Macroeconomic Dynamics, **18**, 2014, 1313–1325. Printed in the United States of America.
doi:10.1017/S1365100512000971

DID THE INTRODUCTION OF THE EURO HAVE AN IMPACT ON INFLATION UNCERTAINTY?—AN EMPIRICAL ASSESSMENT

MATTHIAS HARTMANN
Ruprecht-Karls-University Heidelberg

HELMUT HERWARTZ
Georg-August-University Goettingen

We compare inflation uncertainty in distinguished groups of economies. Results indicate that during the recent financial crisis the global inflation climate has become markedly more uncertain than previously. We document that in comparison to other economies, member states of the European Monetary Union are less exposed to inflation uncertainty. Three European Union members that are not part of the monetary union and five other OECD member economies serve as control groups. With regard to the quantification of inflation uncertainty, results are robust over a set of alternative estimates of the latent inflation risk processes.

Keywords: Monetary Policy Regimes, Euro Introduction, Inflation Uncertainty, Uncertainty Measurement

1. INTRODUCTION

In addition to the costs of excess inflation, uncertainty about inflation is commonly believed to have several negative effects on economic activity ([(1993), Vitek (2002), inter alia]. Examples of the disadvantages of inflation uncertainty (IU) are shifts in wealth allocation among creditors and debtors [Fama (1976), Barnea et al. (1979), Grauer and Litzenberger (1980)] or reduced output growth [Friedman (1977)]. Higher inflation risk premia on long-term bonds may lead to welfare losses especially in countries with high government debt [Blanchard (2004)]. Moreover, excess IU likely increases renegotiation frequencies for wage contracts, because

We appreciate helpful suggestions from the participants in the research seminar at the Directorate-General for Economic and Financial Affairs of the European Commission, Brussels, the Econometrics Workshop at the European University Institute, Florence, the 5th Nordic Econometric Meeting, Lund, and the DIW Macroeconometric Workshop, Berlin. We are particularly grateful to Andrew Bernard, Kai Carstensen, Helmut Lütkepohl, Werner Roeger, and an anonymous referee for helpful comments. Financial support by Deutsche Forschungsgemeinschaft (He 2188/3-1) is also gratefully acknowledged. Address correspondence to: Matthias Hartmann, Alfred-Weber-Institute for Economics, Ruprecht-Karls-University Heidelberg, Bergheimer Straße 58, D-69115 Heidelberg, Germany: e-mail: matthias.hartmann@awi.uni-heidelberg.de.

 1365-1005/13

such agreements are typically not indexed to inflation rates [Vroman (1989)]. Fischer and Modigliani (1978) discuss how IU reduces aggregate investment because of increasing demand for inflation hedges like real estate or gold. It is the aim of this study to investigate whether being part of the European Monetary Union (EMU) reduces inflation risks among its member states. To this end, IU in the monetary union is compared with inflation risk in economies that do not take part in the EMU. We investigate the level of IU in episodes before and initially after the Euro introduction and during the recent recession. The selection of control groups serves as a means to approximate a counterfactual situation where no common monetary policy is in effect. The systemic background can be seen both as an independent determinant of IU and as a channel that transmits, for example, the effects of output fluctuations. This is reflected in theoretical discussions on the emergence of IU. For example, Devereux (1989) and Ball (1992) regard IU as uncertainty among individuals about the future steps taken by the central bank. An ongoing debate centers on the question of which institutional background may provide viable insurance against upcoming inflation risks. In particular, it is controversial whether the formation of a monetary union is a sensible way to protect its member states from excess IU. Mundell (1961), Cukierman (2000), and Alesina et al. (2003) investigate such issues when characterizing optimal currency areas. They argue that countries participating in monetary unions may benefit from higher credibility of a central bank's aim to stabilize inflation or from the nonsynchronous timing of elections in the participating states.

It is also possible that the formation of a monetary union increases overall IU. Feldstein (2005) points out that the formation of a monetary union may give rise to a free-rider problem if member countries retain their fiscal authority. Large budget deficits in particular member states may put the central bank under pressure to allow higher inflation rates. As argued by Davig et al. (2011), inflation risks arise in such situations, as it is unclear to which extent these pressures can be repelled. A further potential trigger of IU is persistent inflation differentials among member states. Divergent inflation rates cannot be accommodated by a central bank that is in charge for the entire monetary union [Arnold and Lemmen (2008)].

In an empirical study, Caporale and Kontonikas (2009) compare the effects of currency union participation on IU among several EMU member states. In our study, however, IU in the union is not only evaluated over time periods before and after the monetary unification but also compared with that in non-EMU economies. Moreover, to offer a robust assessment of the monetary unification effect on IU, we consider three alternative IU measures. In this way we acknowledge that there exist complementary model perspectives on IU.

In general, IU may refer to either current or future states of inflation. Fama (1976) approximates IU by means of the standard deviation of inflation rates over past time instances. Ball and Cecchetti (1990) argue that it is rather the volatility of inflation surprises that is associated with IU. This view is also reflected in many empirical investigations. Moreover, forecasting-based IU measures are likely most relevant from a practitioner's perspective. For example, policymakers or investors have to make decisions based on their perceived risks of loss from future inflation. For this reason, we propose three measures, two of which quantify IU from the viewpoint of forecasting inflation at distinguished anticipation horizons covering short to medium time spans. To preview some of the results, it is first documented that IU has been on the uprise across industrialized economies during the recent decade. Second, we find that after the introduction of the euro, EMU members are characterized by a significantly lower IU than other economies. These results are robust across IU measures and the horizon of anticipation.

