Modeling Time-Variation Over the Business Cycle (1960-2017): An International Perspective

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Modeling Time-Variation Over the Business Cycle (1960-2017): An International Perspective[*]

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Abstract

In this paper, I explore the changes in international business cycles with quarterly data for the eight largest advanced economies (U.S., U.K., Germany, France, Italy, Spain, Japan, and Canada) since the 1960s. Using a time-varying parameter model with stochastic volatility for real GDP growth and inflation allows their dynamics to change over time, approximating nonlinearities in the data that otherwise would not be adequately accounted for with linear models (Granger et al. (1991), Granger (2008)). With that empirical model, I document a period of declining macro volatility since the 1980s, followed by increasing (and diverging) inflation volatility since the mid-1990s. I also find significant shifts in inflation persistence and cyclicality, as well as in macro synchronization and even forecastability. The 2008 global recession appears to have had an impact on some of this. I ground my empirical strategy on the reduced-form solution of the workhorse New Keynesian model and, motivated by theory, explore the relationship between greater trade openness (globalization) and the reported shifts in international business cycles. I show that globalization has sizeable (yet nonlinear) effects in the data consistent with the implications of the model—yet globalization's contribution is not a foregone conclusion, depending crucially on more than the degree of openness of the international economy.

Keywords: Great Moderation, Globalization, International Business Cycles, Stochastic Volatility, Time-Varying Parameters

JEL Classification: E31, E32, F41, F44

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1. Introduction

Although linear models feature prominently in the econometrics toolbox, there is growing recognition that non-linear models can better characterize macroeconomic time series. Yet, empirical modeling can be challenging when nonlinearities/asymmetries are difficult to identify and difficult to estimate in the data. Nonlinearities in the data-generating process (DGP) can often be fully captured with an appropriate time-varying parameter (TVP) model (Granger *et al.* (1991))—a framework with a long tradition in applied international macroeconomics (Teräsvirta and Anderson (1992), Stock and Watson (2003a,b)). More generally, as shown in Granger (2008) (via White's Theorem), any non-linear model can be approximated by a linear TVP model. The linear TVP tends to be more tractable, readily interpretable, and straightforward to aggregate than the exact non-linear model underlying the data.

In this paper, I use the reduced-form solution of the well-known workhorse open-economy New Keynesian framework (Clarida *et al.* (2002), Martínez-García and Wynne (2010), Martínez-García (2017)) to motivate a benchmark linear time series model for international data on real GDP growth and inflation. Then, following Granger (2008), I adopt a more flexible specification of this linear benchmark allowing time-variation in the autoregressive coefficients and—to capture exogenous sources of variation in the volatility of the time series—stochastic volatility as well. I build upon the econometric techniques of Stock and Watson (2003a,b), and the related work of Stock and Watson (2007), Teräsvirta (2012), and Amado and Teräsvirta (2008, 2013, 2017), among others, to estimate this linear TVP model. This empirical strategy is flexible to let the data speak for itself and can capture international business cycles shifts over time.

I use a quarterly data on real GDP and its subcomponents by expenditure type and by sector and data on the GDP deflator for the eight largest advanced economies (U.S., U.K., France, Germany, Canada, Italy, Japan, and Spain) over the 1960:Q1-2017:Q4 period.[1] After the Great Inflation of the 1970s, major advanced economies experienced declining inflation rates and somewhat more robust

[1] I focus on the common empirical features of these eight major advanced economies, abstracting from their idiosyncratic (country-specific) patterns. The eight countries reflect a broad cross-section of advanced economies accounting for nearly 30 percent of PPP-adjusted world real GDP in 2017 (and an even higher share earlier on).

growth between the 1980s and mid-2000s (the Great Moderation period). Here, I document the other key shifts in the international business cycle:

(a) Changes in macroeconomic volatility:
  i. Gradual yet sizeable declines in real GDP growth volatility since the mid-1970s, predating the onset of the Great Moderation in the 1980s.
    - Contractions became both shorter and less frequent during the Great Moderation, as growth volatility declined.
  ii. Widespread declines in inflation (based on the GDP deflator) volatility during the 1980s and early-1990s, after experiencing high volatility in the 1970s accentuated during the oil crises of 1973 and 1979. Rising inflation volatility—albeit not in the U.S.—and greater cross-country disparities followed since the mid-1990s.
  iii. Forecastability of either real GDP growth or inflation with simple univariate time series models tends to improve whenever macroeconomic volatility is lower.

