The Economic Effects of Global Inflation Uncertainty*

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This paper investigates the impacts of inflation uncertainty on inflation and economic activities. We take three steps. We first put together various measures of inflation uncertainty—including survey based and model based—and extract a common measure for the group of seven advanced economies and seven large emerging market economies. Using the novel cross-country data, we estimate a panel structural VAR model to analyze how inflation uncertainty affects macroeconomic and financial variables. Finally, we explore the transmission channels of the uncertainty shock through the lens of the dynamic stochastic general equilibrium (DSGE) model. We find that inflation uncertainty has sharply risen globally since the COVID-19 pandemic, reaching historically high levels comparable to those of the 1970s and 1980s. The empirical results suggest that higher inflation uncertainty has been unambiguously followed by large economic growth declines, particularly in investment. Meanwhile, the relationship between inflation uncertainty and inflation has been heterogeneous across countries and time varying. The simulation results from our DSGE model suggest that different types of propagation channels, through demand and supply, of inflation uncertainty shocks could lead to negative business cycle co-movement and heterogeneous consequences on inflation.

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1. Introduction

This paper examines the impacts of inflation uncertainty—defined as a common component from various types of inflation uncertainty measures—on economic activities (output, consumption, investment, and industrial production) and inflation. While global inflation and short-term inflation expectations have risen sharply since the COVID-19 pandemic, the uncertainty about future inflation developments has also heightened sharply, reflecting a variety of underlying factors that have altered the perceptions on future inflation after the pandemic's commodity market disruptions, lockdowns, and pent-up demand, supply bottlenecks, and fluctuations in currency values. Inflation uncertainty, which often refers to unpredictable inflation volatility, is an essential concept in economic theory, as it affects consumers' savings and investors' and policymakers' decisions (Rossi, Sekhposyan, and Soupre 2016).

The literature often documents the evidence that higher inflation uncertainty is typically associated with economic slowdowns. However, the causal relationship between inflation uncertainty and inflation is ambiguous and time varying (Bachmann, Berg, and Sims 2015 and Binder 2017 among many others).[1] If inflation uncertainty is expected to rise further in the near future, it will make the prediction of inflation more difficult and strain the recovery of the global economy, which will inevitably complicate the design of macroeconomic policies.

This paper seeks to answer the following questions:

- How has global inflation uncertainty evolved, particularly since the COVID-19 pandemic?
- What is the relationship between inflation uncertainty, inflation, and economic growth?
- What are the economic channels behind the propagation of inflation uncertainty shocks?

We take three steps to answer these questions. First, we uniquely compile a variety of measures for inflation uncertainty: so-called survey-, model-, forecast-, and news-based measures of inflation

[1] A detailed review of the related literature is presented in Appendix A.

uncertainty, as well as common components across the measures. We then adopt a structural vector-autoregressive (SVAR) specification to assess the effects of inflation uncertainty on inflation and real economic activities. More specifically, using monthly (from 2004 to 2019) and quarterly data (1970–2019), we estimate a panel SVAR model that consists of inflation uncertainty, inflation, output, consumption and investments (or industrial production for goods and non-durable goods in the case of monthly frequency), interest rates, and exchange rates in seven of the largest advanced economies (G7) and seven of the largest emerging market economies (EM7).[2]

Finally, to understand further the transmission channels of inflation uncertainty shocks into macroeconomic conditions, we construct a dynamic stochastic general equilibrium (DSGE) model that explicitly incorporates the inflation uncertainty into the New Keynesian framework. In this model, inflation uncertainty is assumed to affect nominal bond yields and a firm's costs in changing nominal prices, altering consumption, investments, and labor demand and supply. Hence, the model allows us to examine the transmission of inflation uncertainty shocks into the economy on both demand and supply side.

The main findings of this paper are summarized as follows. First, inflation uncertainty rose sharply with the onset of the COVID-19 pandemic, consistent across countries and based on different types of inflation uncertainty measures. The post-pandemic level of uncertainty, based on the cross-country averages, was beyond the level of the late 2000s and almost comparable to the level in the 1970s and 1980s when the global economy was hit by oil crises and soaring inflation, followed by global recessions as a result of tightening monetary policies to rein in inflation.

Second, over the recent five decades, heightened inflation uncertainty has been unambiguously followed by large declines in output, in particular in investment and consumption of durable goods, which is entirely consistent with the predictions by Bachmann, Berg, and Sims (2015) and Binder (2017). However, the relationship between inflation uncertainty and inflation has changed over time. In G7

[2] G7 includes the United States, Canada, France, Germany, Italy, Japan, and the United Kingdom, while EM7 encompasses Brazil, China, Mexico, India, Indonesia, Russia, and Turkey.

economies, for instance, inflation persistently rose following heightened uncertainty in the 1970s and 1980s, whereas it declined in the 2000s and 2010s. The changing reactions of inflation over time may reflect the evolving nature of underlying shocks (and their transmission channels) behind the inflation uncertainty around the episodes of the global events—e.g., large adverse supply shocks in the 1970s and 1980s or negative demand shocks around the global financial crisis in the late 2000s.

Third, our empirical results suggest heterogeneous consequences of inflation uncertainty across G7 and EM7. The negative impacts of inflation uncertainty on economic activities were more sizable and statistically significant for G7 countries; a one-standard-deviation increase in inflation uncertainty was associated with a decline in industrial production by up to 10 percent within two years after the shock. Meanwhile, the impacts were relatively short-lived and less sizable (up to 6 percent decline) in EM7 countries. The impacts of inflation uncertainty on inflation were again heterogeneous across the country groups. Among G7 economies, inflation (along with outputs) significantly declined following a positive inflation uncertainty, suggesting that inflation uncertainty might have played a main role as a negative demand shock. On the contrary, among EM7, inflation uncertainty was followed by a substantial increase in inflation (and a reduction in economic activities), possibly reflecting some supply-side forces that led to the opposite directional movements of inflation and outputs in the economies.[3]

Finally, our New Keynesian DSGE model sheds some more light on the propagation mechanism of inflation uncertainty shocks into the economy. On the one hand, the model generates negative comovement among output, investment, and consumption from a rise in inflation uncertainty, leading to adverse fluctuations in the aggregate demand. The dampened consumption demand triggered by heightened inflation uncertainty causes a decline in output according to the national account identity and in investment due to a decreased marginal revenue product of capital. The reduced demand in turn leads to declines in inflation. On the other hand, a heightened inflation uncertainty raises markups of the firms and inflation together

[3]This observation is consistent with the synchronized episodes of high inflation and inflation uncertainty in those countries in the 2000s and 2010s.

and thereafter lowers the firm's demand for labor inputs. This can reduce the final production (supply) to the extent that it offsets the effects of the increased precautionary labor supply by households. Reflecting these different channels, our simulation results suggest that inflation can either rise or decline in response to the heightened inflation uncertainty depending upon the main underlying channels behind the shock, which are determined by the structure of the model economy (as reflected in the model parameters)—including the degree of risk aversion of economic agents.

The paper is expected to contribute to the literature in three ways. First, to our investigation, this paper is one of the first to put together various types of cross-country inflation measures in a wide range of countries and to examine the global (common) effects of inflation uncertainty. Second, this paper contributes to the literature on inflation uncertainty and economic growth. Our finding is largely in line with the classical theory proposed by Friedman (1977) that inflation brings about high uncertainty about the future, thereby leading to high unemployment and low output, and with the main empirical evidence in a large body of studies including Davis and Kanago (1998), Grier and Perry (2000), Elder (2004), and Binder (2017).[4] Our results are, however, in contrast to those studies that find positive or negligible relation (Clark 1997; Barro 1998; Fountas 2010; Baharumshah, Slesman, and Wohar 2016).[5]

This study is also expected to shed more light on the debates on the relation between inflation uncertainty and inflation by exploring the data in a broad panel of countries over the long term. Our empirical results based on the data over the period of the 1970s–1990s are in line with the theories such as by Cukierman and Meltzer (1986) as well as the empirical findings in Leduc, Sill, and Stark

[4]These studies use different estimation methods. For example, Grier and Perry (2000) apply a generalized autoregressive conditional heteroskedasticity (GARCH) model to test the adverse impact of uncertainty on output, and Binder (2017) uses round number responses from surveys to show that higher uncertainty explains low consumption on durable goods, cars, and homes.

[5]Armantier et al. (2015) and Baharumshah, Slesman, and Wohar (2016) explain that the positive relation between inflation uncertainty and output growth can partly reflect the precautionary consumption and consumer behaviors. Main mechanisms of the relationship could be understood in a New Keynesian framework as briefly discussed in Section 5.

(2007) that argue the positive relation between inflation uncertainty and inflation. Fountas (2010) also documents the inflationary effect of inflation uncertainty, along with some country-specific evidence in Berument, Yalcin, and Yildirim (2012) for the United States, Ozdemir (2010) for the United Kingdom, Berument, Yalcin, and Yildirim (2011) for Turkey, and Jiang (2016) for China. Our result based on more recent (post-2000) data, to the contrary, supports the Holland hypothesis (Holland 1995), which explains the negative relationship from the viewpoint of social cost, supported by the empirical findings of Balcilar and Ozdemir (2013) based on the estimation of a Markov-switching VAR model.

The paper is organized as follows. Section 2 introduces the measures of inflation uncertainty and its evolution. Section 3 explains an empirical model and data and Section 4 discusses the main empirical results. In Section 5, the key empirical features of macroeconomic response to inflation uncertainty are explored in a New Keynesian framework. Section 6 concludes. Related literature, the details of empirical and theoretical models, and robustness checks are discussed in the appendices.[6]

2. Inflation Uncertainty Measures

Inflation uncertainty is an unobserved variable, and many different measures have been proposed in the literature. Some studies adopt a survey-based approach, while others depend on the volatility derived from time-series models. Another strand of literature uses the realized forecast errors of inflation. Each measure is derived from different assumptions that are likely to suffer from idiosyncratic measurement errors. Empirical results on the impact of inflation uncertainty substantially differ depending on the choice of the uncertainty measure.

Against this background, we employ four different types of inflation uncertainty: namely, survey-, model-, forecast-, and news-based

[6]In Appendix A, an extensive body of related literature is reviewed. Appendix B presents the results based on the alternative measures of inflation uncertainty. Appendix C reports additional figures. Appendix D provides the details of the DSGE model.

measures. The common measure of inflation uncertainty is extracted from them using the principal component analysis and is employed as the benchmark indicator of inflation uncertainty. Each specific measure is used for empirical analyses for robustness checks. Table 1 summarizes each measure, and Appendix A provides more technical details.

2.1 Measures of Inflation Uncertainty

Survey-Based Measure. We first use individual surveys for headline consumer price index (CPI) inflation from professional forecasters conducted by Consensus Economics. It reports average annual growth rates of expected inflation for the current and the next year on a monthly basis. The survey has an advantage in collecting responses from knowledgeable, professional forecasters who are well-informed about the economy's current condition.[7] Dovern and Weisser (2011) find that individual forecasts of U.S. inflation are largely unbiased. Following Bomberger and Frazer (1981) and Giordani and Söderlind (2003), we use cross-sectional dispersion of short-term (one-year-ahead) forecasts. We interchangeably use two types of dispersion index: standard deviation and the difference between high and low forecasts within the month.

Model-Based Measure. Next, we estimate the stochastic volatility of inflation as a proxy for inflation uncertainty using a GARCH (1,1) model and an unobserved component stochastic volatility in the mean (UCSVM) model.

Many different types of ARCH models have been used extensively to model inflation uncertainty. A GARCH model with time-varying parameters accommodates events such as alterations in monetary regimes or variations in steady-state inflation. This has the advantage of being flexible to allow for a non-stationary inflation rate. The model is given by a conditional mean (signal) equation (1), a state equation (2), and an evolution of conditional error variance (3).

[7] Additionally, the survey includes individual data and identifies the forecasters by name rather than just assigning them a number. This creates a strong motivation for forecasters to make accurate predictions to protect their reputation.

Table 1. Measures of Inflation Uncertainty

Measures of Inflation Uncertainty		Details	References
A. Model Based	SVM	Decompose inflation into random drift and variance terms	Chan (2017)
		Stochastic variance terms follow AR process	Stock and Watson (2016)
	GARCH (1,1)	Estimate condition variance of residuals in inflation	
		Mean equation is assumed to follow AR process	Batchelor and Dua (1996)
B. Forecast Based	VAR	Standard deviation of forecast error of inflation using VAR model of inflation, output, oil prices, exchange, and interest rates	Giordani and Söderlind (2003)
			Peng and Yang (2008)
C. Survey Based	Consensus Forecast	Mean-squared error of consensus forecasts	Cukierman and Wachtel (1982)
			Batchelor and Dua (1996)
		Cross-sectional disagreement	Giordani and Söderlind (2003)
		(standard deviation) of surveys	Bomberger (1996)
		Dispersion index (high–low) or interquartile range	Mankiw, Reis, and Wolfers (2003)
D. News Based	Google Trends	Total search of keywords “Inflation” in the news articles	Bloom (2014)
			Castelnuovo and Tran (2017)
E. Global Measure		First principal component of the various uncertainty measures	Grimme, Henzel, and Wieland (2014)

$$\pi_t = a_{0,t} + a_{1,t}\pi_{t-1} + a_{2,t}\pi_{t-2} + e_t^{\pi}, \quad e_t^{\pi} \sim \mathcal{N}(0, h_t) \tag{1}$$

$$A_t = A_{t-1} + e_t^A, \quad e_t^A \sim \mathcal{N}(0, Q), \quad \text{where} \quad A_t = [a_{0,t}, a_{1,t}, a_{2,t}]' \tag{2}$$

$$h_t = d + \phi(e_{t-1}^{\pi})^2 + \gamma h_{t-1}, \tag{3}$$

where A_t is a vector of time-varying coefficients. We assume inflation π_t follows an AR(2) process. The coefficient vector follows a random walk. h_t describes conditional error variance from a GARCH(1,1) process. Q is a homoskedastic covariance matrix of shocks e_t^A. The variance combines model uncertainty emerging from time variation of the coefficients and uncertainty emerging from the shock process e_t^A (Evans 1991).

Along with the GARCH model, the UCSVM model is used (Kim, Shephard, and Chib 1998; Stock and Watson 2007; Chan 2017). Following Chan (2017), we consider a time-varying parameter model with stochastic volatility where the stochastic volatility also enters the conditional mean equation. Unlike GARCH models, where error variance is fully described by its own past, the variance of first-moment shocks is assumed to be driven by an exogenous stochastic process. The state-space representation is given by Equations (4), (5), and (6):

$$\pi_t = \tau_t + \alpha_t \exp(\theta_t) + \epsilon_t^{\pi}, \quad \epsilon_t^{\pi} \sim \mathcal{N}(0, \exp(\theta_t)) \tag{4}$$

$$\gamma_t = \gamma_{t-1} + \epsilon_t^{\gamma}, \quad \epsilon_t^{\gamma} \sim \mathcal{N}(0, \Omega), \quad \text{where} \quad \gamma_t = [\tau_t, \alpha_t]' \tag{5}$$

$$\theta_t = \mu + \phi(\theta_{t-1} - \mu) + \beta_t \tau_{t-1} + \epsilon_t^{\theta}, \quad \epsilon_t^{\theta} \sim \mathcal{N}(0, \sigma^2), \tag{6}$$

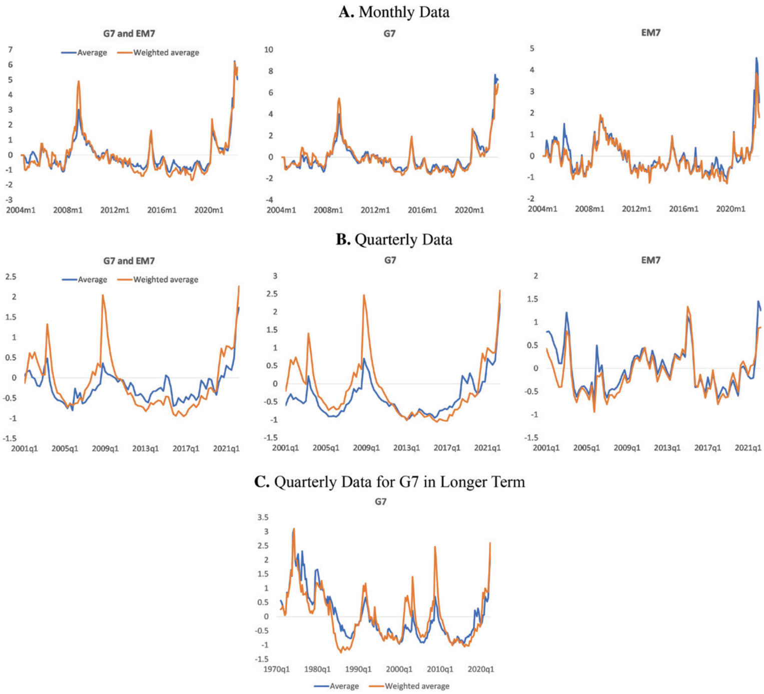
where ϵ_t^{π} is a short-term shock in the measurement equation (4) with variance $\exp(\theta_t)$. The disturbances ϵ_t^{π} and ϵ_t^{θ} are mutually and serially uncorrelated. The log-volatility θ_t follows a stationary AR(1) process with $\mid \phi \mid < 1$, and it is initialized with $\theta_1 \sim \mathcal{N}(\mu, \sigma^2/(1-\phi^2))$. Moreover, the trend component τ_t follows a random walk driven by a (level) shock. Ω is a covariance matrix of the innovation vector ϵ_t^{γ}. The model is estimated with the Gibbs sampler.

Forecast-Based Measures. As a complement to the survey- and model-based measures, a forecast-based approach is suggested, which relies on inflation-forecasting models. For instance, in Giordani and Söderlind (2003), a single VAR model was recursively estimated, and the standard deviation of the forecast error for inflation was calculated for each period. Chua, Kim, and Suardi (2011) implemented this idea by generating error bands using the recursive bootstrapped VAR models introduced by Peng and Yang (2008). We similarly employ a measure of uncertainty derived from VAR residuals, which are assumed to be homoskedastic. More specifically, we estimate monthly and quarterly VAR models that consist of inflation, outputs, consumption, investment, interest rates, and exchange rates (again, for monthly models, consumption and investment are replaced by industrial productions for durable and non-durable goods, respectively).