The remainder of the paper begins with a description of the employed data series. Section 3 initially introduces three approaches to determining IU. Subsequently, the regression design to investigate the constitutional impact on IU is described. In Section 4, we first examine a graphical impression of IU quantifications for distinct groups of economies. Second, the impact of the Euro on IU is isolated and discussed. Section 5 summarizes the main findings and concludes.

2. DATA

The data set comprises monthly observations for the period from 1977M1 to 2012M1 and 18 economies, namely Austria, Belgium, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom, and the United States. Collected time series include the consumer price index (CPI), industrial production as a measure of output, foreign exchange (FX) rates, the Dow Jones Industrials Average Index (Dow), and price quotes of crude Brent oil (Oil) in terms of domestic currencies. FX rates are determined with respect to the U.S. dollar for all economies except the United States, for which the price of the euro in U.S. dollars is used. We focus on the CPI because broader indices such as the GDP deflator, or the Harmonised Index of Consumer Prices as the primary target variable of the ECB, are not available at the monthly frequency in most countries. Inflation is defined as the annual rate $\pi_t = \Delta_{12} \ln(P_t) = \ln(P_t) - \ln(P_{t-12})$, where P_t is the CPI in month t. Annual differences yield a rather smooth series, which can be approximated in subsequent analysis by relatively parsimonious dynamic models. An alternative definition such as annualized monthly inflation $\pi_t = 12 \times \Delta \ln(P_t)$ may feature more complicated dependence patterns and thus command model specifications with a less intuitive economic interpretation. Moreover, price fluctuations with a periodicity of about one month or less[1] may be only weakly related to business cycle dynamics with period lengths of about 2 to 6 years, say [Canova (1998)]. Hence, measuring inflation in terms of annual rates appears to be a sensible way to separate noisy fluctuations from economically meaningful innovations. Estimates of the output gap, $\tilde{y}_t$, are calculated by means of the Hodrick–Prescott (HP) filter [Hodrick and Prescott (1997)] with smoothing parameter 129,600 [Ravn and Uhlig (2002)]. To obtain out-of-sample inflation forecasts in the most realistic way, trend estimates are computed at each prediction step conditional on available data that are used to form the current prediction. Preliminary predictions of y_t are obtained to alleviate the weak precision of HP trend estimates at the end of an estimation window. All series are obtained from Datastream. The CPI and industrial production series are seasonally adjusted by means of the Census X12 method.

3. THE MEASUREMENT AND DETERMINANTS OF INFLATION UNCERTAINTY

There is no consensus on how to define or measure the unobservable IU. Empirical approaches of IU measurement may draw upon a model for the conditional mean of inflation, such as the widely cited new Keynesian Phillips curve [NKPC; Galí et al. (2005)]. However, the dynamics of inflation rates is presumably affected by recurring structural changes [Evans and Wachtel (1993)]. Hence, it seems recommendable to focus on the most recent data if one aims at the formulation of anticipatory policy recommendations. As a result, nonlinear specifications such as the NKPC are less likely to provide efficient inflation forecasts.[2] Therefore, we employ an autoregressive (AR) scheme as a parsimonious first-order approximation to nonlinear specifications such as the forecasting representation of the NKPC. It should be noted that IU approximations based on inflation forecasts are likely affected by the specific setup (and potential misspecification) of the model for the conditional mean. However, for the purpose of policy-oriented IU anticipation, forecast accuracy may be a more informative model-evaluation criterion than in-sample fit. The NKPC and alternative linear specifications are often found to deliver less accurate inflation forecasts than AR schemes. The distinctive performance of the AR is particularly apparent for low to intermediate anticipation horizons of up to one year, say Canova (2007), Stock and Watson (2008), or Rumler and Valderrama (2010).[3] Hence, two uncertainty measures are based on an AR specification, which is formulated as

$$\pi_{t+\ell} = \mu + \alpha_1 \pi_t + \cdots + \alpha_P \pi_{t-P} + \epsilon_{t+\ell}, \tag{1}$$

where $\epsilon_{t+\ell} \overset{\text{iid}}{\sim} (0, \sigma_\epsilon^2)$ and μ denotes a constant term. Owing to linearity of (1), the determination of ex ante forecasts, denoted as $\hat{\pi}_{\tau+\ell|\tau}$, by means of parameter estimates and time series information available in time τ is straightforward. In the following, we provide more details on how inflation forecasts are obtained. A discussion of distinct IU measures follows.

3.1. Implementation

Estimation of the model in (1) is conducted within rolling sample windows of fixed size $A = 96$ for all forecast horizons ℓ such that the time index t in (1) takes values $t = \tau - A + 1, \ldots, \tau$. Let T indicate the most recent observation (2012M1).

We determine out-of-sample predictions $\hat{\pi}_{\tau+\ell|\tau}$ for the rolling forecast origin(s) $\tau = \tau_0 - \ell, \tau_0 - \ell + 1, \ldots, T - \ell$. Counterfeiting a real-time forecasting situation, we obtain a total of $T - \tau_0 + 1 = 277$ forecasts for the ex ante determination of IU. From the set of potential covariates, effective predictors are selected by means of a *specific-to-general* predictor selection proposed in Herwartz (2009). An admittedly highly restrictive baseline model is successively augmented by additional autoregressive terms. The model is extended until LM tests indicate that no further lag term carries explanatory content with 5% significance [Godfrey (1988)].