(b) Changes in macroeconomic persistence:
  i. The persistence of growth has remained low and fairly stable over time.
  ii. The persistence of inflation was quite high earlier on, but gradually declined since the late-1970s (leveling off around the time of the 2008 global recession).

(c) Other features of the international business cycle have changed as well:
  i. The synchronization of real GDP growth across countries has remained low and largely stable until it quickly spiked in the aftermath of the 2008 global recession.
  ii. Before the mid-1990s, the cross-country correlation (synchronization) of inflation was very high and countercyclical. Since then, the cross-country correlation has dropped (only gained some ground after 2008) and has become largely acyclical.

International business cycles have indeed shifted significantly. The question is why. The literature continues to debate whether these changes—the Great Moderation in particular—are the result of "good luck" (Ahmed *et al.* (2004), Stock and Watson (2003a,b), Primiceri (2005), Sims and Zha (2006), Galí and Gambetti (2009)), improved macroeconomic policies—particularly better monetary policy—internationally (Clarida *et al.* (2000), Lubik and Schorfheide (2004), Benati and Surico (2009)), changes in the structure of the economy or structural transformation, or some combination of all of them.

The "good luck" hypothesis posits that shifts in macro volatility can occur if the exogenous shocks hitting the economy become smaller over a period of time. Changes in the contribution of different shocks to the business cycle are also part of the explanation (Galí and Gambetti (2009)). This hypothesis generally implies that business cycle changes are largely exogenous and out-of-the-control of policy-makers. In turn, improved performance of macroeconomic policies, in particular better monetary policy, attributes those business cycle changes to policy shifts that align the implemented policy closer to the optimal one (see, e.g., Taylor (2016) on this point) or to a move from passive to active monetary policy (Lubik and Schorfheide (2004)). Substantial changes in the operational frameworks for central banking, increased independence, and improved accountability and transparency have all likely contributed to produce better macroeconomic outcomes.

Some of the key explanations investigated in the literature in relation to the structural transformation hypothesis include:

1. Changes in the composition of output away from more volatile manufacturing and toward more stable services, as investigated in Stock and Watson (2003a,b). Market structure and deregulation are also some of the related developments under consideration here.
2. Improved supply-chain and inventory management policies, as McConnell and Perez-Quirós (2000), Stock and Watson (2003a,b), Cecchetti *et al.* (2005), and Davis and Kahn (2008).
3. Financial innovation and improvements in risk-sharing, as advocated by Cecchetti *et al.* (2005) and Dynan *et al.* (2006): "Financial globalization" through deepening domestic and international financial markets, increased international capital flows, financial deregulation, etc., since at least the 1970s.
4. Demographics, particularly population aging as in Jaimovich and Siu (2009), Heer *et al.* (2017).
5. Global commodity prices (and oil prices in particular), of which Blanchard and Galí (2007) is one of the most comprehensive studies.
6. Globalization through increased international trade openness, as in Barrell and Gottschalk (2004), Cecchetti *et al.* (2005), and Bianchi and Civelli (2015), among others.[2] Also important is globalization through increased migration and cross-border information flows.

[2] Bernanke (2007) focused the debate on the impact of globalization on the business cycle in the following terms: "(a)t the broadest level, globalization influences the conduct of monetary policy through its powerful effects on the economic and financial environment in which monetary policy must operate."

