(1945)–1972	USD
						1983:Q4–	USD
21	Hungary		Jun. 2001	3.00±0.00		(1946:Q3)–2001:Q1	DEM/EUR
22	Iceland		Mar. 2001	2.50±0.00		1947–1977	USD
						1984–2000	DEM/EUR
23	India					(1945)–1969	GBP
						1970	USD
						1971–1978	GBP
						1980–2007	USD

(*continued*)

Table 3. (Continued)

No.	Country	IIT Start	EIT Start	IT Value	ZLB Start (End)	ER Intervals	ER Types
24	Indonesia	May 1999	Jul. 2005	5.00±1.00		(1945)–1949	GBP
						1969–1997	USD
25	Iran					1954–1976	USD
26	Ireland		Jan. 1999	1.75±0.25	May 2013	1980–1998	DEM
27	Israel	Jun. 1992	Jun. 1997	8.50±1.50		(1948)–1950	GBP
			Jan. 1999	4.00±0.00		1962–1970	GBP
			Jan. 2000	3.50±0.50		1971–1975	USD
			Jan. 2001	3.00±0.50		1980–1998	GBP
			Jan. 2002	2.50±0.50		1986–1998	USD
			Jan. 2003	2.00±1.00			
28	Italy		Jan. 1999	1.75±0.25	May 2013	1952–1975	USD
						1979:Q2–1998	DEM
29	Japan	Jan. 2010	Feb. 2012	1.00±1.00	Oct. 1995	1949–1977	USD
			Jan. 2013	2.00±0.00			
30	Jordan					(1945)–1971	GBP
						1972–	USD
						1975–1988	SDR
31	Korea (South)	Apr. 1998	Jan. 2000	2.50±1.00		(1945)–1997	USD
			Jan. 2001	3.00±1.00			
			Jan. 2004	3.00±0.50			
			Jan. 2010	3.00±1.00			
			Jan. 2013	3.00±0.50			
			Jan. 2016	2.00±0.00			

(continued)

Table 3. (Continued)

No.	Country	IIT Start	EIT Start	IT Value	ZLB Start (End)	ER Intervals	ER Types
32	Kuwait					(1959)–1961	DEM
						1969–	USD
						1975:Q2–2002	DEM/EUR
						2007:Q3–	EUR
33	Latvia					1995–2013	DEM/EUR
34	Lithuania					1995–2001	USD
						2002–2014	EUR
35	Luxembourg		Jan. 1999	1.75±0.25	May 2013	(1945)–1955	USD
						1956–1998	DEM
36	Malaysia					1946–1975	GBP
						1976–1997	USD
						1999–2005	USD
37	Mauritius					(1945)–1975	DEM
						1972:Q3	USD
						1976–1994:Q2	USD
38	Mexico	Jan. 1996	Jan. 2001	3.00±1.00		(1945)–1976:Q3	USD
						1982:Q3–1994	USD
39	Morocco					(1945)–	DEM
40	Netherlands		Jan. 1999	1.75±0.25	May 2013	1951–1970	USD
						1971–1998	DEM
41	New Zealand		Mar. 1990	2.00±1.00		(1945)–1971	GBP
						1972–1982	USD Peg via AUD

(*continued*)

Table 3. (Continued)

No.	Country	IIT Start	EIT Start	IT Value	ZLB Start (End)	ER Intervals	ER Types
42	Nigeria					(1945)–1971	DEM
						1983:Q3–1984:Q2	USD
						1991:Q3–1998	USD
43	Norway	Feb. 1999	Mar. 2001	2.50±0.00		(1945)–1972	USD
						1973–1992	DEM
44	Pakistan					(1945)–1971	GBP
						1972–2007	USD
45	Peru		Jan. 2002	2.00±1.00		(1945)–1971	USD
						1994–2007	USD
46	Philippines	Jul. 1993	Jan. 2002	4.00±1.00		1952–1956	USD
						1962–1968	USD
						1973–1982	USD
						1986–1990	USD
47	Poland	Aug. 1997	Oct. 1998	2.50±1.00		1990–2000	USD
						1991–2000	DEM/EUR
48	Portugal		Jan. 1999	1.75±0.25	May 2013	(1945)–1972	USD
						1973–1998	DEM
49	Romania	Jan. 2002	Aug. 2005	3.00±1.00		1990–2002	USD
						1990–1993	DEM
						2009–	EUR
50	Russia	Jan. 2001				1995–1998	USD
						2005–2008	USD
						2005–2008	DEM/EUR