3.2. Ex ante and ex post Measures of Inflation Uncertainty

Conclusions regarding the impact of the monetary policy framework on IU might be affected by the IU quantification employed. Three distinct measures of IU are considered in this work and briefly described in turn. First, according to (1), the estimated forecast error standard deviation is

$$\hat{\sigma}_{\tau+\ell|\tau} = \sqrt{\hat{\sigma}_{\epsilon}^2(1 + \mathbf{x}'_{\tau,\ell}(X'_\tau X_\tau)^{-1}\mathbf{x}_{\tau,\ell})}, \quad \tau = \tau_0 - \ell, \ldots, T - \ell. \qquad \textbf{(2)}$$

In (2), $\hat{\sigma}_{\epsilon}^2$ is the usual in-sample error variance estimator, X_τ is a rolling (subset) autoregression design matrix, and $\mathbf{x}_{\tau,\ell}$ collects a constant and the AR lags selected to have predictive content. Second, an estimate of local IU in the spirit of RiskMetrics [Zangari (1996)] is

$$\hat{h}_{\tau+1|\tau} = \sqrt{\lambda(\Delta\pi_\tau)^2 + (1-\lambda)\overline{(\Delta\pi)^2}}, \qquad \textbf{(3)}$$

where $\overline{(\Delta\pi)^2} = (1/(B-1))\sum_{t=\tau-B+1}^{\tau-1}(\Delta\pi_t)^2$ and $B = 24$. In (3), the parameter λ determines the degree of news response.[4] The estimator $\hat{h}_{\tau+1|\tau}$ is regarded as an ex ante alternative to (G)ARCH type evaluations [Engle (1982), Bollerslev (1986), Baillie et al. (1996)]. Note that although the approximation of IU by means of GARCH models in small rolling windows is most likely infeasible, full sample model estimates would leave the framework of ex ante IU determination. Finally, complementing the ex ante quantities $\hat{h}_{\tau+1|\tau}$ and $\hat{\sigma}_{\tau+\ell|\tau}$, a realized measure of IU is the absolute forecast error

$$\hat{a}_{\tau+\ell} = |\hat{\pi}_{\tau+\ell|\tau} - \pi_{\tau+\ell}|. \qquad \textbf{(4)}$$

It is worthwhile to point out that the quantities $\hat{\sigma}_{\tau+\ell|\tau}$ and $\hat{h}_{\tau+1|\tau}$, on one hand, and $\hat{a}_{\tau+\ell}$, on the other, assess IU conditional on distinct information sets. The former may describe the (public's) perception of future inflation risks, whereas the latter quantifies IU from an ex post perspective.

3.3. Inflation Uncertainty and the Euro Introduction

Apart from institutional conditions such as participation in a monetary union, the dynamics in financial, FX, or energy markets is also likely to have an impact on IU. Kontonikas et al. (2005) argue that stock returns, being streams of nominal income, should reflect uncertainty about inflation. Gosh et al. (1995) and Gagnon and Ihrig (2001) find that the dynamics of FX rates affects both the level and the volatility of inflation. Evans and Wachtel (1993) and Barsky and Kilian (2002) describe relations between oil price shocks and inflation, IU, and real economic activity. To incorporate measures of such aggregate financial and commodity risks, we consider realized standard deviations [Schwert (1989), Andersen et al. (2004)] as explanatory variables in our analysis. Such quantities are determined as

$$\mathrm{RS}_t(u) = \sqrt{\sum_{m\in t}(\Delta \ln u_m)^2}, \tag{5}$$

where an observation at day m is denoted as u_m and u represents daily quotes of either FX rates or oil or stock prices, i.e., $u \in \{\mathrm{FX}, \mathrm{Oil}, \mathrm{Dow}\}$. Distinct influences on IU are related by means of an analysis of variance (ANOVA) regression, where an extra index, $i = 1, \ldots, 18$, indicates country-specific quantities. The set of explanatory variables is $\mathbf{z}_{i,\tau-1} = (\pi_{i,\tau-1}, \tilde{y}_{i,\tau-1}, \mathrm{RS}_{i,\tau-1}(\mathrm{FX}), \mathrm{RS}_{i,\tau-1}(\mathrm{Oil}), \mathrm{RS}_{\tau-1}(\mathrm{Dow}))'$, where $\tilde{y}_{i,\tau-1}$ denotes the output gap. Three ANOVA regressions are considered, namely

$$s_{i\tau} = \mu + \nu_{i\tau} + \mathbf{z}'_{i,\tau-1}\boldsymbol{\theta} + \epsilon_{i\tau}, \quad \tau = \tau_0 - \ell, \tau_0 - \ell + 1, \ldots, T - \ell,$$

$$\text{with } s_{i\tau} \in \{\hat{\sigma}_{i,\tau+\ell|\tau}, \hat{h}_{i,\tau+1|\tau}\}, \text{ and} \tag{6}$$

$$\hat{a}_{i\tau} = \mu + \nu_{i\tau} + z'_{i,\tau-1}\boldsymbol{\theta} + \epsilon_{i\tau}, \quad \tau = \tau_0, \tau_0 + 1, \ldots, T. \tag{7}$$

In (6) and (7), constitutional determinants of IU are expressed by means of a function of dummy variables,

$$\nu_{i\tau} = \gamma_1 \mathrm{DB}_{i\tau}^{(\mathrm{EMU})} + \gamma_2 \mathrm{DB}_{i\tau}^{(\mathrm{EU3})} + \gamma_3 \mathrm{DA}_{i\tau}^{(\mathrm{EMU})} + \gamma_4 \mathrm{DA}_{i\tau}^{(\mathrm{EU3})} + \gamma_5 \mathrm{DR}_{i\tau}^{(\mathrm{EMU})} + \gamma_6 \mathrm{DR}_{i\tau}^{(\mathrm{EU3})}. \tag{8}$$