While a thorough review of all plausible hypotheses is beyond the scope of this paper, the main take-away from the existing literature seems to be that no single hypothesis can quantitatively explain the observed business cycle changes. To foreshadow my conclusions, my findings are broadly consistent with logic of the workhorse open-economy New Keynesian model that points at increased trade openness (globalization) as one of the leading forces of structural transformation behind the observed shifts in international business cycles.

Since the 1960s, the world economy certainly has undergone major structural changes that cannot be easily dismissed. Arguments based on structural transformation postulate that changes in institutions, technology, or other structural features of the world economy—such as globalization—can affect the national economy's ability to absorb shocks or alter the propagation of different shocks over the business cycle. The workhorse New Keynesian open-economy model suggests that shifts can be attributed to (nonlinear) changes in deep structural parameters—and, in particular, to changes that affect the impact of the trade channel (an important dimension of globalization).[3]

Some forms of structural change can occur fairly rapidly, but structural transformation through greater trade integrations is often thought of as a gradual process unfolding over a prolonged period of time. In this paper, broadly in line with the implications of New Keynesian theory, I find robust empirical evidence supporting the view that common cross-country shifts in international business cycles—in regards to volatility, persistence, and even on the synchronization and cyclicality of real GDP growth and inflation—are strongly and nonlinearly related to greater trade openness (globalization). To my knowledge, this evidence showing that international business cycles have changed with increased globalization has not been fully documented in the literature before.

Finally, motivated by theory, I also argue that the impact of globalization as well as the properties of international business cycles may also evolve as a result of other developments: due to exogenous changes in the contribution of different shocks; with the central bank becoming more independent and more actively concerned with fighting inflation; with labor markets becoming more competitive; and with the country's financial system becoming more developed and perhaps more fragile too. For

[3] The theoretical framework that I rely upon (and its closely related variants) features prominently as a benchmark in the international macro literature. There is also a body of research suggesting the practical relevance of the workhorse New Keynesian open-economy model for empirical analysis and forecasting (Martínez-García (2015), Duncan and Martínez-García (2015), Kabukçuoglu and Martínez-García (2016, 2018)).

instance, the boom in real estate investment leading to the 2008 global recession appears to showcase some of the perils associated with excessive risk-taking and international financial spillovers (contagion).

In the remainder of this paper, I introduce the open-economy New Keynesian framework that underpins my analysis and I describe the empirical strategy used (Section 2). In Section 3, I discuss the empirical evidence since the 1960s for the eight largest advanced economies through the lens of the linear TVP model that extended the reduced-form time series representation of the solution to the open-economy New Keynesian model. I also provide a detailed exploration of developments in international business cycles: volatility, persistence, forecastability, cyclicality, synchronization, etc. In Section 4, I focus on the extent to which trade openness (globalization) has contributed to shifting international business cycles. Section 5 provides evidence on other possible explanations for the evidence and discusses the possible significance of the 2008 global recession. Finally, Section 6 provides some concluding remarks and the Appendix includes additional results—a discussion on the perceived flattening of the short-run Phillips curve during the Great Moderation.

2. Modeling International Business Cycles

I take as reference the linearized two-country New Keynesian workhorse model—micro-founded in Clarida *et al.* (2002) and further developed in Martínez-García and Wynne (2010) and Martínez-García (2017). The model features two distortions in the goods market that are characteristic in the New Keynesian literature: monopolistic competition in production and staggered price-setting behavior à la Calvo (1983). The workhorse model assumes the law of one price (LOOP) holds at the variety level as firms price all their sales (domestic and foreign) in units of their local currency and quote them in the other country's currency at the prevailing bilateral nominal exchange rate. It also abstracts from capital accumulation—with a linear-in-labor technology—and posits a mass one of varieties produced in each country (all costlessly traded across borders). Business cycle fluctuations are driven by country-specific productivity shocks, cost-push shocks, and monetary policy shocks.