News-Based Measure. More recently, a growing number of studies have proposed an alternative measure of so-called news-based uncertainty that employs the density of certain keywords in news articles (Bloom 2014, among many others). Following Castelnuovo and Tran (2017), we construct Google Trends based inflation uncertainty indices for the countries of interest. Google Trends inflation uncertainty indices are based on the assumption that economic agents, represented by Internet users, search for online information when they feel uncertain. This assumption implies that the search frequency of terms associated with future uncertain events increases when the level of uncertainty is high. The index is based on keywords of "*inflation*" or "*price*."

Common Measure of Inflation Uncertainty. As previously discussed, individual measures may be contaminated by idiosyncratic measurement errors. In addition, each measure may deliver economic implications in different aspects, reflecting its underlying drivers (Kozeniauskas, Orlik, and Veldkamp 2018; Cascaldi-Garcia et al. 2023). This calls into question whether an individual measure delivers a reliable signal. A simple average over individual measures could be a viable measure that delivers a robust indicator of inflation uncertainty. However, it does not entirely account for the variability in the data. In general, individual measures have a greater tendency to diverge during periods of turbulence. Furthermore, when macroeconomic variables become more volatile, a researcher may encounter survey participants who adhere to the consensus rather than expressing their own views. Therefore, to capture each measure's variations,

Figure 1. Inflation Uncertainty



Note: These figures show inflation uncertainty measures based on monthly (A) and quarterly (B) data. Panel (C) uses longer-term data for G7 countries starting from 1970. The uncertainty is based on the first principal components of the survey-, model-, forecast-, and news-based measures of inflation uncertainty. Please see Section 3 for more details.

we employ the first principal component to capture common information in different uncertainty measures. The first principal component loads broadly equally on each measure and helps alleviate the measurement error problem.

2.2 Evolution of Inflation Uncertainty

Over the recent two decades, the global inflation uncertainty, proxied by the average across G7 and EM7, has fluctuated around global economic events, as shown in the first chart of panel A in Figure 1. It has been relatively stable (below the long-term average) during the period leading up to the global financial crisis. The uncertainty rose sharply from late 2007 until it started to decline in early 2009 when global inflation fluctuated significantly amid a widespread collapse in global commodity prices, followed by the global financial crisis in late 2008. In 2014–15, the inflation uncertainty rose due mainly to the significant oil price plunges, although the degree of the uncertainty rise was around one-half of that around the global financial crisis.

Since the onset of the COVID-19 pandemic, inflation uncertainty has risen sharply. It jumped in March and April 2020 when the global economy was hit hard by sizable adverse health and economic shocks due to the pandemic. The inflation uncertainty then declined to around the long-term average before it rose again in the third quarter of 2021. As of June 2022, the inflation uncertainty is four to seven standard deviations higher from the long-term average, depending on the country groups and the aggregation method, which is higher than the peak in the late 2000s.

We also report the evolution of inflation uncertainty across different groups of countries, G7 and EM7. The results are broadly consistent across the country groups, as shown in the two right charts in panel A of Figure 1. The inflation uncertainty rose sharply around the global financial crisis in 2008–09, and oil price plunged in the mid-2010s in both country groups. However, the inflation uncertainty for EM7 countries was more volatile in the early 2000s and the late 2010s when some EM7 countries experienced domestic financial and economic crises.

The evolution of inflation uncertainty is consistent with quarterly, model-based measures, as shown in panel B of Figure 1. When using long-term quarterly data that span to the 1970s, where we use GDP-weighted or simple average of G7 inflation uncertainty, the results suggest that the inflation uncertainty spiked in the mid-1970s and the early 1980s when the global economy suffered the first and second oil crises and the subsequent global recessions in 1975 and 1982 (panel C of Figure 1).

Country-specific results are presented in Figure C.1 of Appendix C. Inflation uncertainty measures in G7 economies were more broad based than those in EM7 economies. Among G7 economies, Germany and Italy exhibit higher volatility of inflation uncertainty than other G7 economies. In most G7 countries except the United

States and Japan, the uncertainty level as of June 2022 has already exceeded that of the global financial crisis.

Meanwhile, the inflation uncertainty has been more heterogeneous across EM7 economies. Brazil, Mexico, and Indonesia experienced a surge in inflation uncertainty from the early to mid-2000s. Brazil experienced considerable inflation uncertainty between late 2002 and early 2003 when economic confidence plunged, caused by a reversal in capital flows and unstable domestic political conditions.[8] In Mexico, the rise of uncertainty in 2008–09 was driven by the global financial crisis and its reliance on the United States as an export market. In Indonesia, the inflation uncertainty rose sharply in 2005 due to soaring energy prices (International Monetary Fund 2008).

In India, Russia, and Turkey, inflation uncertainty rose sharply in the mid-to-late 2010s. While India's inflation uncertainty rose sharply around the global financial crisis, the uncertainty spiked again in late 2013, when higher domestic inflation was followed by increasing food prices and domestic structural problems.[9] In Russia, food supply shocks and currency depreciation seem to have caused a surge in inflation uncertainty.[10] Meanwhile, in Turkey, a substantial currency devaluation in 2018 and concerns about the central bank's independence and diplomatic issues with the United States led to a surge in inflation and inflation uncertainty.

Furthermore, the inflation uncertainty exhibits analogous movements across different measures. As shown in Figure C.1 of Appendix C, the survey-based inflation measure generally followed the common factor for inflation uncertainty. Based on model- and forecast-based measures, the uncertainty reached a somewhat greater level in the 1970s and 1980s than after the 2000s. That said, in the United

[8]Markets feared that shifts in political power from elections would lead to different attitudes toward capital accounts and monetary policy (Bevilaqua and Loyo 2005).

[9]Rising food prices were driven by rising farm wages, increasing global food prices, and loose fiscal and monetary policies as well as market support prices for farmers, which continued to grow even without natural disasters, thus causing market distortions (Gulati and Saini 2013).

[10]The government imposed bans on food imports from the United States, the European Union, and other countries in response to sanctions over Russia's actions in Ukraine. Sharp ruble depreciation, which started in the second half of 2014, also increased the cost of imports.

States, the uncertainty was most significant in the late 2000s, and the level in 2022 was also comparable to that in the 1970s and 1980s. Meanwhile, based on the news-based measure available only after 2004, the level was the highest in 2022.

2.3 Inflation Uncertainty and Other Variables

Our inflation uncertainty measures are constructed based on various approaches, and they can be mirroring other structural shocks, in particular those associated with inflation. Also, the measure may contain common information with different types of uncertainty. To check these issues, we carry out a battery of univariate regressions that test the exogeneity of the inflation uncertainty measure, following the preceding studies (Kozeniauskas, Orlik, and Veldkamp 2018; Berger, Dew-Becker, and Giglio 2020):

$$z_t = \alpha + \beta_i m_{i,t} + \theta_{i,t}, \tag{7}$$

where z_t denotes our measure of inflation uncertainty and m_i corresponds to the different macro variable or uncertainty measure i. We test the null hypothesis of $\beta_i = 0$ to determine whether the inflation uncertainty measure correlates with m_i.

Regarding m_i, we mainly consider two groups of variables. First, different measures of uncertainty are compared with the inflation uncertainty. In doing so, we examine whether our measure of inflation uncertainty delivers distinct information from other types of uncertainty in the literature or reflects similar information to them. In this vein, we employ VIX (Bloom 2009), economic policy uncertainty (Baker, Bloom, and Davis 2016), geopolitical risk (Caldara and Iacoviello 2022), financial and macroeconomic uncertainty (Jurado, Ludvigson, and Ng 2015), monetary policy uncertainty (Husted, Rogers, and Sun 2020; Arce-Alfaro and Blagov 2023), trade policy uncertainty (Caldara et al. 2020), and world uncertainty (Ahir, Bloom, and Furceri 2022) for m_i.[11]

Second, various macroeconomic and financial shocks related to inflation and economic activity are considered based on the previous

[11] For a recent extensive survey of uncertainty measures, see Cascaldi-Garcia et al. (2023).

studies. This is expected to help understand the underlying nature of inflation uncertainty and its interlinkage with business and financial cycles (Gilchrist and Zakrajšek 2012; Baker, Bloom, and Davis 2016). In addition, various policy shocks, such as monetary policy (Gürkaynak, Sack, and Swanson 2005) and fiscal policy (Romer and Romer 2010) shocks are also tested. Correlated with news shocks, uncertainty shocks may act as potential drivers of business cycles (Beaudry and Portier 2014; Berger, Dew-Becker, and Giglio 2020). Hence, news shocks (Barsky and Sims 2011) and productivity shocks (Levchenko and Pandalai-Nayar 2020) are also used as a regressor. Considering the relationship among uncertainty, commodity market, and economic activity, oil prices and production are employed (Kilian 2008; Ha, Kose, and Ohnsorge 2019). Finally, given a close relation between inflation uncertainty and expectation, we also compare its movements with inflation expectations (Drakos, Konstantinou, and Thoma 2020).

The estimation results for global inflation uncertainty are summarized in Table 2. In most cases, our estimation does not reject the null hypothesis of $\beta_i = 0$ at the 1 percent significance level, suggesting that our measure of inflation uncertainty is not significantly correlated with different types of uncertainty and other structural shocks. For the robustness of results, we also implement similar tests on the inflation uncertainty measures for the sub-groups of G7 and EM7, each reported in Table C.1 of Appendix C, respectively. By and large, the results are consistent with the case of global inflation uncertainty. These indicate that global inflation uncertainty delivers distinct information from other uncertainties and does not only mirror other structural shocks in the economy.[12]

That said, there are a few exceptional cases where our measure of inflation uncertainty exhibits a correlation with structural shocks at the 5 or 10 percent significance level. Notably, such cases include financial shocks in common, and policy shocks in particular in EM7. These significant correlations may indicate that inflation uncertainty

[12]This point is also confirmed by our robustness checks using VIX and EPU in the panel SVAR framework, as documented in Appendix B. In addition, although not reported, we conduct residual tests by comparing the residuals of endogenous variables in the VAR with inflation uncertainty. All the correlation coefficients are shown to be insignificant.

Table 2. Regression Results of Global Inflation Uncertainty on Other Uncertainties and Structural Shocks[1]

Structural Shocks		Country	Related Studies	β	SE	*P*-value	Obs.	Sample
Uncertainty	VIX	US	Bloom (2009)	0.00	0.01	0.73	185	2004:M8–2019:M12
	Macro Uncertainty ($h = 3$)[2]	US	Jurado, Ludvigson, and Ng (2015)	–0.06	0.22	0.78	185	2004:M8–2019:M12
	Financial Uncertainty ($h = 3$)[2]	US	Jurado, Ludvigson, and Ng (2015)	–0.06	0.19	0.74	185	2004:M8–2019:M12
	Geopolitical Risk	Global	Caldara and Iacoviello (2022)	–0.03	0.03	0.36	185	2004:M8–2019:M12
	Monetary Policy Uncertainty	US	Husted, Rogers, and Sun (2020)	–0.03	0.03	0.25	185	2004:M8–2019:M12
	Trade Policy Uncertainty	Global	Caldara et al. (2020)	–0.04	0.04	0.23	185	2004:M8–2019:M12
	Economic Policy Uncertainty	Global	Baker, Bloom, and Davis (2016)	–0.03	0.03	0.34	185	2004:M8–2019:M12
	World Uncertainty (All)	Global	Ahir, Bloom, and Furceri (2022)	–0.02	0.01	0.20	80	2000:Q1–2019:Q4
Monetary Policy[3]	MP1	US	Gertler and Karadi (2015), Gürkaynak, Sack, and Swanson (2005)	–1.33	1.22	0.28	179	2004:M8–2019:M6
	MP2			–2.53	2.11	0.23	179	2004:M8–2019:M6
	FF1			–5.75	5.18	0.27	179	2004:M8–2019:M6
	FF2			–1.98	2.20	0.37	179	2004:M8–2019:M6
Fiscal Policy[4]	Government Spending (1)	US	Romer and Romer (2010)	0.00	0.00	0.37	32	2000:Q1–2007:Q4
	Government Spending (2)			0.00	0.00	0.31	32	2000:Q1–2007:Q4
Financial[5]	GZ Spread (1)	US	Gilchrist and Zakrajšek (2012)	0.18	0.08	0.03	74	2004:M8–2010:M9
	GZ Spread (2)			0.18	0.11	0.09	74	2004:M8–2010:M9

(*continued*)

Table 2. (Continued)

Structural Shocks		Country	Related Studies	β	SE	P-value	Obs.	Sample
Inflation	Breakeven Inflation (10-year)	US	Drakos, Konstantinou, and Thoma (2020), Kose et al. (2019)	–0.07	0.05	0.15	185	2004:M8–2019:M12
	Inflation Expectation (Consensus Forecast, US)			–0.05	0.07	0.49	185	2004:M8–2019:M12
Oil Price	Oil Production	Global	Kilian (2008)	0.00	0.00	0.97	41	2004:M8–2007:M12
	Oil Price	Global	Ha, Kose, and Ohnsorge (2019)	0.00	0.00	0.69	41	2004:M8–2007:M12
News Shock	VAR(3) Residual	US	Barsky and Sims (2011)	–0.10	0.14	0.47	51	2000:Q1–2012:Q3
	VAR(4) Residual	US	Beaudry and Portier (2014)	–0.05	0.07	0.51	51	2000:Q1–2012:Q3
Productivity[6]	VAR(6) Residual	US	Levchenko and Pandalai-Nayar (2020)	–0.07	0.16	0.66	72	2000:Q1–2017:Q4

Note: 1. This table reports the estimates (β_i) of regression (7). Newey-West heteroskedasticity and autocorrelation consistent (HAC) standard errors are reported.
2. MP1, MP2, FF1, and FF2 indicate the monetary policy shocks identified using intraday movements of federal funds futures rates as suggested by Gertler and Karadi (2015).
3. Three-month-ahead measures of macro and financial uncertainty are taken from Jurado, Ludvigson, and Ng (2015).
4. Exogenous tax changes (1) and those based on the present value (2) are taken from Romer and Romer (2010).
5. Predicted GZ spreads (1) and those controlled for the term structure and interest effects (2) are taken from Gilchrist and Zakrajšek (2012).
6. Following Levchenko and Pandalai-Nayar (2020), residuals of labor productivity are regarded as a proxy for productivity, estimated in the six-variable VAR: labor productivity, real GDP, private consumption, investment, employment, and consumer price.

often coincided with global financial distress in the late 2000s, which led to subsequent global slowdowns, and policy spillovers from a center country. However, the explanatory power, as measured by $\bar{R}^2$ in the regression, was generally less than 5 percent.[13]

In a similar vein, Figure C.6 provides a summary of correlation coefficients between inflation uncertainty and other shocks in a box chart format. Each box and whisker is characterized by 14 (G7 and EM7) correlations between inflation uncertainty in an individual country and the aforementioned shocks or uncertainties. The results largely align with our findings, demonstrating no significant correlations between inflation uncertainty and other structural shocks except in a few cases, such as monetary policy shocks (FF1), financial shocks (GZ spreads), and financial uncertainty.

3. Empirical Framework

Following the previous literature that examines the effects of uncertainty on economic activities, we estimate a panel SVAR model that includes seven endogenous variables—inflation uncertainty, consumer price inflation, GDP, consumption, investment, interest rates, and exchange rates. For the monthly data set, GDP, consumption, and investment are replaced by industrial production and the production of durable and non-durable consumption goods.

3.1 Methodology

In its structural form, the panel SVAR model is represented by

$$B_{i,0}Z_{i,t} = A_i + \sum_{j=1}^{L} B_{i,j}Z_{i,t-j} + \epsilon_{i,t}, \tag{8}$$

where $Z_{i,t}$ consists of seven endogenous variables for each country i. The vector $\epsilon_{i,t}$ consists of a shock to the inflation uncertainty ("*inflation uncertainty shock*") and other types of structural

[13]Except in the case of GZ credit spreads that do not control for term structure and interest rate effects, $\bar{R}^2$ of the correlation regression reaches around 28 percent. This high explanatory power of GZ credit spreads might be, at least partly, due to the short sample period (2004:M8–2010:M9), which includes the global financial crisis.

macroeconomic and financial shocks corresponding to the other variables. The model enables us to assess the impacts of inflation uncertainty shocks on output, inflation, and financial variables.

The baseline strategy for the identification of global inflation uncertainty shocks is to employ recursive restrictions by using Cholesky decomposition of variance-covariance as in Baker, Bloom, and Davis (2016), Leduc and Liu (2016, 2020), and Levchenko and Pandalai-Nayar (2020). The inflation uncertainty indicator is ordered first, assuming that a structural shock in inflation uncertainty does affect other variables within a period while other structural shocks do not influence the inflation uncertainty indicators. This short-run identification assumption considers that the surveys on inflation are executed during the current period (t)—usually around the middle of the month—while the macroeconomic and inflation variables are observed at the time ($t + 1$).

That said, the direction of causation between inflation uncertainty and inflation and economic activity remains debatable. In this regard, to check the sensitivity of the baseline results, we additionally consider two alternative identification schemes: (i) Cholesky restriction that orders the uncertainty last, or (ii) generalized impulse response functions that are not conditional on the variable ordering.

Bayesian method is used in estimating the SVAR model. The procedure draws 1,000 iterations with 500 burn-ins. In reporting the impulse response functions, we present the median of the 500 draws and 16–84 percentile confidence intervals for each forecasting horizon. In the Bayesian estimation, the independent normal-Wishart priors are used.

3.2 Data

Following Barsky and Sims (2012), Leduc and Liu (2020), and Levchenko and Pandalai-Nayar (2020), we include various macro and financial indicators in the VAR system. Monthly data are employed as a baseline for 2004–19.[14] For the estimation of the panel SVAR model, G7 and EM7 data are pooled together or by country groups.

[14] In the literature on the impact of uncertainty, many existing studies used quarterly data, partly due to the unavailability of monthly GDP data. By employing monthly data, it is expected that the identification of the impacts of inflation uncertainty is more accurately obtained.

First, levels of inflation uncertainty indicators are employed. As explained in the previous section, each measure of inflation uncertainty is subject to measurement errors, and we use here the common inflation uncertainty, estimated by using the first principal component of different inflation uncertainty measures. Month-on-month growth rates of industrial output (total, consumption goods on durable and non-durable goods) are employed as proxies for business cycle fluctuations. Inflation rates are based on month-over-month inflation rates of the consumer price index. Interest rates are based on three-month Treasury-bill (TB) yields or policy rates depending on the data availability. For exchange rates, nominal effective exchange rates (NEERs) are used.