Dummy variables in (8) serve as a means to distinguish the level of IU in the referential $O5$ group from economies subjected to monetary unification (EMU) and EU members outside the monetary union (EU3). The association of economies with the latter groups *before* the advent of the euro (AE) is controlled by $\mathrm{DB}_{i\tau}^{(\mathrm{EMU})}$ and $\mathrm{DB}_{i\tau}^{(\mathrm{EU3})}$, respectively, where

$$\mathrm{DB}_{i\tau}^{(\bullet)} = \begin{cases} 1 & \text{if } i \text{ belongs to } \bullet \text{ and } \tau < \mathrm{AE} \\ 0 & \text{otherwise.} \end{cases}$$

The AE date is chosen as 1999M1, when the common currency was introduced in the 11 initial EMU economies. Further, we emphasize the period covering the

https://doi.org/10.1017/S1365100512000971 Published online by Cambridge University Press

advent of the common currency in 1999M1 and ending before the recent financial crisis. Respective dummy variables $\mathrm{DA}_{i\tau}^{(\bullet)}$, $\bullet = \mathrm{EMU}, \mathrm{EU3}$ are defined as follows:

$$\mathrm{DA}_{i\tau}^{(\bullet)} = \begin{cases} 1 & \text{if } i \text{ belongs to } \bullet \text{ and AE} \leq \tau < \text{2007M12} \\ 0 & \text{otherwise.} \end{cases}$$

The large-scale stimulus packages put forth during the recent economic crisis may have increased IU [Feldstein (2005), Davig et al. (2011)]. Hence, we distinguish the relative capability of the EMU and the EU3 to accommodate inflation risks during the NBER recession period from 2007M12 to 2009M6 by means of dummy variables given by

$$\mathrm{DR}_{i\tau}^{(\bullet)} = \begin{cases} 1 & \text{if } i \text{ belongs to } \bullet \text{ and } \tau \in \text{NBER recession period} \\ 0 & \text{otherwise,} \end{cases}$$

where $\bullet = \mathrm{EMU}, \mathrm{EU3}$. As a robustness check, an alternative break date $\mathrm{AE} = 1997\mathrm{M}1$ is used for the determination of $\mathrm{DB}_{i\tau}^{(\bullet)}$ and $\mathrm{DA}_{i\tau}^{(\bullet)}$, because some euro effects might have been anticipated before the official date of monetary unification [Caporale and Kontonikas (2009)].

4. EMPIRICAL EVALUATION OF THE EURO IMPACT ON INFLATION UNCERTAINTY

In this section, we discuss average trajectories of IU for the three considered groups of economies and subsequently interpret the outcomes of the ANOVA regression in (6) and (7).

4.1. Inflation Uncertainty Dynamics in Distinct Groups of Economies

Figure 1 displays time series of alternative IU approximations $\bar{\sigma}_{\tau+\ell|\tau}$, $\bar{h}_{\tau+1|\tau}$, and $\bar{a}_{\tau+\ell}$, denoting the cross-sectional means (for the EMU, EU3, and $O5$) of the IU measures in (2), (3), and (4). The $\bar{\sigma}_{\tau+\ell|\tau}$ quantification allows a more pronounced distinction among the three groups of economies than $\bar{h}_{\tau+1|\tau}$ and $\bar{a}_{\tau+\ell}$. The latter metrics deliver slightly more volatile approximations of IU. However, the overall impression of IU dynamics is broadly similar across IU measures.[5] At the beginning of the sample period, all processes indicate decreasing IU until a minimum level is attained around the year 2000. With the emergence of the global recession around 2007, IU appears to increase rapidly. This uprise coincides with the implementation of monetary and fiscal stimulus packages in many advanced economies.

4.2. Marginal Impacts on Inflation Uncertainty

Before the impact of EMU participation on IU is analyzed, we discuss several potential macroeconomic determinants. Because IU likely depends on the specific