The model is log-linearized around a deterministic, zero-inflation steady state (see Martínez-García (2017) for further details on the model derivations). I denote $\widehat{w}_t \equiv \ln W_t - \ln W$ as the deviation of a given endogenous/exogenous variable in logs from its steady state. I use the superscript $*$ to distinguish variables that are specific to the Foreign country from those that correspond to the Home country and mark the frictionless variables—those that would prevail absent all frictions in both countries—with an upper bar. As seen in Table 1, the log-linearized equilibrium conditions are summarized with an open-economy Phillips curve, an open-economy dynamic investment-savings (IS) equation, and a Taylor (1993) rule for monetary policy in each country. I.e., the workhorse open-economy New Keynesian model is a straightforward extension of the standard three-equation (closed-economy) New Keynesian model (Woodford (2003)).

The system of equations in Table 1 pins down Home and Foreign inflation (quarter-over-quarter changes), $\widehat{\pi}_t$ and $\widehat{\pi}_t^*$, Home and Foreign slack (deviations of output from the potential that would be achieved absent all frictions), $\hat{x}_t$ and $\hat{x}_t^*$, and Home and Foreign short-term nominal interest rates, $\hat{i}_t$ and $\hat{i}_t^*$. Table 1 also includes two definitions relating output in each country, $\hat{y}_t$ and $\hat{y}_t^*$, to the country's output potential plus slack—so Home and Foreign output can be expressed as $\hat{y}_t = \hat{\bar{y}}_t + \hat{x}_t$ and $\hat{y}_t^* = \hat{\bar{y}}_t^* + \hat{x}_t^*$, respectively. The description of the model in Table 1 is completed with a pair of Fisherian equations for the Home and Foreign real interest rates defined as $\hat{r}_t \equiv \hat{i}_t - E_t\left(\widehat{\pi}_{t+1}\right)$ and $\hat{r}_t^* \equiv \hat{i}_t^* - E_t\left(\widehat{\pi}_{t+1}^*\right)$, respectively.

The natural (real) rates of interest that prevail absent all frictions for the Home and Foreign countries are denoted $\hat{\bar{r}}_t$ and $\hat{\bar{r}}_t^*$. The natural rates are a function of Home and Foreign potential output growth—where Home and Foreign potential output, $\hat{\bar{y}}_t$ and $\hat{\bar{y}}_t^*$, depend exclusively on the Home and Foreign productivity shocks, $\hat{a}_t$ and $\hat{a}_t^*$, respectively. Apart from productivity shocks, the model includes two other country-specific exogenous shocks: cost-push shocks, $\hat{u}_t$ and $\hat{u}_t^*$, and monetary policy shocks, $\widehat{m}_t$ and $\widehat{m}_t^*$. As indicated in Table 1, all shocks follow bivariate VAR(1) stochastic processes but only productivity shocks incorporate international spillovers explicitly. Shock innovations can be correlated across countries, but in principle spillovers across the three different types of shocks are ruled out.