To supplement the monthly results, examine the impact of inflation uncertainty on private consumption and investment, and date back to a more extended period up to the 1970s; the panel SVAR model is also estimated using quarterly data. In this case, GDP, private consumption, and investments are used along with inflation, interest rates, and exchange rates as endogenous variables.

4. Empirical Results

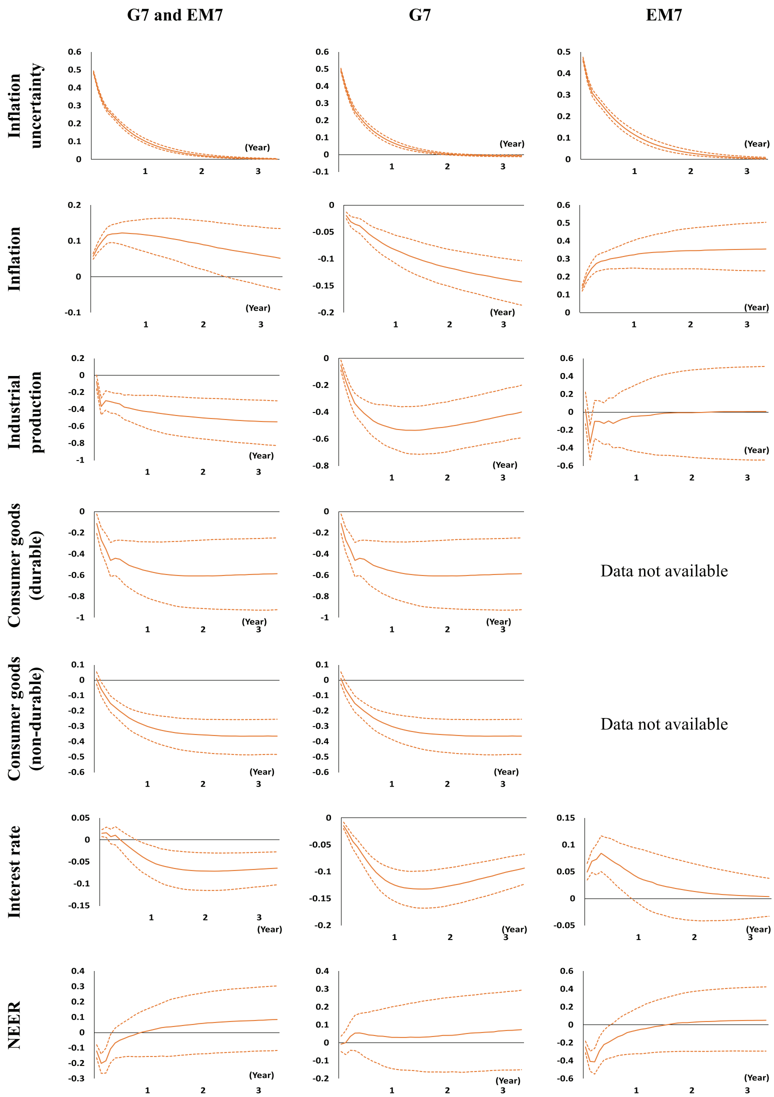
4.1 Impact of Inflation Uncertainty on Economic Growth

Figure 2 presents the dynamic responses of the macroeconomic and financial variables in G7 and EM7 to a positive inflation uncertainty shock, based on monthly (panel A) and quarterly (panel B) data sets. We first explore the results based on monthly data and then check the quarterly results. The sample periods are 2004–19 for both exercises.

Output. Inflation uncertainty exhibits countercyclical properties (as shown in the first column of the figure for the combined results for G7 and EM7). Following a one-standard-deviation increase in the uncertainty, monthly industrial production declines by up to 0.6 percentage point (about 7 percentage points annually), whereas the production for durable goods (0.6 percentage point) declines more dramatically than non-durable goods (0.3 percentage point). The negative responses of outputs following the inflation uncertainty shock are in line with, inter alia, the *wait-and-see* effect that economic agents would optimally pause their investments in

Figure 2. Impulse Responses of Variables to Inflation Uncertainty

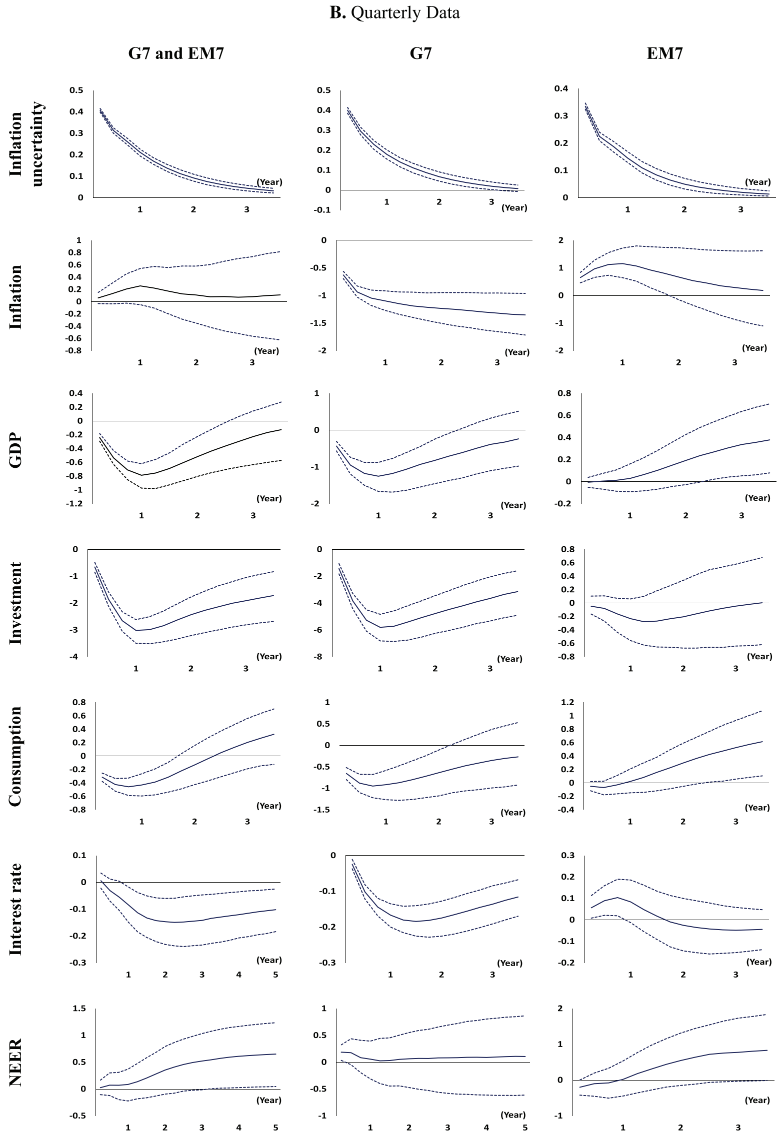
A. Monthly Data



Note: The y-axis indicates percent (or percentage point for interest rate). The x-axis indicates years after shock. Broken lines are the 16 and 84 percentiles of the empirical distribution based on Bayesian estimation.

(*continued*)

Figure 2. (Continued)



Note: The y-axis indicates percent (or percentage point for interest rate). The x-axis indicates years after shock. Broken lines are the 16 and 84 percentiles of the empirical distribution based on Bayesian estimation.

productive activities and purchases in durable goods and wait until the uncertainty mainly disappears. This is consistent with the finding of Binder (2017) that more uncertain consumers are more reluctant to spend on durable goods, cars, and homes. Our results also align with Grier and Perry (2000), or more recently with Caglayan, Kocaaslan, and Mouratidis (2016), who use time-series models to show the contractionary effects of inflation uncertainty.

Inflation. The dynamic responses of CPI inflation following the inflation uncertainty shock are moderately positive (up to 0.1 percentage point) over the forecasting horizon.[15] This relationship is consistent with what Cukierman and Meltzer (1986) argued. Combined with the dynamic responses of output variables, these results suggest that the main drivers of inflation uncertainty may have been supply-side shocks, including oil price shocks or domestic crises and the subsequent currency depreciation, at least based on the combined data of G7 and EM7.[16]

Financial Variables. Interest rates (three-month TB yields) fall persistently by up to 0.1 percentage point following an increase in inflation uncertainty. The negative effects may reflect the responses to accommodative policy, which aims to attenuate domestic economic slowdowns. NEERs do not point to any significant reactions, at least based on an aggregate (panel) result.

Results Using Quarterly Data. As shown in panel B of Figure 2, the results are consistent when employing quarterly data over the same sample period. Following a heightened inflation uncertainty, domestic output unambiguously declines while inflation responds positively (although statistically insignificant). That said, there are some nuanced differences in the reactions of output variables: the responses of outputs and consumption return to normal levels around three years after the shock. Meanwhile, the impacts are most sizable and persistent on investment, consistent with the results from monthly frequency data, which report more pronounced impacts on durable than non-durable goods. Based on quarterly data, the effects

[15] As will be discussed in the next sub-section, the moderate response of inflation is partly attributable to the heterogeneous responses of the variable across different country groups.

[16] Underlying channels of demand- or supply-driven uncertainty shocks will be discussed further in Section 5.

on interest rates are negative (accommodative), and those on NEER are not statistically significant.

4.2 Group-Specific Evidence

We now present the empirical results across two different groups of countries: G7 (in the second column of Figure 2) and EM7 (in the third column). The results are both similar and different across the two country groups based on the variables.

Output. The dynamic responses of output (monthly industrial production) are overall (qualitatively) consistent but quantitatively different across G7 and EM7. More specifically, the negative impacts of inflation uncertainty on economic activities are much more sizable for G7 economies such that industrial production declines by 0.5 percentage point (6 percentage points annually), and the impacts are maximized around two years after the shock. Meanwhile, the negative impacts on industrial production are up to around 0.3 percentage point in EM7 (3–4 percentage points annually). The more sizable and significant effects on outputs in G7 may reflect more synchronized movements of outputs among G7 than among EM7.[17] In the case of G7, where the data for durable and non-durable goods consumption are available for all countries, the impacts of inflation uncertainty are again more sizable for the consumption of durable goods than non-durable goods.

Inflation. The impacts on inflation were dynamically opposite across the country groups.[18] Among G7, inflation significantly and consistently declines following a positive inflation uncertainty shock, suggesting that inflation may have been driven mainly by negative demand shocks (Leduc and Liu 2016; Basu and Bundick 2017). On the contrary, inflation uncertainty is followed by a rapid, albeit short-lived, increase in inflation in EM7, which observation

[17]Although not shown in the paper, we also estimated the models based on country-specific data (rather than panel data). The results are quite homogeneous among G7 economies, while they were more heterogeneous regarding the magnitude, persistence, and statistical significance of the impulse response functions.

[18]Indeed, inflation uncertainty rose sharply around the global financial crisis in 2008–09 in all G7 countries.

is consistent with the positive correlation between inflation uncertainty and inflation around the episodes of sharp rising food and energy prices in those countries, as explained in Section 2.[19] This positive relationship is also documented in Fountas (2010), Berument, Yalcin, and Yildirim (2011), and Jiang (2016), supporting the Cukierman–Meltzer (1986) hypothesis.[20]

Financial Variables. The responses of interest rates are again in the opposite direction across G7 and EM7 economies. Interest rates decline in G7 following a heightened inflation uncertainty while they rise in EM7. The effects on NEER are insignificant in G7, while the heightened inflation uncertainty leads to currency depreciation in EM7 countries, which could have been another important source of inflationary effects of the inflation uncertainty.

Results Using Quarterly Data. Again, the heterogeneous results across G7 and EM7 are confirmed with the estimation using quarterly data (as shown in panel B of Figure 2). These include more sizable and persistent effects of inflation uncertainty on investments than consumption in both G7 and EM7 and heterogeneous impact on inflation and interest rates across the two country groups.

Policy Implication. Inflation uncertainty shocks have different impacts across the country groups. Unlike their consistent contractionary impacts in G7 and EM7, albeit stronger in G7, the uncertainty shocks lower inflation in G7 but raise it in EM7. This implies that the shocks resemble demand-side shocks in G7 and supply-side shocks in EM7. Remarkably, short-term interest rates decline in G7 upon the shocks, while the rates rise in EM7. As elaborated upon above, these heterogeneous responses to the inflation uncertainty shocks may reflect the different underlying drivers of inflation uncertainty or the different states of the economy in each group.

From the perspectives of policy reaction to inflation, the dynamic responses of short-term interest rates are consistent with the effects of inflation uncertainty on inflation—i.e., policy accommodation

[19] An increase in inflation could also reflect the pricing behavior of firms, which will be elaborated upon in Section 5. Firms prefer to adjust their current prices to insure themselves from the risks of being stuck with low prices in the future. In economies with a historical prevalence of high inflation, this pricing behavior and the associated supply-side channel are likely to be more pronounced.

[20] See also Mumtaz and Theodoridis (2015) and Katayama and Kim (2018) for the related theoretical mechanisms.

against deflationary pressure in G7 and policy tightening in reaction to inflationary pressure in EM7. The adoption of inflation targeting has facilitated the policy action being more aggressive in this process (McGettigan et al. 2013; Thornton and Vasilakis 2017).

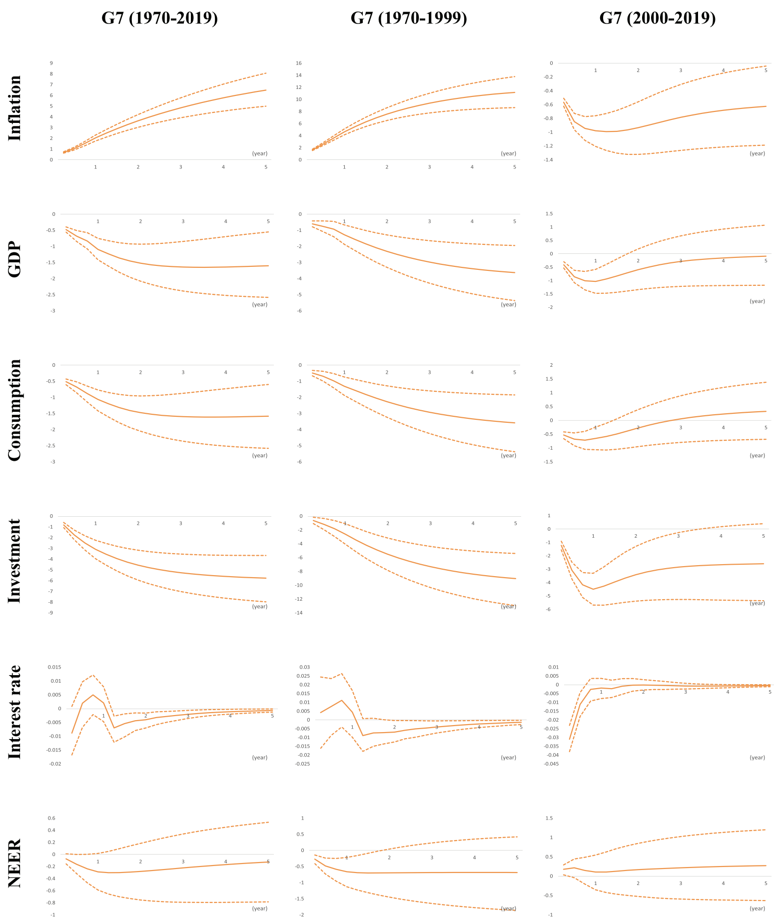
The policy reaction, in conjunction with the responses of output and exchange rates, can also provide alternative implications from a different angle. A large literature on the cyclical properties of policy documents that monetary policy in practice is countercyclical (or acyclical) in advanced economies, but it is procyclical in emerging market economies (*when it rains, it pours* phenomenon; Kaminsky, Reinhart, and Végh 2005). Given the correlation between short-term rates and the business cycle, this implies that in bad (good) times, the interest rate is reduced (raised) in advanced economies while it is raised (reduced) in emerging economies, a pattern also observed in our results. Particularly, monetary policy procyclicality in emerging economies may be at least partially because central banks seek to defend their currency against depreciation in times of negative shocks (*fear of floating;* Calvo and Reinhart 2002). Put differently, the capacity of central banks to implement countercyclical policy is often constrained by the potential devaluation of their exchange rates due to capital outflows (Cordella and Gupta 2015; Ocampo and Ojeda-Joya 2022).[21]

4.3 Time-Specific Evidence

In G7 economies, quarterly data are available for a longer-term period, dating back to the 1970s. Using the quarterly data, we now investigate whether the impacts of inflation uncertainty have changed over time. To this end, the sample periods are divided into two sub-groups: 1970–99 and 2000–19. The latter sub-sample overlaps with our baseline sample period (2004–19). During the first period, the global economy experienced a series of global recessions in 1975, 1982, and 1991, mainly associated with the historical oil crises. The second sample period coincides with the Great Moderation, although global inflation registered significant volatility around

[21]Végh et al. (2017) and Ocampo and Ojeda-Joya (2022) argue that the monetary policy dilemma, which involves making decisions between economic growth and stable inflation in response to negative supply shocks, is more pronounced in emerging markets because of procyclical capital flows.

Figure 3. Impulse Response to Inflation Uncertainty: 1970:Q1–2019:Q4



Note: The y-axis indicates percent (or percentage point for interest rate). The x-axis indicates years after shock. Broken lines are the 16 and 84 percentiles of the empirical distribution based on Bayesian estimation.

the global financial crisis in 2008–09 and the period of large oil price plunges in the mid-2010s.

As depicted in Figure 3, the impacts of inflation uncertainty have changed over time. The effects on GDP growth were contractionary over both periods. However, the consequences were much more sizable and significant during the first period (up to –4 percentage points following a one-standard-deviation inflation uncertainty shock) than the second period (1 percentage point).

Inflation significantly rose following a heightened inflation uncertainty in the pre-2000 sample period, while it declined in the post-2000 period. Again, the results suggest potential differences in the underlying shocks that have driven inflation uncertainty. Increases in inflation uncertainty may reflect the large adverse supply shocks—including the oil crises in the 1970s and 1980s and the early 1990s, as argued by Leduc, Sill, and Stark (2007) based on U.S. data. Meanwhile, the heightened inflation uncertainty after the global financial crisis in 2008–09, as well as the euro-area debt crises and oil price plunges in the mid-2010s, may point to the effects of large negative demand or positive supply shocks. The halved magnitude of the impacts on inflation during the second sample period may also reflect the better-anchored inflation expectations—with the help of the improved monetary policy frameworks including inflation targeting—that are expected to make the effects of demand- and supply-side economic shocks less persistent.[22] Consistent with the dynamic responses of output and inflation, interest rates clearly and significantly declined in the second period. In contrast, the reactions of interest rates are moderately positive, although not statistically significant, during the first period.