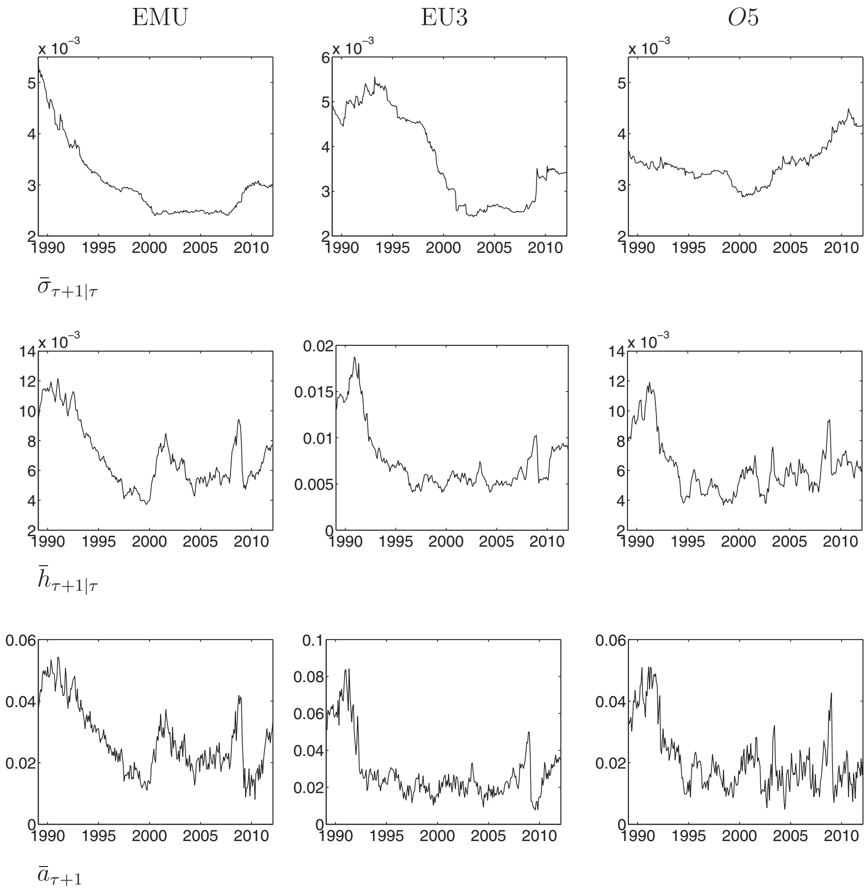

FIGURE 1. Inflation uncertainty as expressed by the specifications (2)–(4) for distinct groups of economies and the forecasting horizon $\ell = 1$. Trajectories of IU for higher anticipation horizons are qualitatively similar and available from the authors upon request.

planning horizon of a decision taker, we particularly emphasize the distinction of the effect of macroeconomic variables on IU for anticipation horizons ℓ from 1 up to 12 months. In the upper panel of Table 1, respective coefficient estimates are reported. The estimates are largely in line with theoretically asserted relations. First, the way IU is related to inflation and the output gap corresponds with the widely cited proposition of Friedman (1977). He argues that accelerating inflation gives rise to IU, whereas IU and output are negatively associated because of distortions in the price mechanism. The empirical validity of the Friedman (1977) conjecture is empirically confirmed by Grier and Perry (2000) and Hartmann and Herwartz (2012), among others. Moreover, the impact of FX rate volatility $\text{RS}_{i,\tau-1}(\text{FX})$ on IU is particularly significant. The impact of oil and stock price volatility is less

TABLE 1. ANOVA regression estimates with t-ratios in parentheses

	$\ell = 1$			$\ell = 3$		$\ell = 6$		$\ell = 12$	
	$\hat{\sigma}_{i,\tau+\ell\vert\tau}$	$\hat{h}_{i,\tau+1\vert\tau}$	$\hat{a}_{i,\tau+\ell}$	$\hat{\sigma}_{i,\tau+\ell\vert\tau}$	$\hat{a}_{i,\tau+\ell}$	$\hat{\sigma}_{i,\tau+\ell\vert\tau}$	$\hat{a}_{i,\tau+\ell}$	$\hat{\sigma}_{i,\tau+\ell\vert\tau}$	$\hat{a}_{i,\tau+\ell}$
ANOVA estimates ($\times 10^{-3}$) based on alternative IU quantifications and distinct anticipation horizons ℓ.									
$\pi_{i,\tau-1}$	**21.12**	**166.34**	**824.80**	**37.97**	**716.59**	**62.65**	**536.43**	**139.84**	**211.10**
	(7.36)	(43.22)	(59.31)	(8.03)	(34.66)	(8.52)	(16.47)	(10.61)	(4.26)
$\tilde{y}_{i,\tau-1}$	−0.00	−0.00	−0.00	−0.00	**−0.01**	−0.00	**−0.01**	0.00	**−0.01**
	(−0.71)	(−1.28)	(−1.47)	(−0.60)	(−2.70)	(−0.36)	(−2.93)	(0.30)	(−2.21)
$\text{RS}_{i,\tau-1}$(FX)	**8.02**	**13.81**	23.39	**15.87**	**84.26**	**15.23**	**125.11**	16.16	88.13
	(3.15)	(3.94)	(1.68)	(3.78)	(4.02)	(2.33)	(3.96)	(1.38)	(1.93)
$\text{RS}_{i,\tau-1}$(Oil)	0.28	1.70	**14.37**	−0.06	**31.76**	0.06	**29.70**	2.08	19.63
	(0.34)	(1.45)	(3.04)	(−0.04)	(4.33)	(0.03)	(2.66)	(0.54)	(1.26)
$\text{RS}_{\tau-1}$(Dow)	−1.72	1.44	**17.88**	−1.94	9.06	−4.25	−31.64	**−12.35**	**−88.88**
	(−1.40)	(0.84)	(2.58)	(−0.96)	(0.83)	(−1.35)	(−1.96)	(−2.18)	(−3.92)
$\text{DB}_i^{(\text{EMU})}$	−0.19	−0.16	**1.69**	−0.27	**2.46**	0.41	**4.28**	**1.50**	**10.11**
	(−1.26)	(−0.78)	(2.40)	(−1.09)	(2.37)	(1.08)	(2.61)	(2.20)	(4.00)
$\text{DB}_i^{(\text{EU3})}$	**0.81**	**0.57**	**2.05**	**1.56**	**3.74**	**3.03**	**6.16**	**3.91**	**14.53**
	(3.80)	(1.99)	(2.02)	(4.43)	(2.50)	(5.51)	(2.60)	(3.98)	(3.98)
$\text{DA}_{i\tau}^{(\text{EMU})}$	**−0.99**	**−1.02**	**−1.56**	**−1.75**	**−2.39**	**−2.17**	−3.38	**−2.67**	**−5.61**
	(−6.20)	(−4.82)	(−2.07)	(−6.64)	(−2.15)	(−5.30)	(−1.93)	(−3.66)	(−2.07)
$\text{DA}_{i\tau}^{(\text{EU3})}$	**−0.66**	**−0.95**	−1.51	**−1.33**	−2.15	**−1.52**	−3.16	−1.36	−5.23
	(−2.73)	(−2.96)	(−1.32)	(−3.34)	(−1.27)	(−2.47)	(−1.19)	(−1.23)	(−1.27)
$\text{DR}_{i\tau}^{(\text{EMU})}$	**−0.69**	−0.15	−0.95	**−1.57**	−0.16	**−3.04**	1.45	**−5.38**	−8.39
	(−2.52)	(−0.40)	(−0.70)	(−3.48)	(−0.08)	(−4.33)	(0.46)	(−4.27)	(−1.75)
$\text{DR}_{i\tau}^{(\text{EU3})}$	**−1.56**	−0.79	−1.38	**−2.98**	−1.08	**−5.24**	1.91	**−7.38**	−12.73
	(−3.17)	(−1.18)	(−0.57)	(−3.66)	(−0.30)	(−4.14)	(0.33)	(−3.25)	(−1.48)
ANOVA estimates with alternative AE date ($\times 10^{-3}$)									
$\text{DA}_{i\tau}^{(\text{EMU})}$	**−0.89**	**−1.05**	**−1.52**	**−1.57**	**−2.11**	**−1.89**	−2.75	**−2.15**	−3.70
	(−5.76)	(−5.31)	(−2.14)	(−6.18)	(−2.01)	(−4.76)	(−1.65)	(−3.03)	(−1.43)
$\text{DA}_{i\tau}^{(\text{EU3})}$	−0.36	**−0.92**	−1.25	**−0.81**	−1.74	−0.48	−2.50	0.48	−3.86
	(−1.61)	(−3.16)	(−1.19)	(−2.16)	(−1.12)	(−0.82)	(−1.02)	(0.46)	(−1.01)
ANOVA estimates ($\times 10^{-3}$) with alternative definition of inflation: $\pi_{it} = 12 \times \ln(P_t/P_{t-1})$									
$\text{DA}_{i\tau}^{(\text{EMU})}$	**−6.85**	**−8.49**	**−5.87**	**−7.14**	**−8.13**	**−7.10**	**−8.76**	**−7.32**	**−7.02**
	(−5.33)	(−4.35)	(−2.40)	(−5.50)	(−3.09)	(−5.32)	(−3.24)	(−4.96)	(−2.34)
$\text{DA}_{i\tau}^{(\text{EU3})}$	**−5.65**	**−8.89**	**−7.28**	**−6.03**	**−9.47**	**−5.82**	**−12.24**	**−6.03**	−8.87
	(−2.90)	(−3.00)	(−1.97)	(−3.06)	(−2.37)	(−2.88)	(−2.99)	(−2.70)	(−1.95)