(continued)

Table 3. (Continued)

No.	Country	IIT Start	EIT Start	IT Value	ZLB Start (End)	ER Intervals	ER Types
51	Saudi Arabia					(1945)–1958	DEM
						1959–	USD
52	Singapore				Jan. 2009	(1945)–1971	DEM
						1972–1998	USD
53	Slovak Republic		Jan. 2009	1.75±0.25	May 2013	(1991)–1997	USD
						(1991)–1997	DEM
						1999–2008	EUR
54	Slovenia	Nov. 2003	Jan. 2007	1.75±0.25	May 2013	1993–2006	DEM/EUR
55	South Africa	Jan. 1990	Feb. 2000	4.50±1.50		(1945)–1973	DEM
56	Spain	Jan. 1995	Jan. 1999	1.75±0.25	May 2013	(1945)–1946	USD
						1949–1980	USD
						1981–1998	DEM
57	Sri Lanka					(1945)–1967	DEM
						1972–2011	USD
58	Sudan					1958–1978	USD
						(1990)–	USD
59	Sweden		Jan. 1993	2.00±1.00	Apr. 2009	1946–1972	USD
					(Aug. 2010)	1973–1992	DEM
60	Switzerland	Jan. 1975	Jan. 2000	1.00±1.00	Dec. 2008	(1945)–1973	USD
						1982–	DEM/EUR
61	Taiwan					—	—
62	Thailand		May 2000	1.75±1.75		(1945)–1947	DEM
			Sep. 2009	1.75±1.25		1948–1997	USD
			Jan. 2015	2.50±1.50			

(*continued*)

Table 3. (Continued)

No.	Country	IIT Start	EIT Start	IT Value	ZLB Start (End)	ER Intervals	ER Types
63	Tunisia					(1945)–	DEM
64	Turkey	Jan. 2002	Jan. 2006	5.50±0.00		1946–1953	USD
						1961–1980	USD
						1998–2000	DEM/EUR
65	Ukraine					1997–2006	USD
66	United Kingdom		Oct. 1993	2.00±0.00	Mar. 2009	(1945)–1971	USD
						1991–1992	DEM
67	United States	1992	Jan. 2012	2.00±0.00	Jan. 2009	(1945)–	(USD)
68	Venezuela					(1945)–1982	USD
						1994–	USD

Notes: Implicit (IIT) and explicit (EIT) inflation targeting and zero lower bound (ZLB) regimes have mostly starting dates (no IT regime has ended yet, and only two ZLB regimes have ended within our sample time span). We report these with monthly precision. Annual inflation target values or bands are always converted to a midpoint plus/minus a half range (zero in case of exact target rate), and are reported in percentage points; the conversion was done for convenience of estimation irrespective of whether a central bank has a specific rate or band as a target. For the euro zone we use values of 1.75±0.25; this solution reflects a slightly vague commitment of the European Central Bank (ECB) to keep the annual inflation rate close to or below 2 percent (different target value options reflecting the commitment do not yield materially different results). For some IT values (EIT and ZLB starting dates) a shaded background marks that the specific country adopted a given regime because of its euro-area membership. The exchange rate regime (ER) intervals are reported with quarterly precision. The Q1 notations at starting dates and Q4 notations at ending dates are omitted. The starting dates in parentheses indicate the approximate starting point of a given ER regime, but this does not affect our analysis, as our data sample starts later on. In case of a variant of currency basket pegs, the exchange rate regime involves a peg to more than one currency during the specific period.

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