5. Theoretical Channels of the Inflation Uncertainty

Our empirical results clearly show that adverse shocks in inflation uncertainty were significantly associated with declines in output, consumption, and investment in both G7 and EM7 countries. However, an anomaly in the response of inflation to the shocks is also observed across the two country groups and over the sample periods. This may reflect the different nature of underlying shocks behind

[22]In fact, the studies provide the abundant evidence that, counteracting more aggressively against inflationary pressure, monetary policy is implemented now with more agility than in the past (Lubik and Schorfheide 2004; Cogley and Sargent 2005).

the inflation uncertainty and their propagation into the economy.[23] In this section, we provide a further explanation for the transmission channels of inflation uncertainty in a DSGE model as described below.

5.1 Main Features of the Model

Our model is primarily an extension of Basu and Bundick (2017), which incorporates the role of uncertainty in the model economy. This choice offers several advantages.

First, the framework enables us to reproduce the negative co-movement of macro variables easily—including output—caused by inflation uncertainty shocks, which was observed in our empirical exercises. In fact, Basu and Bundick (2017)'s original model adopts the preference uncertainty in a New Keynesian framework, successfully generating the stylized facts of business cycle co-movements among output, consumption, investment, and employment following uncertainty shocks. However, less attention has been paid to the response of inflation in their model, which can be heterogeneous, as shown in Section 4. Together with the impacts of the shocks on the macroeconomy, we will explore the response of inflation.

Another appealing feature of the model is that it considers demand- and supply-side drivers of inflation uncertainty. Specifically, in the model, a heightened inflation uncertainty leads not only to a decline in consumption (or an increase in precautionary saving) but also to an increase in labor supply. Depressed consumption, in turn, reduces aggregate demand, thereby dampening labor demand. Hence, inflation uncertainty in nature may simultaneously bring about varying effects on the labor market. Under the assumption of sticky prices and countercyclical markups, a decrease in labor demand may surpass the effects of an increase in labor supply, and as a result, employment (hours worked) would decline. Furthermore, inflation uncertainty has additional impacts, which raise inflation

[23] As argued in the previous sections, following a rise in inflation uncertainty, for instance, inflation can decline if the inflation uncertainty is mainly driven by adverse demand shocks—i.e., deflationary pressures. Meanwhile, inflation would rise when inflationary adverse supply shocks are more critical in driving inflation uncertainty.

and price markups by affecting firms' pricing decisions. Considering the effects of inflation uncertainty on demand and supply, we can explore the different views on the relationship of inflation uncertainty with economic growth and inflation. (For detailed discussions on the different views in the literature, see Appendix A.)

Given the similarities between our model and Basu and Bundick (2017), this section focuses solely on the critical features of the model, particularly the relationship between inflation uncertainty and macro variables. (A more detailed description of the model is presented in Appendix D.) Specifically, our model deviates from Basu and Bundick (2017) by considering the inflation uncertainty process, which affects both demand- and supply-side channels. In our setup, we consider the inflation uncertainty, which evolves with a stochastic process, parameterized as

$$\Gamma_t = (1 - \rho_\Gamma)\,\Gamma + \rho_\Gamma \Gamma_{t-1} + \sigma^\Gamma_{t-1}\varepsilon^\Gamma_t \tag{9}$$

$$\sigma^\Gamma_t = (1 - \rho_{\sigma^\Gamma})\,\sigma^\Gamma + \rho_{\sigma^\Gamma}\sigma^\Gamma{}_{t-1} + \sigma^{\sigma^\Gamma}\varepsilon^{\sigma^\Gamma}_t, \tag{10}$$

where ε^Γ_t and $\varepsilon^{\sigma^\Gamma}_t$ denote first- and second-moment shocks which capture innovations to the stochastic process for the level and the volatility of inflation uncertainty, respectively. The two stochastic shocks are orthogonal and follow the standard normal distribution. The second-moment shocks are referred to as the inflation uncertainty shock.

We assume that this process affects the model economy in two ways. First, it works as an ingredient that determines nominal bond yields. Specifically, motivated by the recent macro-finance literature (e.g., Haubrich, Pennacchi, and Ritchken 2012; Hördahl and Tristani 2012; Bianchi, Kung, and Tirskikh 2018), we adopt the relationship that a nominal bond rate R_t can be decomposed into inflation risk-free rate R^*_t and premium compensated for variations of inflation risk Θ_{t+1}. In real terms, Θ_{t+1} represents a wedge between inflation risk-free real rates and ex ante real rates. In addition, Θ_{t+1} is assumed to be a linear function of an evolution of the stochastic process of $\Gamma_t(= E_t[\Gamma_{t+1}/\Gamma_t])$.[24]

[24]Our focus is not on embedding the term structures, which typically relies on flexible features of the pricing kernel, but on investigating directly the impacts of

$$R_t = R_t^* \Theta_{t+1} \tag{11}$$

Second, inflation uncertainty can affect a firm's price setting. To the extent that higher inflation uncertainty leads to a more flexible price change, we assume that a quadratic cost of adjusting nominal price $P_t(i)$ that each monopolistic firm i faces is subject to the inverse of Γ_t, as given by

$$\frac{\phi_p}{2\Gamma_t}\left[\frac{P_t\left(i\right)}{\Pi P_{t-1}\left(i\right)} - 1\right]^2 Y_t, \tag{12}$$

where ϕ_p denotes the degree of nominal price rigidity and Y_t denotes the final good. Similar to Bundick and Smith (2021), this setup can be interpreted that inflation uncertainty affects price adjustment cost via the long-term inflation level (Π).[25]

These properties together allow us to rethink the main equations in the model—nominal Euler equation and the Rotemberg-type New Keynesian Phillips curve (NKPC henceforth)—deviated from those of the standard model. First, the Euler equation for a zero net supply of nominal bonds can be reformulated in terms of inflation risk-hedged yield and inflation risk premium, which is a function of Γ_t as in (13):

$$1 = R_t E_t\left[\frac{M_{t+1}}{\Pi_{t+1}}\right] = R_t^* E_t\left[\frac{M_{t+1}}{\Pi_{t+1}}\Theta_{t+1}\right], \tag{13}$$

inflation uncertainty on the nominal bond yields. In addition, Θ_{t+1} differs to some extent from the conventional *inflation risk premium.* As elaborated in Bianchi, Kung, and Tirskikh (2018), inflation risk premium can be typically expressed in terms of the second-moment relations between inflation and stochastic discount factor in the Euler equation. Hence, Θ_{t+1} can be viewed as the uncertainty-related process which induces the shocks into such second-moment relations.

[25] Another interpretation for this feature is that the uncertainty around inflation directly affects price misalignment from the desired level, and thus raises the probability of price adjustment (Grier and Perry 1996; Luo and Villar 2021). For example, Drenik and Perez (2020) conjecture that the aggregate price level is subject to the state of the economy (named as the common knowledge component) and the standard deviation of the noise of the aggregate price signal, which is time dependent. In addition, Jin and Wu (2021) show that high uncertainty attenuates cost stickiness by deteriorating firms' expectations of future demand and adjustment costs.

where M_{t+1} and Π_{t+1} are a stochastic discount factor (SDF) and an inflation rate between t and $t+1$, respectively.[26,27]

In addition, with a cost of changing prices given as (12), solving the maximization problem of a firm's cash flows yields the Phillips curve as

$$\begin{aligned}\phi_P\left(\frac{\Pi_t}{\Pi\Gamma_t}-1\right)\left(\frac{\Pi_t}{\Pi\Gamma_t}\right) &= 1-\theta_\mu+\frac{\theta_\mu}{\mu_t}\\ &+\phi_P E_t\left[M_{t+1}\frac{Y_{t+1}}{Y_t}\left(\frac{\Pi_{t+1}}{\Pi\Gamma_{t+1}}-1\right)\left(\frac{\Pi_{t+1}}{\Pi\Gamma_{t+1}}\right)\right], \end{aligned} \tag{14}$$

where μ_t is the markup of price over marginal cost, and θ_μ is the elasticity of substitution for intermediate goods. Because all firms face the same maximization problem, the same price and the same quantity are chosen, i.e., $P_t(i) = P_t$ and $Y_t(i) = Y_t$, and the NKPC can be expressed in a symmetric equilibrium.

5.2 Transmission Channels of Inflation Uncertainty

Guided by the two modified equations, we now investigate the main mechanisms of interaction between inflation uncertainty and macro variables.

[26]Since we consider the representative household's utility maximization problem under Epstein-Zin preferences identical to Basu and Bundick (2017), M_{t+1} is derived as

$$M_{t+1}=\beta\frac{a_{t+1}}{a_t}\left(\frac{u\left(C_{t+1},\ N_{t+1}\right)}{u\left(C_t,\ N_t\right)}\right)^{\frac{1-\sigma}{\theta_V}}\left(\frac{C_t}{C_{t+1}}\right)\left(\frac{V_{t+1}^{1-\sigma}}{E_t\left[V_{t+1}^{1-\sigma}\right]}\right)^{1-\frac{1}{\theta_V}},$$

where $u\left(C_t,\ N_t\right)=C_t^{\eta}\left(1-N_t\right)^{1-\eta}$ and σ, ψ are risk aversion and intertemporal elasticity of substitution, respectively, ($\theta_V=(1-\sigma)\left(1-\frac{1}{\psi}\right)^{-1}$).

[27]It is noteworthy that this allows us to reinterpret the monetary policy rule such that the central bank in the model adjusts R_t^*, additionally taking the evolution of inflation risk into consideration.

$$\begin{aligned}log\left(R_t^*\right) &= \left(1-\rho_{R^*}\right)\left[log\left(R^*\right)+\rho_\Pi log\left(\frac{\Pi_t}{\Pi}\right)+\rho_Y log\left(\frac{Y_t}{Y_{t-1}}\right)\right]\\ &+\rho_{R^*}log\left(R_{t-1}^*\right)-log\left(\Theta_{t+1}\right)\end{aligned}$$

In Equation (13), higher inflation uncertainty brings about a precautionary saving effect by dampening the demand for consumption goods. The fall in consumption leads to a decline in aggregate demand, thereby reducing output through the national income account identity ($Y_t = C_t + I_t$). A decrease in output (Y_t) also deteriorates the marginal revenue product of capital and labor, thus lowering the demand for capital stock (K_t) and labor (N_t) as well as firms' marginal costs. The reduced investment puts more downward pressure on output. Notably, this demand-side channel would be prone to the degree of risk aversion: the more risk-averse households are, the less they consume.

On the other hand, increased inflation uncertainty induces two different effects on firms' pricing decisions. To examine the firms' decision for pricing, (14) is rewritten in infinite sum form as

$$\left\{ E_t \sum_{j=0}^{\infty} M_{t,t+j} \left(1 - \theta_\mu + \frac{\theta_\mu}{\mu_{t+j}}\right) Y_{t+j} \right\} - \phi_P \left(\frac{\Pi_t}{\Pi\Gamma_t} - 1\right) \frac{\Pi_t}{\Pi\Gamma_t} Y_t = 0. \tag{15}$$

According to Equation (15), firms first lower their prices to boost the demand for output, implying a decline in inflation, when they face a fall in marginal costs caused by inflation uncertainty. Due to the existence of price adjustment costs, a decrease in the prices is smaller than that of the marginal costs, thereby inducing a rise in markups. Furthermore, Equation (15) also indicates that inflation uncertainty shocks raise inflation and markups by shifting up the New Keynesian Phillips curve. In the labor market, these effects lower labor demand in sequence, and thus, despite an increase in precautionary labor supply, hours worked (N_t) would finally decline in response to a heightened inflation uncertainty.[28]

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[28]As illustrated in Basu and Bundick (2017), an increase in uncertainty also reduces labor demand as markups rise under the assumption of price stickiness. Intuitively, this is because labor is the only input that can change, consistent with a reduction of output. Subsequently, for a firm's labor

In short, swings in inflation uncertainty would negatively influence both aggregate demand and supply, leading to a contraction in output and its components including consumption and investment.[29] Unlike the reactions of other macro variables, however, inflation can either increase (similar to Cukierman and Meltzer 1986) or decrease (Holland 1995) in response to inflation uncertainty shocks. This is because the inflation response would be finally determined by the relative significance of the aforementioned demand- and supply-side channels. Among the determinants which produce such a difference between aggregate demand and supply, we focus on the risk appetite of economic agents because it substantially affects the size of the household's precautionary savings and firms' markups.[30]

5.3 Quantitative Results

We now quantitatively examine the impacts of inflation uncertainty shocks on macro variables. The model is calibrated and solved, primarily taking the parameter values from Basu and Bundick (2017). Notably, for our baseline simulation, we also set the risk-aversion parameter σ as 80. In addition, those for the stochastic process of the first- and the second-moment inflation uncertainty are chosen such that ρ_Γ and ρ_{σ^Γ} are set to 0.85, and σ^{σ^Γ} is set to 0.001.

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demand to decrease, markup should rise, as given by the labor demand equation:

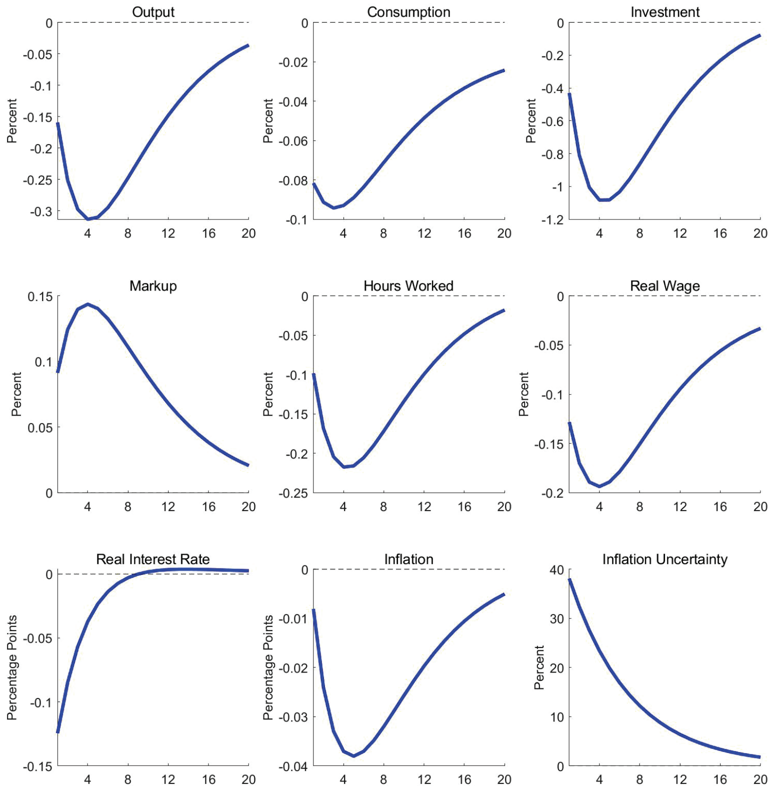
$$\frac{W_t}{P_t} N_t\left(i\right) = \frac{1-\alpha}{\mu_t}\left[K_t\left(i\right) U_t\left(i\right)\right]^{\alpha}\left[Z_t N_t\left(i\right)\right]^{1-\alpha}.$$

[29]Under the assumption of price flexibility, however, hours worked increase due to precautionary labor supply while labor demand stays unchanged. Hence, depending on the price stickiness and the relative significance of impacts on aggregate demand and supply, inflation uncertainty can have either positive or negative impacts on economic growth, as summarized in Appendix A.2.

In addition, under the Calvo pricing setup, the uncertainty shocks can generate additional effects on firms' pricing decisions. Different from the Rotemberg model, the Calvo model assumes relative price dispersion so that it allows firms to determine their prices in a risk-averse manner. Hence, on an uncertainty shock, firms set their prices higher than those under certainty to maximize their profits and to insure against future potential losses from low prices. As a consequence, inflation increases as markups rise by more (*precautionary pricing effect;* Oh 2020).

[30]See Fernández-Villaverde and Guerrón-Quintana (2020) for the detailed explanation on the determinants.

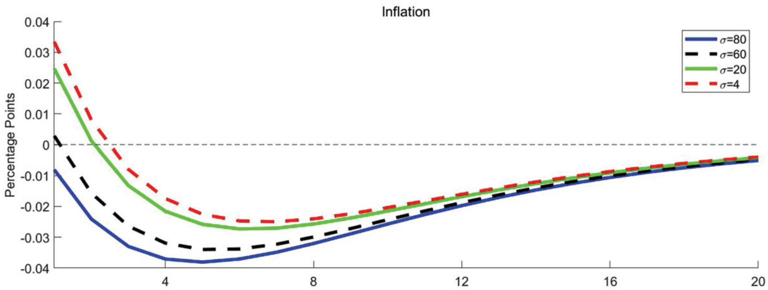
Figure 4. Model-Implied Responses to the Inflation Uncertainty Shock



Note: The x-axis represents the quarters after inflation uncertainty shocks, and the y-axis is the deviation from the steady state in percent (percentage points).

Figure 4 summarizes the impulse responses for the second-moment shock (i.e., inflation uncertainty) with the baseline parameter values. The impulse responses of the model are in line with our prediction and our empirical findings: output, consumption, investment, and hours worked all decrease while markup rises in a countercyclical manner. More specifically, on an inflation uncertainty shock, households consume less due to the demand channel postulated mainly in (13), and it reduces output. Consequently, this leads to a fall in marginal revenue of capital, and thus investment declines. Also, hours worked in equilibrium decrease since an

Figure 5. Responses to the Inflation Uncertainty Shock under Different Risk Aversion



Note: The x-axis represents the quarters after inflation uncertainty shocks, and the y-axis is the deviation from the steady state in percentage points.

increase in markups triggered by inflation uncertainty shocks reduces labor demand. In sum, both demand- and supply-side channels of inflation uncertainty have negative impacts on economic activities, as observed in our empirical analysis in Section 4 and the recent literature including Binder (2017).

The responses of inflation, however, turn out to be heterogeneous depending upon the degree of risk aversion. Figure 5 compares the impulse responses of inflation with four values of the risk-aversion parameter ($\sigma = 80$ for the baseline and $\sigma \in \{4, 20, 60\}$ for comparison). The response of inflation remains negative throughout the simulation periods with the baseline risk-aversion value ($\sigma = 80$, blue line). However, with smaller risk aversion, inflation exhibits even a positive response to the impacts and then it reverses to negative no later than one year after the shock. This heterogeneous response of inflation implies that the demand-side channel of inflation uncertainty dominates in a risk-averse state of the economy while the supply-side channel acts more strongly in a risk-tolerant state, at least in the short run.