Notes: The t statistics are based on robust covariance matrix estimates [Newey and West (1987)]. Estimates that are significant at the 5% nominal level appear in bold face. The IU measure $\hat{\sigma}_{i,\tau+\ell|\tau}$ is the predictive standard deviation from the AR model in (1). From this model, we also obtain the realized absolute forecast error $\hat{a}_{i,\tau+\ell} = |\pi_{i,\tau+\ell} - \hat{\pi}_{i,\tau+\ell|\tau}|$. The IU metric $\hat{h}_{i,\tau+1|\tau}$ as defined in (3) expresses IU by means of a fixed tradeoff between past inflation volatility and news response similarly to GARCH models. The bottom panel shows coefficient estimates of interaction variables for an earlier euro introduction date in 1997M1 and an alternative definition of inflation as a robustness check.

pronounced. This pattern of significant, respectively insignificant coefficient estimates for the distinct volatility measures may result from the practice of monetary policy as currently adopted in advanced economies. Central banks accommodate oil price uncertainty and risks from international capital flows, but at the same time, they face constraints in keeping FX rate fluctuations under control [Obstfeld et al. (2005)]. The positive coefficients of $\text{RS}_{i,\tau-1}$(Oil) might indicate some (remaining) impact of oil price shocks on IU after potential policy interventions. Similarly, the modest evidence for a negative influence of $\text{RS}_{\tau-1}$(Dow) may reflect that equities are often considered as a hedge against inflation risks [Fischer and Modigliani (1978), Schotman and Schweitzer (2000)].

4.3. The Benefits of EMU Participation in Terms of Inflation Uncertainty

In this section, the euro effect on IU is evaluated over time and across economies with distinct institutional settings. Parameter estimates for constitutional determinants of IU as expressed in (8) are displayed in the middle and bottom parts of Table 1. The parameter estimates associated with $\mathrm{DB}_{i\tau}^{(\mathrm{EMU})}$ and $\mathrm{DB}_{i\tau}^{(\mathrm{EU3})}$ indicate that prior to the advent of the euro, the EU3 economies exhibit a slightly higher level of IU than the EMU and the $O5$ group. After the monetary unification, IU in the EMU and to a slightly smaller degree in the EU3 economies is reduced relative to that in the $O5$. This can be seen from the coefficient estimates of the $\mathrm{DA}_{i\tau}^{(\mathrm{EMU})}$ and $\mathrm{DA}_{i\tau}^{(\mathrm{EU3})}$ dummy variables. Distinct reactions of IU over groups of economies during the recent global recession are indicated by $\mathrm{DR}_{i\tau}^{(\mathrm{EMU})}$ and $\mathrm{DR}_{i\tau}^{(\mathrm{EU3})}$. The estimates indicate that during this period, both the EMU and the EU3 group experienced further reductions in IU relative to the $O5$ group. As a robustness check, the ANOVA regression is also implemented for an earlier break date, AE = 1997M1, and for an alternative definition of inflation as an annualized monthly rate. The resulting coefficient estimates for $\mathrm{DA}_{i\tau}^{(\mathrm{EMU})}$ and $\mathrm{DA}_{i\tau}^{(\mathrm{EU3})}$ are given in the lower panels of Table 1. The outcomes are in almost all cases qualitatively similar to the results discussed previously.