6. Conclusion

This paper adopts four different measures for inflation uncertainty (survey, model, forecast, and news based) and identifies key trends of the uncertainty over the past two decades. The fluctuations of uncertainty broadly coincide with major global crises as well as country-specific events. The current level of inflation uncertainty, mainly due to the COVID-19 pandemic, is as high as in the previous global crises of the late-2000s and 1970s/1980s.

Using a Bayesian panel SVAR, we empirically test the impacts of inflation uncertainty across country groups and periods. Our results suggest that heightened inflation uncertainty generally leads to weakening economic activities, including output, investment, and consumption, with G7 countries experiencing more output losses due to inflation uncertainty than EM7 countries. Meanwhile, the impact of the uncertainty on inflation appears mixed across the country groups. Our results also show that in G7 countries, the impact of uncertainty on inflation has varied over time. Unlike G7 countries, where the inflation rate drops in response to higher uncertainty, EM7 countries usually experience higher inflation. The inflation uncertainty had negative (dis-inflationary) impacts on the inflation rate in the 2000s/2010s, potentially due to adverse demand shocks. In comparison, it had positive (inflationary) effects in the 1970s through 1990s, when adverse supply shocks frequently occurred.

With the help of a simple DSGE model incorporating inflation uncertainty, we also investigate the transmission channels of inflation uncertainty to macroeconomic variables. Consistent with our empirical findings, this exercise suggests that inflation uncertainty shocks have adverse impacts on outputs, consumption, and investments but have heterogeneous effects on the inflation rates depending upon the primary underlying sources of inflation uncertainty. More specifically, the inflation uncertainty shocks transmitted mainly through the economy's demand channels tend to lead to lowered inflation rates. In contrast, those through supply-side channels result in higher inflation rates. Moreover, the degree of risk aversion plays a vital role in determining the dominant channels in the economy.

Policymakers should adjust the assessments of economic and inflation conditions and outlook, including the expected effects of their monetary policies on future economic conditions, flexibly and preemptively. On the one hand, our results suggest that the heightened uncertainty for future inflation will strain long-term economic growth, mainly through weakening investments. This implies that the policymakers should react aggressively, even to small deviations from an inflation target, to avoid the adverse effects of inflation deviations from a target. Having said that, on the other hand, our results also imply that for policymakers to reduce policy errors due to misunderstanding about future economic conditions and finally have an appropriate policy stance, they must clearly understand the underlying sources of the uncertainty for future inflation.[31] In doing so, central banks should take more caution when delivering forward guidance to reduce adverse impacts of inflation uncertainty on the economy.

In this paper, we focused on the causal effects of inflation uncertainty on economic growth and inflation and did not explore the opposite directional relationship—such as the impacts of inflation shocks or real business cycle shocks on inflation uncertainty. We will leave these for future research.

Appendix A. Literature Review

A.1 Inflation Uncertainty Measures

Given that inflation uncertainty is an unobserved variable, many different types of uncertainty measures have been proposed in the literature. Some studies rely on survey measures, while others depend on inflation volatility derived from time-series models. Another strand of literature employs realized forecast errors. Since each measure is based on distinct assumptions unlikely to be fulfilled, they are prone to idiosyncratic measurement errors. Hence, the empirical results on the impact of inflation uncertainty depend crucially on the choice of the uncertainty measure.

Several studies have compared various types of inflation uncertainty measures. For instance, Batchelor and Dua (1993, 1996) compared inflation uncertainty derived from subjective probability distributions obtained from the U.S. Survey of Professional Forecasters with model-based measures. They find little significant correlation

[31] For instance, by using a medium-scale DSGE model, Madeira, Madeira, and Monteiro (2023) investigate how dissent in the Federal Open Market Committee is affected by structural macroeconomic shocks. They find that dissent is less (more) frequent when demand (supply) shocks are the predominant source of inflation fluctuations and that supply shocks are found to raise private-sector forecasting uncertainty about the path of interest rates.

between both categories. Using uncertainty measures obtained from professional forecasts as a reference point, Giordani and Söderlind (2003) conclude that model-based estimates generally struggle to detect regime changes promptly. However, they point out that the standard deviation of a VAR-estimated uncertainty on a rolling window successfully tracks the time profile of SPF uncertainty. Meanwhile, Giordani and Söderlind (2003) also compare different inflation uncertainty measures: standard deviation of point forecast, survey based, and time-series model based. They show that cross-sectional dispersion and standard deviations from the VAR model perform well. Chua, Kim, and Suardi (2011) employ a particular GARCH model that closely matches the professional forecast measure. In what follows, we provide more details of the related studies, particularly survey-based and model-based measures.

A.1.1 Survey-Based Measures

Some studies use surveys of professional forecasts for CPI inflation conducted by Consensus Economics. Besides the advantages listed in Section 2, using Consensus Economics data is beneficial because it is provided on a monthly frequency. Since uncertainty can experience sudden shifts, it becomes more challenging to discern many of the effects we wish to measure when using low-frequency data.

For the measurement of uncertainty, Bomberger and Frazer (1981), Bomberger (1996, 1999), and Giordani and Söderlind (2003) propose the cross-sectional dispersion (disagreement) of point forecasts. Since the forecast horizon varies for each month, the cross-sectional dispersion of forecasts is likely to be strongly seasonal and to converge towards zero at the end of each year (Lahiri and Sheng 2010). To obtain 12-month-ahead inflation forecasts, Dovern and Weisser (2011) calculate a weighted moving average of the annual forecasts. In addition, as the dispersion index does not consider the form of the distribution, Rich and Tracy (2010) suggest using a histogram-based entropy, which indicates the relative frequency of individual forecasts.

The literature has used density forecasts to study whether disagreement is a valuable proxy for average uncertainty but found conflicting evidence (Zarnowitz and Lambros 1987; Boero, Smith, and Wallis 2008; Lahiri and Sheng 2010; Rich and Tracy 2010).

Boero, Smith, and Wallis (2015) find that when the economy is turbulent, disagreement among professional forecasters can be a good indicator for average uncertainty; however, high-frequency movements in disagreement and uncertainty are not strongly correlated. While Bomberger and Frazer (1981), Bomberger (1996, 1999), and Giordani and Söderlind (2003) find supportive results for the usefulness of disagreement as a proxy for uncertainty, other studies report only a weak relationship or even reject the relationship (Zarnowitz and Lambros 1987; Lahiri, Tiegland, and Zaporowski 1988; Rich and Butler 1998; Döpke and Fritsche 2006; Rich and Tracy 2010). Lahiri and Sheng (2010) argue that disagreement is a reliable proxy for overall uncertainty, provided the forecast environment is stable.

Relatedly, micro-level inflation uncertainty measure has also been actively considered for a closer examination of the link between uncertainty and reported outcomes. Bachmann, Berg, and Sims (2015), for instance, discovered that survey participants who hold higher inflation expectations tend to report less favorable attitudes toward spending on durable goods such as cars and homes. When including the uncertainty measure based on rounding in comparable regression analyses, it becomes evident that more uncertain consumers also exhibit less favorable attitudes toward spending. Moreover, the coefficient on expected inflation remains small and negative. Binder (2017) uses round responses in pre-existing survey data and finds that inflation uncertainty is countercyclical and correlated with inflation disagreement, volatility, and the Economic Policy Uncertainty index. In addition, high-income consumers, college graduates, males, and stock market investors have the lowest level of uncertainty. Higher uncertainty leads to less favorable spending toward durables, cars, and homes.

A.1.2 Model-Based Measures

Conditional Forecast Error Variance. Autoregressive conditional heteroskedasticity (ARCH) models of many different types have been extensively used to model inflation uncertainty. Many studies have pointed out the existence of structural breaks in the inflation process. To accommodate events such as changes in monetary regime or variations in the level of steady-state inflation, the use of a generalized ARCH (GARCH) model with time-varying parameters is common practice. The flexibility of the GARCH model provides an advantage in that it accommodates non-stationarity in the inflation rate. By employing time-varying coefficients, Evans (1991) distinguishes between two types of inflation uncertainty: uncertainty regarding the short-term outlook for inflation, which is measured using the conditional variance of the residuals from the inflation equation, and uncertainty regarding the long-term outlook for inflation, which is measured using the varying coefficients of the inflation equation. Using time-varying coefficients, Berument, Kilinc, and Ozlale (2005) similarly distinguish among impulse uncertainty, structural uncertainty, and steady-state uncertainty. Caporale, Onorante, and Paesani (2012) estimate inflation uncertainty using AR-GARCH models and examine the linkage with inflation in a multivariate VAR framework.

Stochastic Volatility in Mean. Along with the GARCH model, an unobserved component stochastic volatility in mean (UCSVM) model is used (Kim, Shephard, and Chib 1998; Stock and Watson 2007, 2016; Chan 2017). Kim, Shephard, and Chib (1998) uses Markov chain Monte Carlo sampling methods to estimate stochastic volatility models and shows that SVM fits better than the GARCH model. Berument, Yalcin, and Yildirim (2009) employ SVM to construct monthly inflation uncertainty, and based on this, Chan (2017) develops SVM with time-varying coefficients in the conditional mean. Stock and Watson (2007, 2016) employ univariate and multivariate models that allow for common persistent and transitory factors, time-varying factor loadings, and stochastic volatility in the common and sectoral components.

A.2 Inflation Uncertainty, Inflation, and Economic Growth

A.2.1 Inflation Uncertainty and Economic Growth

Both the theoretical and empirical studies have documented mixed results on the relationship between inflation uncertainty and real economic activity.

Theories. There is still no consensus in the theoretical literature regarding the impact of inflation uncertainty on economic growth (Friedman 1977; Cecchetti 1993; Tommasi 1994; Dotsey and Sarte 2000; Berument, Kilinc, and Ozlale 2005). Tobin (1965), one of the pioneering studies in this area, argues that inflation uncertainty incentivizes households to hold a greater amount of real capital assets, which, in turn, promotes capital productivity and economic growth.[32] Dotsey and Sarte (2000) also suggest a positive correlation between economic growth and inflation uncertainty. When the volatility of money growth (inflation) increases, the expected return on money balances becomes uncertain. This leads to a decrease in the demand for real money balances and consumption. This increases precautionary savings, which in turn stimulates economic growth through a larger pool of investment resources, as higher anticipated inflation encourages investment.[33] Another explanation provided by Aghion and Saint-Paul (1998) and Blackburn (1999) relies on the models where technological change is the outcome of deliberate (internal) learning or research and development (R&D) activity. Increased uncertainty is then likely to enhance the long-run growth prospects through economic actions that substitute production activities.

The stagflation of the 1970s, however, stemming mainly from increases in oil prices, debunked the ideas and cast doubts on the existence of a positive relationship between inflation and economic growth (Friedman 1977; Ball 1992). Some studies suggest that inflation uncertainty reduces investment by hindering long-term contracts or by increasing the option value of delaying an irreversible investment (Kantor 1983; Kimball 1990; Lusardi 1998). Therefore, inflation uncertainty, as either the cause or the effect of inflation, negatively affects economic variables including consumption, investment, and growth. Inflation uncertainty implies uncertainty about real income, which would increase precautionary saving, and about the real return on saving, which would make saving less attractive for risk-averse consumers. Similarly, some argue that inflation uncertainty deteriorates the allocative efficiency of the price system if it is associated with increased variation in relative prices. Inflation can

[32]Tobin (1965) suggests that higher anticipated inflation can lead to an increase in capital per head, as households adjust their asset portfolios by moving away from non-interest-bearing money (real money balances) and toward real capital assets (more productive forms).

[33]See also Loayza, Schmidt-Hebbel, and Servén (2000) for the precautionary motive of savings.

raise the cost of capital by dampening capital accumulation and by lowering its productivity (De Gregorio 1993) and thereupon inhibiting long-run growth.[34] Jordà and Salyer (2003) show that monetary uncertainty tends to lower nominal interest rates.

Cecchetti (1993) suggests that general equilibrium, representative-agent models do not convincingly produce an unambiguous result about the impact of uncertainty on real economic activity. He concludes that the aggregate impact of inflation uncertainty is therefore fundamentally an empirical issue. The empirical literature on inflation uncertainty, however, has also reported conflicting results.

Empirical Results. While empirical studies using uncertainty proxies typically find a negative connection between inflation uncertainty and real activity (Evans and Wachtel 1993; Davis and Kanago 1996; Judson and Orphanides 1999; Grier and Perry 2000; Elder 2004), some find a positive or negligible relationship (Coulson and Robins 1985; Clark 1997; Barro 1998).

Negative Relation. Durable consumption, which is costly to reverse and highly volatile, is particularly sensitive to uncertainty (Bertola, Guiso, and Pistaferri 2005). Judson and Orphanides (1999) and Barro (2013) examine the joint effect of inflation and inflation uncertainty on economic growth. Based on panel data analysis, Judson and Orphanides (1999) find that both inflation and its uncertainty are negatively correlated with economic growth of high-inflation countries. More precisely, the magnitude of the negative impacts of the uncertainty is smaller in non-OECD countries with higher inflation. The authors conclude that a sound policy should aim to both reduce and stabilize the level of inflation. They further argue that inflation stability is more important than the level of inflation itself in promoting high economic growth. This means that neglecting the effect of inflation uncertainty in the growth model could lead to underestimating the negative impact of high inflation levels on economic growth. That said, more recent studies show negative effects (Apergis 2004). Grier and Grier (2006) find that

[34]Friedman (1977) conjectures that the more volatile inflation is as a consequence of the increase in its average, the less effective the price mechanism to coordinate economic activities is. Ball (1992) formalizes Friedman's proposition in the context of a repeated game between the monetary authority and the public. A high inflation rate produces greater uncertainty about the direction of future government policy, and thus about the future inflation rates.

economic growth and inflation uncertainty in Mexico are negatively correlated.

Most recent literature studies the impact of inflation expectation on consumer behaviors (e.g., Armantier et al. 2015; Coibion et al. 2019; Candia, Coibion, and Gorodnichenko 2020; Crump et al. 2020; D'Acunto, Hoang, and Weber 2022). However, there exist a few papers focusing on inflation uncertainty. For instance, Binder (2017) finds that higher inflation uncertainty reduces consumers' incentive to purchase durable goods, which is consistent with a precautionary saving channel. Consistent with expected utility theory, Armantier et al. (2015) report experimental evidence showing that inflation expectations and uncertainty determine people's investment decisions. Ben-David et al. (2019) complement the literature by showing that higher inflation uncertainty is associated with more caution in households' consumption, investment, and borrowing behaviors.

Positive Relation. Meanwhile, earlier studies, using mainly U.S. data, find positive growth effects of inflation uncertainty (e.g., Coulson and Robins 1985). Employing much longer historical time-series data, Fountas (2010) argues that uncertainty about inflation leads to higher growth due to precautionary motives, supporting Dotsey and Sarte (2000)'s theoretical argument. Similar results are reported for the case of G7 countries (Bredin and Fountas 2005; Fountas and Karanasos 2007) and Asian countries (Bredin, Elder, and Fountas 2009; Baharumshah, Hamzah, and Sabri 2011; Mohd, Baharumshah, and Fountas 2013). They typically rely on GARCH-type models, which require high-frequency time-series data.

Mixed Results. Holland (1993a) summarizes 4 studies that find a positive or insignificant relationship between inflation uncertainty and real economic activity, together with 14 that report a negative relationship. While there is a robust negative relationship between inflation and economic growth in the literature, the relationship between inflation uncertainty and growth is more tenuous. In other words, it is challenging to find consistent results across different samples and specifications. Barro (2013) also examines the simultaneous interactions of inflation and inflation uncertainty based on a wide range of countries, and provides contradicting results. The author's findings suggest that inflation level, even at low rates, has a significant negative impact on growth, while inflation uncertainty is not significantly related to growth when controlling for other important factors that drive growth, such as institutions. Barro (2013) tests non-linear relationships between inflation and economic growth, but does not find enough empirical evidence to support such a pattern. In addition, the estimated effects of inflation uncertainty vary substantially in terms of magnitude and timing.

A.2.2 Inflation Uncertainty and Inflation

Another large body of the literature contributes to the ongoing debate about the link between inflation and inflation uncertainty.

Theories. At least four types of hypotheses are proposed to explain the relation. The Friedman-Ball hypothesis posits that high inflation rates may lead to increased inflation uncertainty which brings about economic cost (Bernanke and Mishkin 1997). Based on theoretical perspectives, Friedman (1977) argues that higher inflation rates are less predictable than lower rates.[35] Ball (1992) develops (Friedman-Ball hypothesis) into a formal model that incorporates a repeated game between the monetary authority and the public.[36] In contrast, Cukierman and Meltzer (1986) argue that the causality is from inflation uncertainty to inflation. They claim that, in an economy populated with agents who are highly uncertain, the central bank has an incentive to create surprise inflation to lower unemployment (Cukierman-Meltzer hypothesis).

Another important view is provided by Pourgerami and Maskus (1987). They suggest a negative relation between inflation and inflation uncertainty, rejecting the hypothesis of a harmful effect of high inflation on price predictability (Pourgerami-Maskus hypothesis). Contrary to the Friedman-Ball hypothesis, they argue that higher

[35] Using cross-sectional data for 17 OECD countries for the period 1951–68, Okun (1971) argues that inflation is positively associated with its volatility (standard deviation). According to Okun (1971) there is a positive correlation between inflation and inflation variability since monetary policy becomes more unpredictable during the period of high inflation.

[36] With regard to the effect of inflation on inflation uncertainty, Friedman (1977) and Ball (1992) argue for a positive effect. For example, Ball (1992) develops a repeated game model that incorporates conservative and liberal policymakers and a public in the economic system. The cost of inflation is considered moderate for the liberal policymaker, while it is considered very high for the conservative policymaker. The public does not have information about whether the policymaker will implement a contractionary monetary policy to curb inflation when it is high. Therefore, inflation will co-vary positively with inflation uncertainty.

Table A.1. Theories between Inflation and Inflation Uncertainty

Causality	**Sign**	
	(+)	(−)
Inflation Causes Uncertainty	Friedman (1977), Ball (1992)	Pourgerami and Maskus (1987) Ungar and Zilberfarb (1993)
Uncertainty Causes Inflation	Cukierman and Meltzer (1986)	Holland (1995)

inflation causes economic agents to invest more in generating accurate predictions, subsequently reducing their prediction error (Ungar and Zilberfarb 1993). Therefore, with inflation on the rise, agents may forecast inflation more accurately because they invest more resources in prediction.

Finally, Holland (1993b) suggests that higher inflation uncertainty lowers inflation due to policymakers' motives for stabilizing the economy. Thus, there exists a negative relationship between inflation uncertainty and inflation (Holland hypothesis). Holland (1995) provides an explanation for this negative relationship, stating that it stems from the social costs associated with inflation uncertainty. Inflation uncertainty will raise social costs but also reduce social welfare. To alleviate such adverse effects, policymakers implement stabilization policies, thereby reducing inflation. (See Table A.1.)

Empirical Evidence. Empirical studies also provide conflicting findings for the relationship between inflation and inflation uncertainty. While some studies show a positive relationship between them, others indicate a negative relationship. Furthermore, Grier and Perry (1998, 2000), Grier et al. (2004), and Berument, Kilinc, and Ozlale (2005) document mixed results regarding the direction of the causality.

Such inconsistency in the empirical results can be attributed to the differences in the sample countries, sample periods, or measures of inflation uncertainty. Barnett, Jawadi, and Ftiti (2020) find a significant relationship between inflation and inflation uncertainty that varies depending on the periods and data frequency. The relationship seems to be positive in the short to medium term during the stable periods, confirming the Friedman-Ball theory. However, it turns to be negative during crisis periods.

Using survey-based measure of inflationary shocks, Leduc, Sill, and Stark (2007) suggest that, prior to 1979, the Federal Reserve accommodated temporary shocks to expected inflation, which then resulted in persistent increases in actual inflation. Ungar and Zilberfarb (1993) show that the impact of inflation on inflation uncertainty varies with different levels of inflation, finding a positive effect when inflation is high, while this effect weakens as inflation decreases to lower levels. Focusing on the effect of inflation uncertainty on inflation, the literature also reports mixed results. Many empirical studies support a positive association between inflation uncertainty and inflation, while other studies find no significant or even negative relationship. Recent studies find that the effect highly depends on the business cycles (Holland 1995; Bredin and Fountas 2010).

Country-Specific Evidence. In the framework of the aforementioned different hypotheses, empirical studies generally focused on the advanced economies. Among them, GARCH-type methods have been popularly employed in empirical investigations on the inflation uncertainty since the estimated conditional volatility can perform better as a proxy for the uncertainty than other measures. According to a comprehensive survey by Davis and Kanago (2000), the studies focusing on the advanced countries mostly supported the Friedman-Ball hypothesis rather than the Cukierman-Meltzer hypothesis. In addition, there was also very little evidence to advocate the Pourgerami-Maskus hypothesis and the Holland hypothesis.

Fountas (2010) used a GARCH-in-Mean (GARCH-M) model augmented with lagged inflation in the conditional variance equation for long-term inflation data spanning over one century for 22 advanced economies. He found evidence for the positive effect of inflation uncertainty on inflation supporting the Cukierman-Meltzer hypothesis. Using EGARCH for five European countries, Fountas, Ioannidis, and Karanasos (2004) documented that inflation causes inflation uncertainty in France and Italy, but not in Germany. They also found that uncertainty causes declines in inflation in France and Germany. By using the ARFIMA-FIGARCH approach for the monthly data in the United States, the United Kingdom, and Japan from 1962 to 2001, Conrad and Karanasos (2005) examined the nexus between inflation and its uncertainty. They showed that inflation significantly raises inflation uncertainty in the United States and the United Kingdom as predicted by the Friedman-Ball hypothesis while the results from Japan support the Cukierman-Meltzer hypothesis.

Grier and Perry (1998) explored the relation between inflation and uncertainty for the case of G7 economies from 1948 to 1993 based on a two-step procedure. They first estimated a GARCH model to generate a measure of inflation uncertainty and then tested the Granger causality to examine the relationship between inflation and inflation uncertainty. They provided evidence that inflation significantly raises inflation uncertainty in all G7 countries as predicted by the Friedman-Ball hypothesis. Similarly, Fountas and Karanasos (2007) applied univariate GARCH models for inflation by using monthly data over the periods of 1957–2000 for the G7 countries. Their approach estimated the conditional variance of unanticipated shocks to inflation as proxies for the uncertainty and then implemented the causality test. The result strongly supported the Friedman-Ball hypothesis.

Among the studies focusing on the individual country cases, Bhar and Mallik (2010) reported that inflation uncertainty significantly increased inflation in the United States from 1957 to 2007 by using an EGARCH-M model and bivariate Granger-causality test. Hwang (2001) explored the link of inflation with uncertainty in the United States with long monthly data series from 1926 to 1992 employing various ARFIMA-GARCH-type models. He found that inflation has weakly negative impacts on its uncertainty whereas uncertainty affects inflation insignificantly. Thus, unlike the Friedman-Ball hypothesis, he argued that a high inflation rate does not necessarily result in a high variance of inflation. Wilson (2006) constructed a bivariate EGARCH-M model with inflation data in Japan spanning from 1957 to 2002 to examine the links among inflation, inflation uncertainty, and growth. The author found that in Japan, higher uncertainty is linked to both higher average inflation and lower average growth. Fountas (2001) estimated GARCH-type models using a long data series of the United Kingdom for the decade-long period of 1885–1998. The result supports the Friedman-Ball hypothesis and also provides an important implication that higher inflation uncertainty leads to lower output growth. Kontonikas (2004) examined the relationship between inflation and its uncertainty by estimating the impacts of inflation-targeting policy for the U.K. data over the period of 1972–2002. In the study, the estimated conditional volatility is computed from symmetric and asymmetric component GARCH-M models of inflation, and is used as a proxy for inflation uncertainty. Empirical results indicate a positive association between inflation and uncertainty.

Differences across Countries. Many existing studies suggest that higher inflation rates raise inflation uncertainty in all economies, strongly supporting the Friedman-Ball hypothesis. By contrast, the results on the effect of inflation uncertainty on monthly average inflation are more mixed. Higher inflation uncertainty leads to lower average inflation in Colombia, Israel, Mexico, and Turkey, consistent with the Holland hypothesis; however, it results in higher average inflation in Hungary, Indonesia, and Korea, in line with the hypothesis of Cukierman-Meltzer.

Time-Varying Relation. Assuming the non-normal density and independent regime shifts in inflation developments, Chang (2012) finds that the relationship between inflation uncertainty and inflation has changed over time. The results show that inflation uncertainty has no impacts on inflation, regardless of inflation pressure. That said, inflation has negative impacts on inflation uncertainty during the periods of high inflation volatility, while it has insignificant impacts during the periods of low inflation volatility.

A.2.3 Sources of Inflation Uncertainty

Among the concerns of monetary policymakers, uncertainty about future inflation has been considered as the most important inflation cost. According to Cukierman and Meltzer (1986) and Evans and Wachtel (1993), inflation uncertainty can occur through at least two main sources. First, significant differences among international monetary policy regimes could lead to uncertainty, as through conventional versus unconventional monetary policies. Second, the uncertainty could also be induced by policy regime uncertainty. Furthermore, as economic agents often use new information to update their perceptions regarding the actions of central banks, it is expected that the uncertainty would be time varying and potentially complex to measure.

Inflation uncertainty may reflect the influence of unexpected movements in commodity prices and foreign exchange rates, as well as that of idiosyncratic developments unrelated to broader economic conditions. These factors could easily push overall inflation above or below the target rates for a time. Such disturbances, however, are not a great concern from a policy perspective as long as their effects shortly fade away and inflation expectations remain anchored.

Another source of uncertainty is inflation expectations. In standard economic models, inflation expectation is an important determinant of actual inflation. For instance, inflation expectations affect the economy when companies consider the future overall inflation rate in determining wages and prices for their products and services at a given time. The central bank's monetary policy is believed to be crucial in shaping these expectations by affecting the average inflation rate experienced over extended periods of time and providing direction for the inflation targets that the central bank aims to achieve in the future. Even so, economists have only a limited understanding of how and why inflation expectations change over time. They do not directly observe the inflation expectations relevant to wage and price setting. Instead, they can only imperfectly infer how the inflation expectations might have changed based on the survey responses and other data.

In addition, our framework for understanding inflation dynamics could be misspecified in some aspects because the econometric models overlook some factors that will restrain inflation in the coming years despite solid labor market conditions.

Crisis. Only a handful of papers have studied how households update their inflation expectations in times of crisis. In particular, Galati, Poelhekke, and Zhou (2011) document that inflation expectations increased during the 2007–09 Great Recession, while Gerlach, Hoerdahl, and Moessner (2011) and Trehan and Zorrilla (2012) find that this effect vanished quickly once the recession subsided. Using the data from the Survey of Consumer Expectations (SCE), from the Federal Reserve Bank of New York, Ben-David et al. (2019) show that consumers with higher forecast uncertainty (about inflation, national home price changes, and wage growth) tend to have more cautious consumption, investment, and borrowing behaviors.

COVID-19. Due to the unique features of the pandemic, at the early stage of the COVID-19 crisis, it was difficult to predict whether it would have inflationary or deflationary effects (Binder 2020; Cochrane 2020). On the one hand, weak consumer demand (e.g., for travel, entertainment, or leisure and hospitality) and a prolonged economic slowdown might put downward pressure on inflation. On the other hand, some expected that supply chain disruptions, the rising levels of government debt, and the unprecedented expansion of the Federal Reserve's balance sheet would raise the pressure on future inflation. Furthermore, it has been suggested that households tend to associate deteriorating economic outcomes with higher future inflation (Kamdar 2019; Candia, Coibion, and Gorodnichenko 2020). These opposing forces may have an impact not only on aggregate inflation expectations but also on the level of inflation disagreement among individuals, as well as the degree of uncertainty one may perceive about the future path of inflation.

Binder (2020) documents that greater concerns about COVID-19 were initially associated with higher inflation expectations. Dietrich et al. (2022) report the results of daily surveys that they conducted in the second half of March 2020. They find that short-term inflation expectations actually declined slightly in their surveys, although the median respondent answered that the pandemic should have an inflationary effect. Similarly, Coibion, Gorodnichenko, and Weber (2020) compare two surveys conducted in January and April 2020 and find a decrease in one-year-ahead inflation expectations and an increase in short-term inflation uncertainty. Also, Candia, Coibion, and Gorodnichenko (2020) report that households' inflation expectations subsequently increased in July 2020. The authors argue that this result is consistent with consumers' tendency to associate a worsening economy with higher future inflation.

Another group of studies focuses on the inflation expectations of U.S. firms during COVID-19 and reports conflicting results. Candia, Coibion, and Gorodnichenko (2020) suggest that, similar to households, firms view the pandemic as an inflationary supply shock. In contrast, Meyer, Prescott, and Sheng (2022) report that, similar to market participants and professional forecasters, firms lowered their one-year-ahead inflation expectations in response to COVID-19, as they regard the pandemic as a demand shock. Furthermore, Meyer, Prescott, and Sheng (2022) find that, as of June 2020, firms' longer-run inflation expectations have changed little throughout the pandemic and remained reasonably well anchored.

Appendix B. Robustness Checks

To check the robustness of our headline empirical results, we estimated several alternative models. The baseline results are not sensitive to the alternative models as summarized below.

Variable Ordering. In our baseline panel VAR model, the inflation uncertainty is ordered first. In this way, we assume that inflation uncertainty shock is independent of the shocks that are ordered later within a month (or a quarter). In order to test the sensitivities of the impulse responses to the ordering, the models are tested by placing the uncertainty last or by comparing them with the generalized impulse response functions (not shown here). As shown in panel A of Figure C.2, the responses of variables to inflation uncertainty shocks are largely similar to those of baseline models, both in terms of direction and magnitude.

Additional Control Variables. To examine whether our empirical results are driven by any omitted variables—such as those reflecting common global shocks—we test the alternative models which augment the CBOE Volatility Index (VIX) or the Economic Policy Uncertainty Index (EPU) as exogenous variables. In the baseline model, the level of inflation uncertainty measure is employed. Although the inflation uncertainty is found to be stationary over the sample period, it can be potentially cointegrated with other uncertainty measures specifically driven by global factors, such as the VIX and the EPU.[37] In our robustness check, we additionally use either the VIX or the global EPU index, which is a GDP-weighted average of national EPU indices for 20 countries.

Figure C.3 reports the results from the test which employs VIX (panel A) or global EPU (panel B) as an exogenous variable. With VIX employed as an exogenous variable, the inflation uncertainty shock has significantly negative impacts on output and durable goods consumption while its impacts on non-durable goods consumption are largely insignificant. Partly reflecting the correlations between VIX and inflation uncertainty—in particular, around global

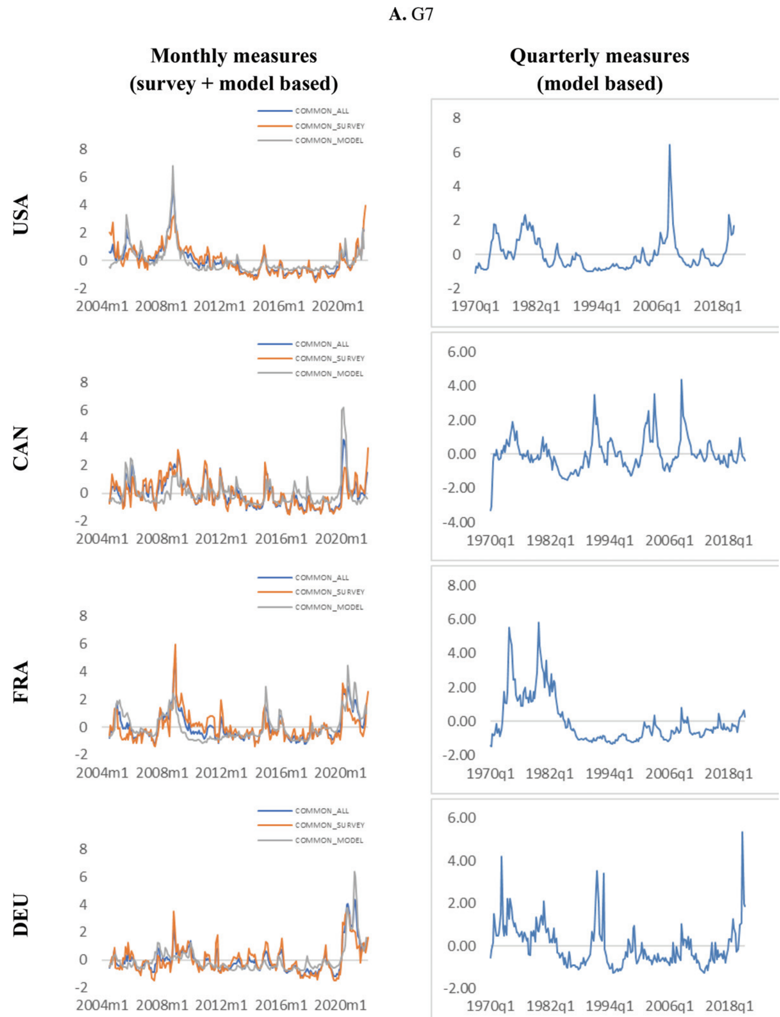
[37]The VIX is calculated using real-time, mid-quote prices of S&P 500 Index call and put options and is one of the most widely used measures of volatility in the global financial market. The EPU is a normalized index constructed from three different sources, including the newspaper, the number of federal tax code provisions set to expire, and disagreement among economic forecasters.

events—the impacts become somewhat more muted and less significant after controlling for VIX. Including global EPU as exogenous variables gives us similar significant results to those of baseline.

Global Averages and the United States. Instead of our baseline panel VAR, we iterate the estimation using country-specific SVAR models and compute the results based on the cross-country averages. We also report the result for the United States only as a representative country. As shown in Figure C.4, on an inflation uncertainty shock, global averages respond in the same direction as our baseline model while the magnitude of the negative impacts on economic variables are relatively smaller than those of panel analysis. The results for the United States are also largely consistent with the baseline results, but with less statistical significance. The output level drops by 1 percentage point in the first two years and then becomes stable. The impact on inflation is negative but insignificant.

Appendix C. Additional Tables and Figures

Figure C.1. Inflation Uncertainty for Individual Countries

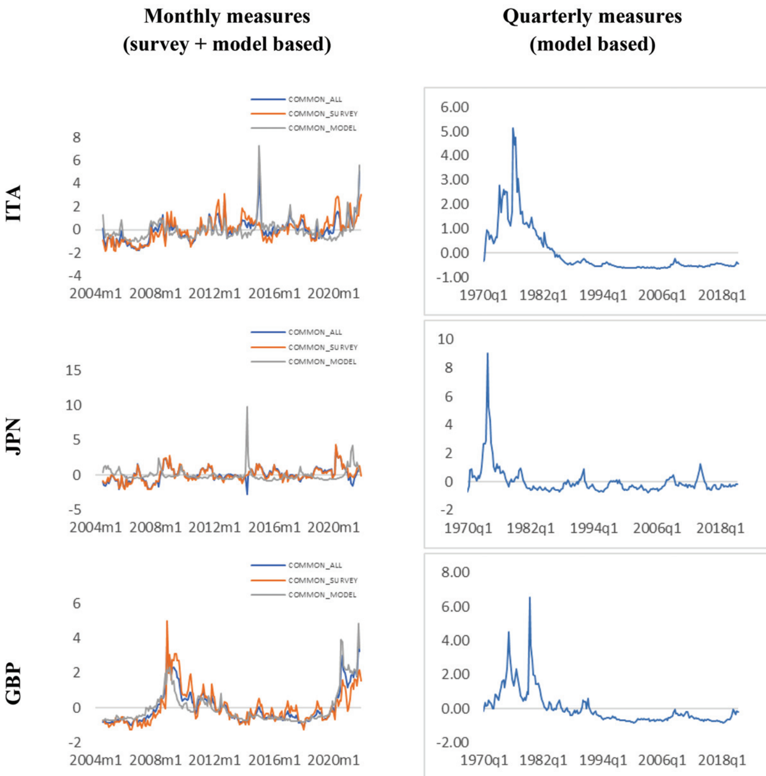


Note: These figures show country-specific inflation uncertainty measures based on monthly (left) and quarterly (right) data. For monthly measures, blue, orange, and gray lines represent the common indicators, survey-based measure, and model-based measure of inflation uncertainty, respectively.

(*continued*)

Figure C.1. (Continued)

A. G7 (cont'd)



Note: These figures show country-specific inflation uncertainty measures based on monthly (left) and quarterly (right) data. For monthly measures, blue, orange, and gray lines represent the common indicators, survey-based measure, and model-based measure of inflation uncertainty, respectively.