5. CONCLUSIONS

This study evaluates the effect of the introduction of the euro on inflation uncertainty. A monetary union may at the same time offer chances to avoid overly large uncertainty levels and enforce risks of unfortunate surprises on inflation [Alesina et al. (2003), Feldstein (2005), Davig et al. (2011)]. We investigate the effect of the formation of the European Monetary Union on inflation uncertainty over distinct time episodes during the last two decades. A graphical display of alternative uncertainty measures suggests that inflation uncertainty has been increasing across industrialized economies since its minimum level around the year 2000. The relative success in repelling emergent inflation risks in the euro area is compared to that for European economies not participating in the European Monetary Union and also to that for other OECD economies. Results show that in the years after its formation in 1999, the European Monetary Union has led on average to a reduction in inflation uncertainty as compared to other economies. Moreover, we do not find evidence for the assertion that the large-scale monetary and fiscal expansions have led to a higher inflation risk exposure of the monetary union in comparison to other economies. To summarize, participation in the European Monetary Union has been a relatively successful safeguard against overly high inflation risks. These findings are robust with regard to the changing macroeconomic conditions industrialized economies have encountered during the recent two decades. Distinct ways of anticipating the latent inflation uncertainty process indicate a largely similar impression of the benefits of participation in the European Monetary Union after its formation. Since the year 2007, inflation uncertainty has been globally on the uprise. Reliable protection against inflation risks is therefore a concern of the utmost importance for current economic policy.

NOTES

1. Such price adjustments may reflect, e.g., temporary sales and are usually not associated with inflation or business cycle fluctuations [Rotemberg (2005)]. Moreover, such events are typically well anticipated by customers and should, therefore, not add to IU.

2. In addition, the NKPC is typically estimated by means of the generalized method of moments [GMM, Hansen (1982)]. This gives rise to specification problems because it is not warranted that a predefined set of instruments is suitable at each step of the forecast recursion [Galí et al. (2005)].

3. IU approximations obtained by augmenting the AR model with additional explanatory variables deliver qualitatively equivalent results, which are available from the authors upon request.

4. Distinct implementations $\lambda \in \{0.05, 0.1, 0.2\}$ span a range of plausible values for this sort of data. Qualitative features of implied IU measurements have been found to be very similar with regard to such alternative choices. Hence we only report results obtained for $\lambda = 0.05$ in the remainder of the paper. Results regarding other parameterizations are available from the authors upon request.

5. In addition to the graphical display of IU measures, we investigated the accord of distinct IU measures by means of correlation coefficients. These results are available from the authors upon request.

REFERENCES

Alesina, Alberto, Robert J. Barro, and Silvana Tenreyro (2003) Optimal currency areas. In Mark Gertler and Kenneth S. Rogoff (eds.), *NBER Macroeconomics Annual*, vol. 17, pp. 321–363. Cambridge, MA: MIT Press.

Andersen, Torben G., Tim Bollerslev, and Francis X. Diebold (2004) Parametric and nonparametric measurement of volatility. In Yacine Aït-Sahalia and Lars P. Hansen (eds.), *Handbook of Financial Econometrics*, vol. 1, pp. 67–138. Amsterdam: North Holland.

Arnold, Ivo J.M. and Jan J.G. Lemmen (2008) Inflation expectations and inflation uncertainty in the eurozone: Evidence from survey data. *Review of World Economics* 144, 325–346.

Baillie, Richard T., Tim Bollerslev, and Hans O. Mikkelsen (1996) Fractionally integrated generalized autoregressive conditional heteroscedasticity. *Journal of Econometrics* 74, 3–30.

Ball, Lawrence (1992) Why does high inflation raise inflation uncertainty? *Journal of Monetary Economics* 29, 371–388.

Ball, Lawrence and Stephen G. Cecchetti (1990) Inflation and uncertainty at short and long horizons. *Brookings Papers on Economic Activity* 1, 215–254.

Barnea, Amir, Amihud Dotan, and Josef Lakonishok (1979) The effect of price level uncertainty on the determination of nominal interest rates: Some empirical evidence. *Southern Economic Journal* 45, 609–645.

Barsky, Robert B. and Lutz Kilian (2002) Oil and the macroeconomy since the 1970s. *Journal of Economic Perspectives* 18, 115–134.

Blanchard, Olivier (2004) Fiscal Dominance and Inflation Targeting: Lessons from Brazil. NBER working paper 10389.

Bollerslev, Tim (1986) Generalized autoregressive conditional heteroscedasticity. *Journal of Econometrics* 31, 307–327.

Canova, Fabio (1998) Detrending and business cycle facts. *Journal of Monetary Economics* 41, 475–512.

Canova, Fabio (2007) G-7 inflation forecasts: Random walk, Phillips curve or what else? *Macroeconomic Dynamics* 11, 1–30.

Caporale, Guglielmo M. and Alexandros Kontonikas (2009) The euro and inflation uncertainty in the European Monetary Union. *Journal of International Money and Finance* 28, 954–971.

Cukierman, Alex (2000) Establishing a reputation for dependability by means of inflation targets. *Economics of Governance* 1, 53–76.

Davig, Troy, Eric M. Leeper, and Todd B. Walker (2011) Inflation and the fiscal limit. *European Economic Review* 55, 31–47.

Devereux, Michael (1989) A positive theory of inflation and inflation variance. *Economic Inquiry* 27, 105–116.

Engle, Robert F. (1982) Autoregressive conditional heteroscedasticity with estimates of the variance of United Kingdom inflation. *Econometrica* 50, 987–1007.

Evans, Martin and Paul Wachtel (1993) Inflation regimes and the sources of inflation uncertainty. *Journal of Money, Credit and Banking* 25, 475–511.

Fama, Eugene F. (1976) Inflation uncertainty and expected returns on treasury bills. *Journal of Political Economy* 84, 427–448.

Feldstein, Martin (2005) The euro and the stability pact. *Journal of Policy Modeling* 27, 421–426.

Fischer, Stanley and Franco Modigliani (1978) Towards an understanding of the real effects and costs of inflation. *Review of World Economics* 114, 810–833.

Friedman, Milton (1977) Nobel Lecture: Inflation and unemployment. *Journal of Political Economy* 85, 451–472.

Gagnon, Joseph E. and Jane E. Ihrig (2001) Monetary Policy and Exchange Rate Pass-through. FRB International Finance Discussion Paper 704.

Galí, Jordi, Mark Gertler, and David Lopez-Salido (2005) Robustness of the estimates of the hybrid new Keynesian Phillips curve. *Journal of Monetary Economics* 52, 1107–1118.

Godfrey, Leslie G. (1988) *Misspecification Tests in Econometrics*. Cambridge, UK: Cambridge University Press.

Gosh, Atish R., Anne-Marie Gulde, Jonathan D. Ostry, and Holger C. Wolf (1995) Does the Nominal Exchange Rate Regime Matter? IMF working paper 121.

Grauer, Frederick L.A. and Robert H. Litzenberger (1980) The pricing of commodity futures contracts, nominal bonds and other risky assets under commodity price uncertainty. *Journal of Finance* 34, 69–83.

Grier, Kevin G. and Mark J. Perry (2000) The effects of real and nominal uncertainty on inflation and output growth: Some GARCH-M evidence. *Journal of Applied Econometrics* 15, 45–58.

Hansen, Lars P. (1982) Large sample properties of generalized method of moments estimators. *Econometrica* 50, 1029–1054.

Hartmann, Matthias and Helmut Herwartz (2012) Friedman–Ball versus Cukierman–Meltzer: A cross sectional empirical investigation on the nature of inflation uncertainty. *Economics Letters* 115, 144–147.

Herwartz, Helmut (2009) A note on model selection in (time series) regression models—General-to-specific or specific-to-general? *Applied Economics Letters* 17, 1157–1160.

Hodrick, Robert J. and Edward C. Prescott (1997) Postwar U.S. business cycles: An empirical investigation. *Journal of Money, Credit and Banking* 29, 1–16.

Huizinga, John (1993) Inflation uncertainty, relative price uncertainty, and investment in U.S. manufacturing. *Journal of Money, Credit and Banking* 25, 521–549.

Kontonikas, Alexandros, Alberto Montagnoli, and Nicola Spagnolo (2005) Stock Returns and Inflation: The Impact of Inflation Targeting. Discussion Paper in Economics/University of Glasgow 11.

Mundell, Robert A. (1961) A theory of optimal currency areas. *American Economic Review* 51, 657–665.

Newey, Whitney and Kenneth D. West (1987) A simple positive semi-definite heteroskedasticity and autocorrelation consistent covariance matrix. *Econometrica* 55, 703–708.

Obstfeld, M., Jay C. Shambaugh, and Alan M. Taylor (2005) The trilemma in history: Tradeoffs among exchange rates, monetary policies, and capital mobility. *Review of Economics and Statistics* 87, 423–438.

Ravn, Morten O. and Harald Uhlig (2002) On adjusting the Hodrick–Prescott filter for the frequency of observations. *Review of Economics and Statistics* 84, 371–376.

Rotemberg, Julio J. (2005) Customer anger at price increases, changes in the frequency of price adjustment and monetary policy. *Journal of Monetary Economics* 52, 829–852.

Rumler, Fabio and Maria T. Valderrama (2010) Comparing the new Keynesian Phillips curve with time series models to forecast inflation. *North American Journal of Economics and Finance* 21, 126–144.

Schotman, Peter C. and Mark Schweitzer (2000) Horizon sensitivity of the inflation hedge of stocks. *Journal of Empirical Finance* 7, 301–315.

Schwert, G. William (1989) Why does stock market volatility change over time? *Journal of Finance* 44, 1115–1153.

Stock, James H. and Mark W. Watson (2008) Phillips Curve Inflation Forecasts. NBER working paper W14322.

Vitek, Francis (2002) An Empirical Analysis of Dynamic Interrelationships among Inflation, Inflation Uncertainty, Relative Price Dispersion, and Output Growth. Bank of Canada working paper 2002-39.

Vroman, Susan B. (1989) Inflation uncertainty and contract duration. *Review of Economics and Statistics*, 71, 677–681.

Zangari, Peter (1996) RiskMetrics—Technical Document, 4th ed. New York: J.P. Morgan.