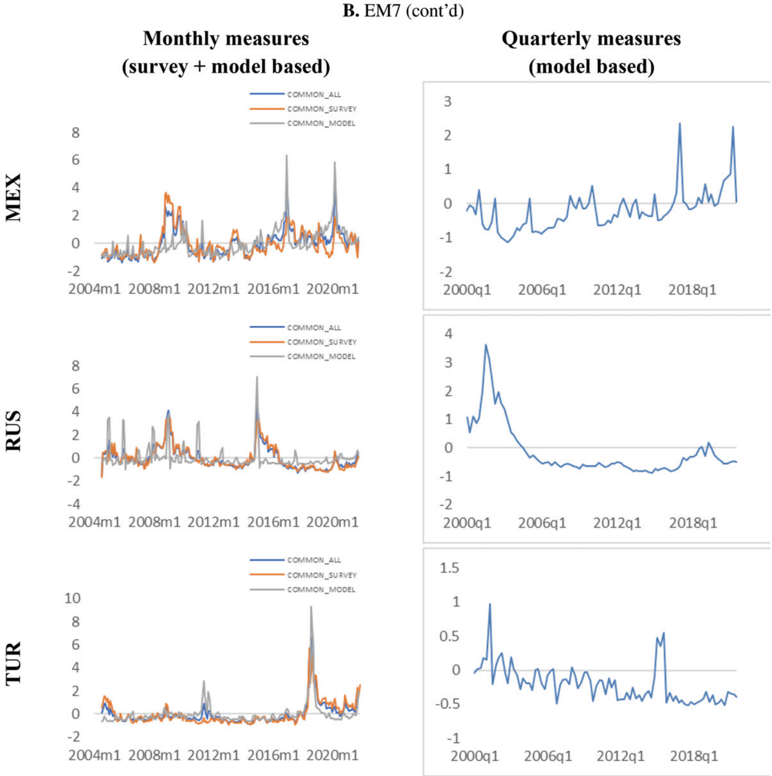
(*continued*)

Figure C.1. (Continued)

Note: These figures show country-specific inflation uncertainty measures based on monthly (left) and quarterly (right) data. For monthly measures, blue, orange, and gray lines represent the common indicators, survey-based measure, and model-based measure of inflation uncertainty, respectively.

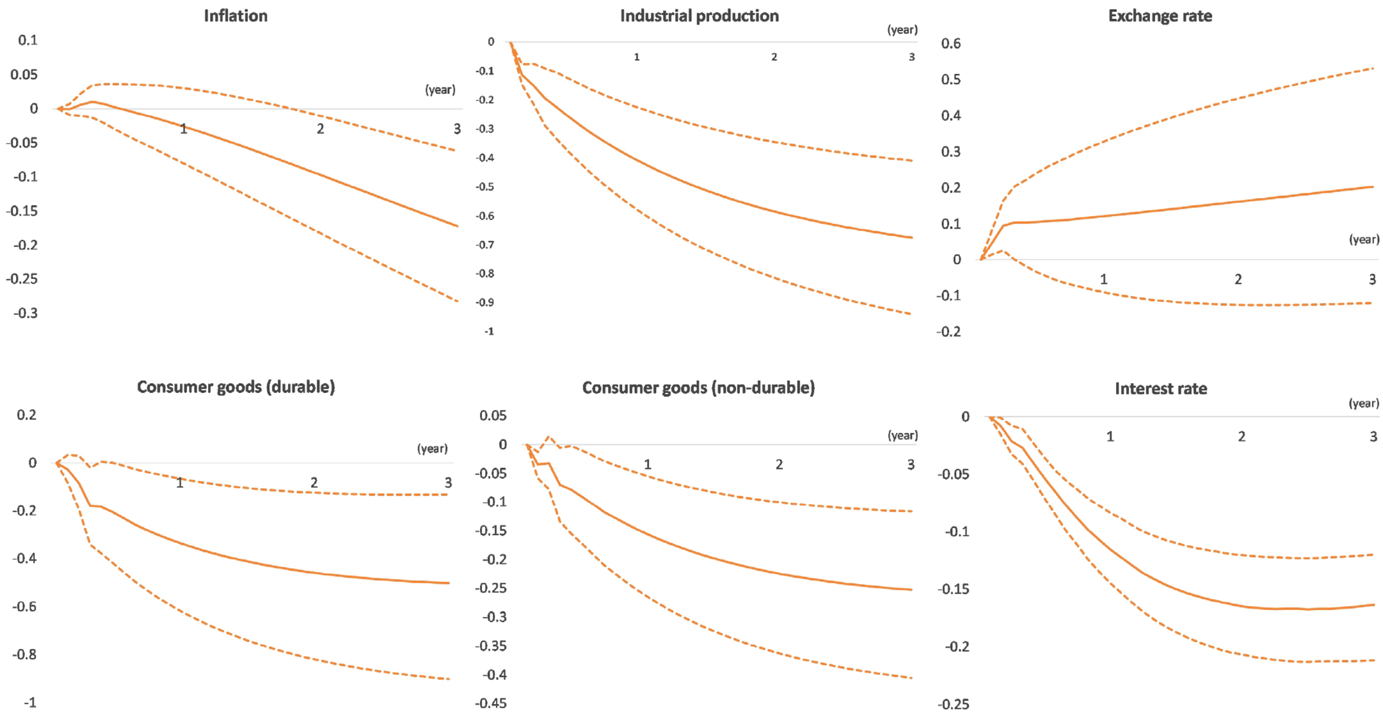
(*continued*)

Figure C.1. (Continued)



Note: These figures show country-specific inflation uncertainty measures based on monthly (left) and quarterly (right) data. For monthly measures, blue, orange, and gray lines represent the common indicators, survey-based measure, and model-based measure of inflation uncertainty, respectively.

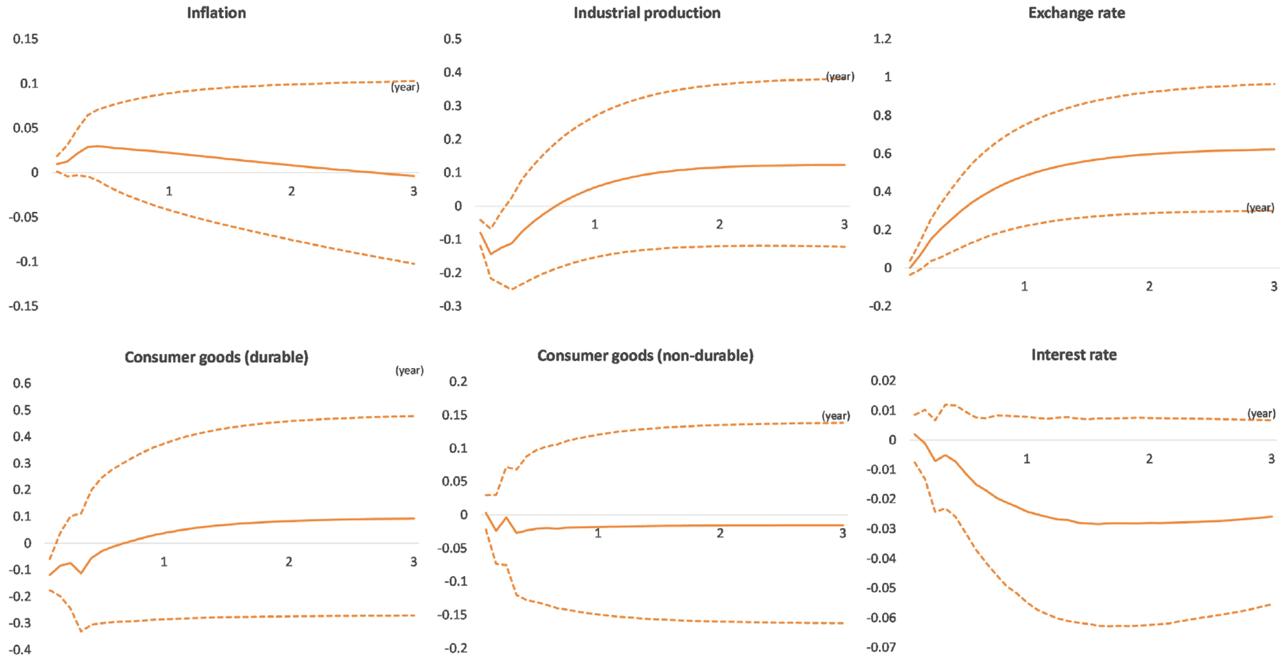
Figure C.2. Robustness Check: VAR Ordering



Note: The figures present dynamic impulse responses of the variables following a positive one-standard-deviation increase in inflation uncertainty, based on the panel VAR model for G7 and EM7 countries where inflation uncertainty is ordered last. The y-axis indicates percent (or percentage point for interest rate). The x-axis indicates years after shock. Broken lines are the 16–84 percentile confidence intervals.

Figure C.3. Robustness Check: Exogenous Variables

A. VIX Employed as an Exogenous Variable

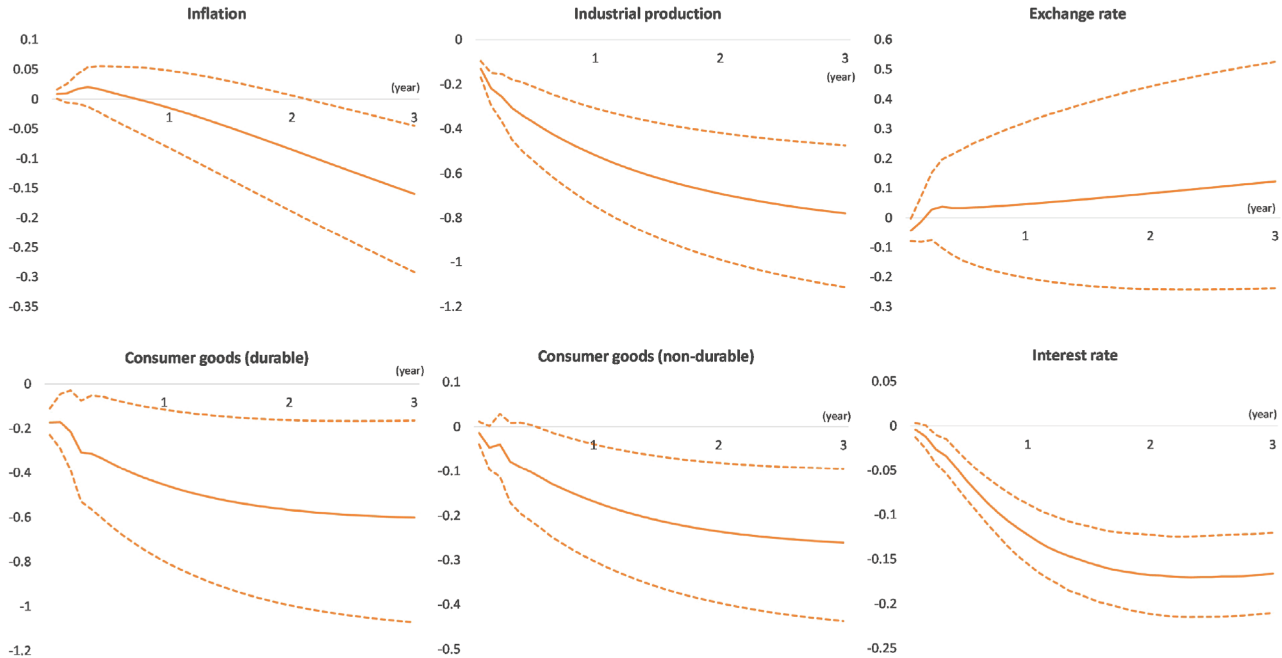


Note: The figures present dynamic impulse responses of the variables following a positive one-standard-deviation increase in inflation uncertainty, based on the panel VAR model for G7 and EM7 countries where VIX is included as a control variable. The y-axis indicates percent (or percentage point for interest rate). The x-axis indicates years after shock. Broken lines are the 16–84 percentile confidence intervals.

(*continued*)

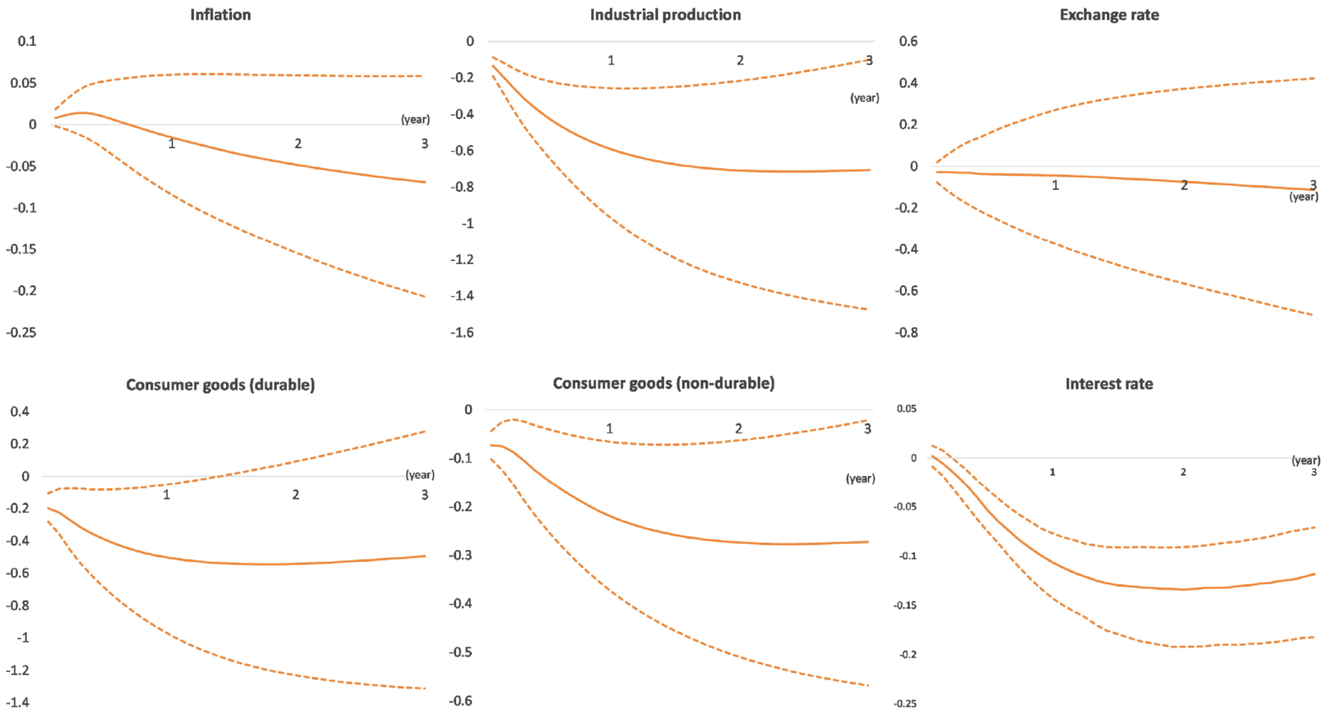
Figure C.3. (Continued)

B. EPU Employed as an Exogenous Variable



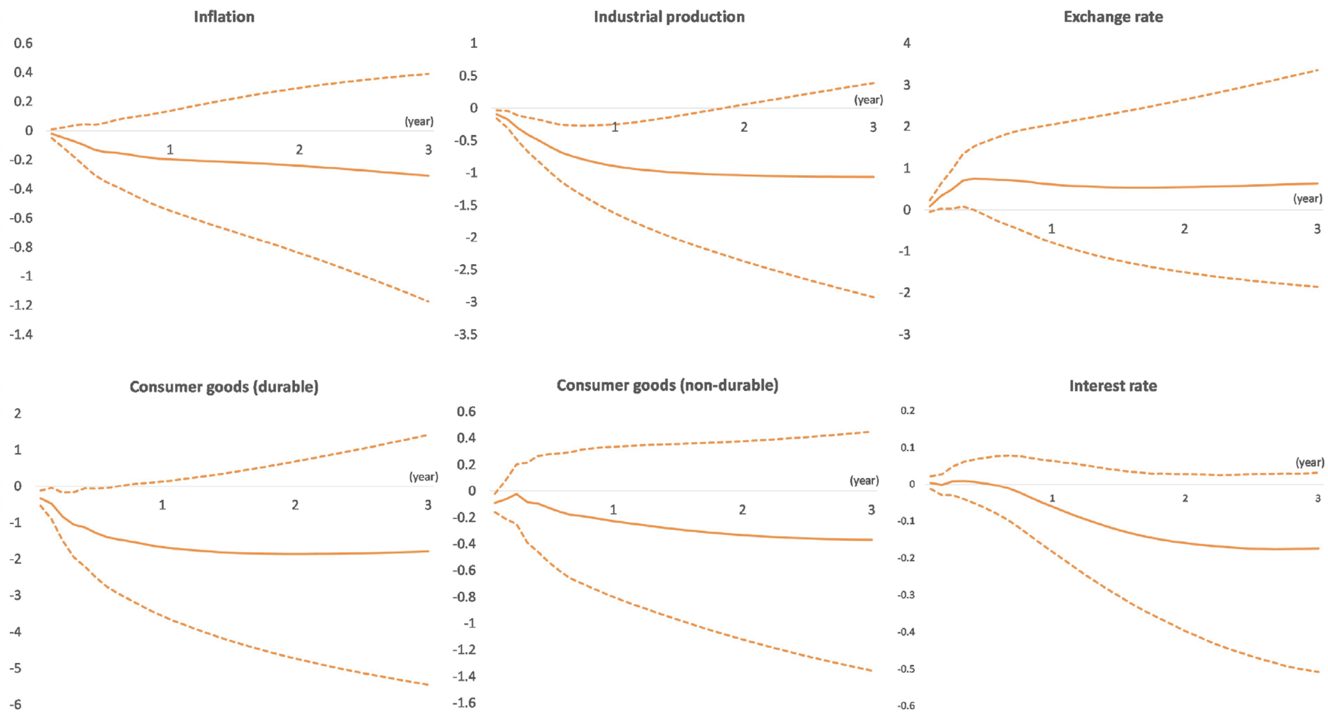
Note: The figures present dynamic impulse responses of the variables following a positive one-standard-deviation increase in inflation uncertainty, based on the panel VAR model for G7 and EM7 countries where global EPU is included as a control variable. The y-axis indicates percent (or percentage point for interest rate). The x-axis indicates years after shock. Broken lines are the 16–84 percentile confidence intervals.

Figure C.4. Robustness Check: SVAR with Global Average Data



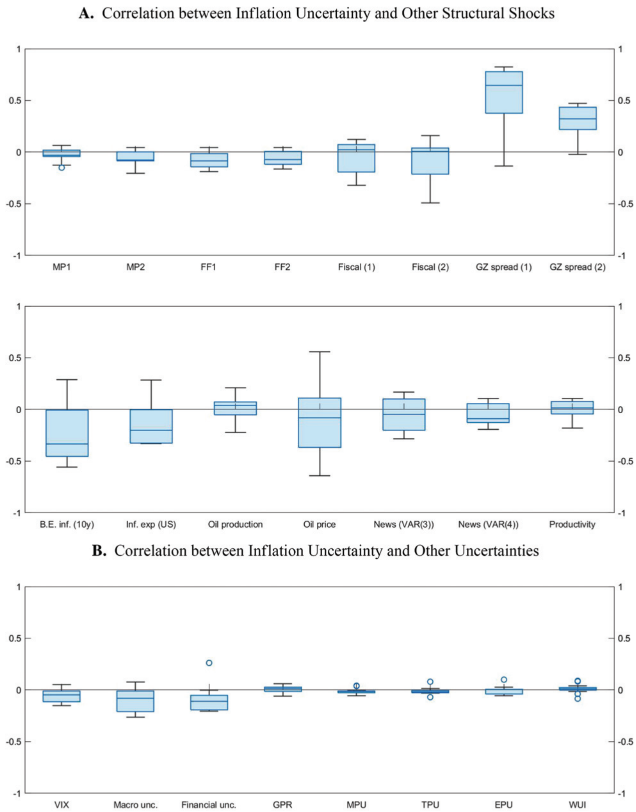
Note: The y-axis indicates percent (or percentage point for interest rate). The x-axis indicates years after shock. Broken lines are the 16–84 percentile confidence intervals.

Figure C.5. Robustness Check: SVAR of United States



Note: The figures present the dynamic impulse responses of the variables following a positive one-standard-deviation increase in inflation uncertainty, based on the panel VAR model for the United States. The y-axis indicates percent (or percentage point for interest rate). The x-axis indicates years after shock. Broken lines are the 16–84 percentile confidence intervals.

Figure C.6. Correlation Coefficients of Inflation Uncertainty with Other Shocks



Note: The figures display the box plots of correlation coefficients of inflation uncertainty with other structural shocks and uncertainties. Each box and whisker is characterized by 14 (corresponding to G7 and EM7) correlation coefficients between inflation uncertainty in an individual country and other shocks. MP1, MP2, FF1, and FF2 indicate the monetary policy shocks identified using intraday movements of federal funds futures rates as suggested by Gertler and Karadi (2015). Fiscal (1) and (2) indicate exogenous tax changes and those based on the present value as identified by Romer and Romer (2010). GZ spread (1) and (2) are the predicted GZ credit spreads and those controlled for the term structure and interest effects, taken from Gilchrist and Zakrajšek (2012). News(VAR(3)) and (VAR(4)) are the news shocks identified by the three- and four-variable VAR frameworks following Barsky and Sims (2011) and Beaudry and Portier (2014), respectively. Productivity denotes productivity shocks, estimated frem the six-variable VAR as in Levchenko and Pandalai-Nayar (2020). Macro unc. and Financial unc. are three-month-ahead measures of macro and financial uncertainty taken from Jurado, Ludvigson, and Ng (2015). GPR, MPU, TPU, EPU, and WUI represent geopolitical risks (Caldara and Iacoviello 2022), monetary policy uncertainty (Husted, Rogers, and Sun 2020), trade policy uncertainty (Caldara et al. 2020), economic policy uncertainty (Baker, Bloom, and Davis 2016), and world uncertainty (Ahir, Bloom, and Furceri 2022), respectively.

Table C.1. Regression Results of Inflation Uncertainty on Other Uncertainties and Structural Shocks[1]

Structural Shocks		Country	Related Studies	β	SE	*P*-value	Obs.	Sample
A. G7								
Uncertainty	VIX	US	Bloom (2009)	0.01	0.01	0.64	185	2004:M8–2019:M12
	Macro Uncertainty ($h = 3$)[2]	US	Jurado, Ludvigson, and Ng (2015)	–0.03	0.24	0.90	185	2004:M8–2019:M12
	Financial Uncertainty ($h = 3$)[2]	US	Jurado, Ludvigson,and Ng (2015)	–0.04	0.20	0.85	185	2004:M8–2019:M12
	Geopolitical Risk	Global	Caldara and Iacoviello (2022)	–0.02	0.03	0.45	185	2004:M8–2019:M12
	Monetary Policy Uncertainty	US	Husted, Rogers, and Sun (2020)	–0.03	0.03	0.33	185	2004:M8–2019:M12
	Trade Policy Uncertainty	Global	Caldara et al. (2020)	–0.04	0.04	0.30	185	2004:M8–2019:M12
	Economic Policy Uncertainty	Global	Baker, Bloom, and Davis (2016)	–0.02	0.03	0.45	185	2004:M8–2019:M12
	World Uncertainty (Advanced Economies)	AEs	Ahir, Bloom, and Furceri (2022)	–0.03	0.01	0.06	120	1990:Q1–2019:Q4
Monetary Policy[3]	MP1	US	Gertler and Karadi (2015), Gürkaynak, Sack, and Swanson (2005)	–1.43	1.51	0.35	179	2004:M8–2019:M6
	MP2			–2.75	2.59	0.29	179	2004:M8–2019:M6
	FF1			–6.62	6.15	0.28	179	2004:M8–2019:M6
	FF2			–2.18	2.59	0.40	179	2004:M8–2019:M6
Fiscal Policy[4]	Government Spending (1)	US	Romer and Romer (2010)	0.00	0.00	0.19	72	1990:Q1–2007:Q4
	Government Spending (2)			0.00	0.00	0.86	72	1990:Q1–2007:Q4
Financial[5]	GZ Spread (1)	US	Gilchrist and Zakrajšek (2012)	0.19	0.10	0.06	74	2004:M8–2010:M9
	GZ Spread (2)			0.18	0.12	0.14	74	2004:M8–2010:M9
Inflation	Breakeven Inflation (10-year)	US	Drakos, Konstantinou, and Thoma (2020), Kose et al. (2019)	–0.07	0.05	0.18	185	2004:M8–2019:M12
	Inflation Expectation (Consensus Forecast, US)			–0.04	0.08	0.63	185	2004:M8–2019:M12

(*continued*)

Table C.1. (Continued)

Structural Shocks		Country	Related Studies	β	SE	P-value	Obs.	Sample
A. G7								
Oil Price	Oil Production	Global	Kilian (2008)	0.00	0.01	0.99	41	2004:M8–2007:M12
	Oil Price	Global	Ha, Kose, and Ohnsorge (2019)	0.00	0.00	0.56	41	2004:M8–2007:M12
News Shock	VAR(3) Residual	US	Barsky and Sims (2011)	–0.16	0.14	0.26	67	1996:Q1–2012:Q3
	VAR(4) Residual	US	Beaudry and Portier (2014)	–0.07	0.11	0.52	67	1996:Q1–2012:Q3
Productivity[6]	VAR(6) Residual	US	Levchenko and Pandalai-Nayar (2020)	–0.17	0.18	0.36	88	1996:Q1–2017:Q4
B. EM7								
Uncertainty	VIX	US	Bloom (2009)	0.00	0.01	0.99	185	2004:M8–2019:M12
	Macro Uncertainty ($h = 3$)[2]	US	Jurado, Ludvigson, and Ng (2015)	–0.11	0.19	0.54	185	2004:M8–2019:M12
	Financial Uncertainty ($h = 3$)[2]	US	Jurado, Ludvigson, and Ng (2015)	–0.11	0.16	0.50	185	2005:M8–2019:M12
	Geopolitical Risk	Global	Caldara and Iacoviello (2022)	–0.03	0.03	0.26	185	2004:M8–2019:M12
	Monetary Policy Uncertainty	US	Husted, Rogers, and Sun (2020)	–0.04	0.03	0.18	185	2004:M8–2019:M12
	Trade Policy Uncertainty	Global	Caldara et al. (2020)	–0.05	0.03	0.15	185	2004:M8–2019:M12
	Economic Policy Uncertainty	Global	Baker, Bloom, and Davis (2016)	–0.03	0.03	0.21	185	2004:M8–2019:M12
	World Uncertainty (Emerging Economies)	EMs	Ahir, Bloom, and Furceri (2022)	–0.02	0.01	0.20	80	2000:Q1–2019:Q4
Monetary Policy[3]	MP1	US	Gertler and Karadi (2015), Gürkaynak, Sack, and Swanson (2005)	–1.10	0.51	0.03	179	2004:M8–2019:M6
	MP2			–1.86	0.95	0.05	179	2004:M8–2019:M6
	FF1			–3.40	2.69	0.21	179	2004:M8–2019:M6
	FF2			–1.38	1.18	0.24	179	2004:M8–2019:M6

(*continued*)

Table C.1. (Continued)

Structural Shocks		Country	Related Studies	β	SE	P-value	Obs.	Sample
B. EM7								
Fiscal Policy[4]	Government Spending (1)	US	Romer and Romer (2010)	0.00	0.00	0.79	32	2000:Q1–2007:Q4
	Government Spending (2)			0.00	0.00	0.00	32	2000:Q1–2007:Q4
Financial[5]	GZ Spread (1)	US	Gilchrist and Zakrajšek (2012)	0.15	0.04	0.00	74	2004:M8–2010:M9
	GZ Spread (2)			0.19	0.08	0.01	74	2004:M8–2010:M9
Inflation	Breakeven Inflation (10-Year)	US	Drakos, Konstantinou, and Thoma (2020), Kose et al. (2019)	–0.07	0.06	0.20	185	2004:M8–2019:M12
	Inflation Expectation (Consensus Forecast, US)			–0.07	0.06	0.30	185	2004:M8–2019:M12
Oil Price	Oil Production	Global	Kilian (2008)	0.00	0.00	0.82	41	2004:M8–2007:M12
	Oil Price	Global	Ha, Kose, and Ohnsorge (2019)	0.00	0.00	0.80	41	2004:M8–2007:M12
News Shock	VAR(3) Residual	US	Barsky and Sims (2011)	–0.03	0.04	0.38	51	2000:Q1–2012:Q3
	VAR(4) Residual	US	Beaudry and Portier (2014)	0.01	0.03	0.86	51	2000:Q1–2012:Q3
Productivity[6]	VAR(6) Residual	US	Levchenko and Pandalai-Nayar (2020)	0.12	0.08	0.17	72	2000:Q1–2017:Q4

Note: 1. This table reports the estimates (β_i) of regression (7). Newey-West heteroskedasticity and autocorrelation consistent (HAC) standard errors are reported.
2. MP1, MP2, FF1, and FF2 indicate the monetary policy shocks identified using intraday movements of federal funds futures rates as suggested by Gertler and Karadi (2015).
3. Three-month-ahead measures of macro and financial uncertainty are taken from Jurado, Ludvigson, and Ng (2015).
4. Exogenous tax changes (1) and those based on the present value (2) are taken from Romer and Romer (2010).
5. Predicted GZ spreads (1) and those controlled for the term structure and interest effects (2) are taken from Gilchrist and Zakrajšek (2012).
6. Following Levchenko and Pandalai-Nayar (2020), residuals of labor productivity are regarded as a proxy for productivity, estimated in the six-variable VAR: labor productivity, real GDP, private consumption, investment, employment, and consumer price.

Appendix D. The Details of the Model for Inflation Uncertainty

The model shares many features of the model of Basu and Bundick (2017), but substantially deviates from it by explicitly incorporating the inflation uncertainty process. The stochastic process related to the formation of inflation directly affects the inflation risk premium and the firm's adjustment cost. The process is governed by the second-moment shock, which is interpreted as the uncertainty about inflation.

A representative household maximizes the lifetime utility given Epstein-Zin preference by choosing consumption (C_t), labor (N_t), bonds (B_t) issued by intermediate goods firm, and equity share (S_t) for all periods:

$$V_t = \max \left[a_t \left(C_t^{\eta} (1 - N_t)^{1-\eta} \right)^{\frac{(1-\sigma)}{\theta_V}} + \beta \left(E_t V_{t+1}^{1-\sigma} \right)^{\frac{1}{\theta_V}} \right]^{\frac{\theta_V}{(1-\sigma)}}$$

subject to the budget constraint

$$C_t + \frac{P_t^E}{P_t} S_{t+1} + \frac{1}{R_t^R} B_{t+1} \leq \frac{W_t}{P_t} N_t + \left(\frac{D_t^E}{P_t} + \frac{P_t^E}{P_t} \right) S_t + B_t,$$

where σ, θ_V denote the parameters for risk aversion and preference on the uncertainty resolution. Solving a household's problem yields the first-order conditions of labor supply and the Euler equations for equity shares and real bonds.

In addition, we assume that nominal bond rate (R_t) is affected by ex ante real rate (R_t^R), inflation (π_t), and premium compensated for inflation risk (Θ_t). Hence, nominal bond rate can be rewritten with regard to inflation risk-free rate (R_t^*) and the premium (Θ_t). Θ_t is assumed to be a linear function of an evolution of the stochastic process of $\Gamma_t (= E_t [\Gamma_{t+1}/\Gamma_t])$.

$$R_t = R_t^* \Theta_{t+1} \tag{D.1}$$

Then, the Euler equation for a zero net supply of nominal bonds can be reexpressed in terms of inflation risk-hedged yield and the premium:

$$1 = R_t E_t \left[\frac{M_{t+1}}{\Pi_{t+1}} \right] = R_t^* E_t \left[\frac{M_{t+1}}{\Pi_{t+1}} \Theta_{t+1} \right]. \tag{D.2}$$

This also allows us to reformulate the conventional Taylor-type rule such that the central bank in the model adjusts R_t^*, additionally taking the evolution of inflation uncertainty into consideration.

$$\begin{aligned} log\left(R_t^*\right) = (1-\rho_{R^*}) \left[log\left(R^*\right) + \rho_\Pi log\left(\frac{\Pi_t}{\Pi}\right) + \rho_Y log\left(\frac{Y_t}{Y_{t-1}}\right) \right] \\ + \rho_{R^*} log\left(R_{t-1}^*\right) - log\left(\Theta_{t+1}\right) \end{aligned} \tag{D.3}$$

Each intermediate goods producer i employs labor $N_t(i)$ and produces intermediate goods $Y_t(i)$ according to the identical Cobb-Douglas type production function. Firm i owns capital stocks $K_t(i)$ and faces the convex costs of capital adjustment. Also, the installed capital depreciates at the rate of δ, which is affected by the rate of capital utilization $U_t(i)$. To reflect the influence of inflation uncertainty on the firm's pricing decision, the stochastic process of Γ_t is assumed to determine the Rotemberg-type price adjustment cost. Taking these conditions into account together, each firm maximizes discounted cash flows $D_t(i)/P_t$

$$\max E_t \sum_{s=0}^{\infty} \left(\frac{\frac{\partial V_t}{\partial C_{t+s}}}{\frac{\partial V_t}{\partial C_t}} \right) \left[\frac{D_{t+s}(i)}{P_{t+s}} \right],$$

where

$$\frac{D_t(i)}{P_t} = \left[\frac{P_t(i)}{P_t} \right]^{-\theta_\mu} Y_t - \frac{W_t}{P_t} N_t(i) - I_t(i) - \frac{\phi_p}{2\Gamma_t} \left[\frac{P_t\left(i\right)}{\Pi P_{t-1}\left(i\right)} - 1 \right]^2 Y_t \tag{D.4}$$

subject to the production function and the capital accumulation equation, which are given as

$$\left[\frac{P_t(i)}{P_t} \right]^{-\theta_\mu} Y_t \leq \left[K_t(i) U_t(i)\right]^{1-\alpha} - \Phi$$

and

$$K_{t+1}(i) = \left(1 - \delta\left(U_t(i)\right) - \frac{\phi_K}{2} \left(\frac{I_t(i)}{K_t(i)} - \delta \right)^2 \right) K_t(i) + I_t(i),$$

where $\delta(U_t(i))$ denotes a depreciation rate $\left(= \delta_0 + \delta_1 (U_t(i) - U) + \left(\frac{\delta_2}{2}\right)(U_t(i) - U)^2\right)$. The firm's optimization implies the first-order conditions with regard to the demands for labor and capital, and the price determination for goods (i.e., NKPC) and installed capital.

The final goods producer transforms intermediate goods $(Y_t(i))$ into final output (Y_t). The producer maximizes the profits by selling final goods at price P_t and buying intermediate goods at price $P_t(i)$:

$$P_t Y_t - \int_0^1 P_t(i) Y_t(i) di$$

subject to the constant returns to scale technology

$$\left[\int_0^1 Y_t(i)^{\frac{(\theta_\mu - 1)}{\theta_\mu}} di\right]^{\frac{\theta_\mu}{(\theta_\mu - 1)}} \geq Y_t.$$

The first-order conditions for profit maximization results in

$$Y_t(i) = \left[\frac{P_t(i)}{P_t}\right]^{-\theta_\mu} Y_t \tag{D.5}$$

$$P_t = \left[\int_0^1 P_t(i)^{1-\theta_\mu} di\right]^{\frac{1}{(1-\theta_\mu)}}. \tag{D.6}$$

In addition to the demand (a_t) and technology (Z_t) shock processes as in Basu and Bundick (2017), we consider the process associated with inflation uncertainty evolution. It is parameterized as

$$\Gamma_t = (1 - \rho_\Gamma)\Gamma + \rho_\Gamma \Gamma_{t-1} + \sigma_{t-1}^\Gamma \varepsilon_t^\Gamma \tag{D.7}$$

$$\sigma_t^\Gamma = (1 - \rho_{\sigma^\Gamma})\sigma^\Gamma + \rho_{\sigma^\Gamma} {\sigma^\Gamma}_{t-1} + \sigma^{\sigma^\Gamma} \varepsilon_t^{\sigma^\Gamma}, \tag{D.8}$$

where ε_t^Γ and $\varepsilon_t^{\sigma^\Gamma}$ denote first- and second-moment shocks which capture innovations to the stochastic process for the level and the volatility of inflation uncertainty, respectively. Specifically, the second-moment shocks are referred to as the inflation uncertainty shock. All the stochastic shocks are orthogonal and follow a standard normal distribution. The rest of the features are identical to Basu and Bundick (2017).

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