Table 1. Workhorse Open-Economy New Keynesian Model

Home country	
NKPC	$\widehat{\pi}_t \approx \beta \mathbb{E}_t\left(\widehat{\pi}_{t+1}\right) + \Phi\left(\varphi+\gamma\right)\left[\kappa \widehat{x}_t + \left(1-\kappa\right)\widehat{x}^*_t + \widehat{v}_t\right]$ $\widehat{v}_t \equiv \left(1-\xi\right)\widehat{u}_t + \xi \widehat{u}^*_t$
Dynamic IS	$\gamma\left(\mathbb{E}_t\left[\widehat{x}_{t+1}\right] - \widehat{x}_t\right) \approx \Omega\left[\widehat{r}_t - \widehat{\overline{r}}_t\right] + \left(1-\Omega\right)\left[\widehat{r}^*_t - \widehat{\overline{r}}^*_t\right]$
Monetary policy	$\widehat{i}_t \approx \psi_\pi \widehat{\pi}_t + \psi_x \widehat{x}_t + \widehat{m}_t$
Definitions	$\widehat{r}_t \equiv \widehat{i}_t - \mathbb{E}_t\left[\widehat{\pi}_{t+1}\right],\ \widehat{y}_t \equiv \widehat{\overline{y}}_t + \widehat{x}_t$
Natural interest rate	$\widehat{\overline{r}}_t \approx \gamma\left[\Theta\left(\mathbb{E}_t\left[\widehat{\overline{y}}_{t+1}\right] - \widehat{\overline{y}}_t\right) + \left(1-\Theta\right)\left(\mathbb{E}_t\left[\widehat{\overline{y}}^*_{t+1}\right] - \widehat{\overline{y}}^*_t\right)\right]$
Potential output	$\widehat{\overline{y}}_t \approx \left(\frac{1+\varphi}{\gamma+\varphi}\right)\left[\Lambda \widehat{a}_t + \left(1-\Lambda\right)\widehat{a}^*_t\right]$
Foreign country	
NKPC	$\widehat{\pi}^*_t \approx \beta \mathbb{E}_t\left(\widehat{\pi}^*_{t+1}\right) + \Phi\left(\varphi+\gamma\right)\left[\left(1-\kappa\right)\widehat{x}_t + \kappa \widehat{x}^*_t + \widehat{v}^*_t\right]$ $\widehat{v}^*_t \equiv \xi \widehat{u}_t + \left(1-\xi\right)\widehat{u}^*_t$
Dynamic IS	$\gamma\left(\mathbb{E}_t\left[\widehat{x}^*_{t+1}\right] - \widehat{x}^*_t\right) \approx \left(1-\Omega\right)\left[\widehat{r}_t - \widehat{\overline{r}}_t\right] + \Omega\left[\widehat{r}^*_t - \widehat{\overline{r}}^*_t\right]$
Monetary policy	$\widehat{i}^*_t \approx \psi^*_\pi \widehat{\pi}^*_t + \psi^*_x \widehat{x}^*_t + \widehat{m}^*_t$
Definitions	$\widehat{r}^*_t \equiv \widehat{i}^*_t - \mathbb{E}_t\left[\widehat{\pi}^*_{t+1}\right],\ \widehat{y}^*_t \equiv \widehat{\overline{y}}^*_t + \widehat{x}^*_t$
Natural interest rate	$\widehat{\overline{r}}^*_t \approx \gamma\left[\left(1-\Theta\right)\left(\mathbb{E}_t\left[\widehat{\overline{y}}_{t+1}\right] - \widehat{\overline{y}}_t\right) + \Theta\left(\mathbb{E}_t\left[\widehat{\overline{y}}^*_{t+1}\right] - \widehat{\overline{y}}^*_t\right)\right]$
Potential output	$\widehat{\overline{y}}^*_t \approx \left(\frac{1+\varphi}{\gamma+\varphi}\right)\left[\left(1-\Lambda\right)\widehat{a}_t + \Lambda \widehat{a}^*_t\right]$
Composite parameters	
	$\Phi \equiv \left(\frac{(1-\alpha)(1-\beta\alpha)}{\alpha}\right),$
	$\kappa \equiv \left(1-\xi\right)\left[1 - \left(\sigma\gamma-1\right)\left(\frac{\gamma}{\varphi+\gamma}\right)\left(\frac{(2\xi)(1-2\xi)}{1+(\sigma\gamma-1)(2\xi)(2(1-\xi))}\right)\right],$
	$\Theta \equiv \left(1-\xi\right)\left[\frac{\sigma\gamma-(\sigma\gamma-1)(1-2\xi)}{\sigma\gamma-(\sigma\gamma-1)(1-2\xi)^2}\right] = \left(1-\xi\right)\left[\frac{1+(\sigma\gamma-1)(2\xi)}{1+(\sigma\gamma-1)(2\xi)(2(1-\xi))}\right],$
	$\Omega \equiv \left(1-\xi\right)\left(\frac{1-2\xi(1-\sigma\gamma)}{1-2\xi}\right),$
	$\Lambda \equiv 1 + \frac{1}{2}\left[\frac{\left(\frac{\gamma}{\varphi+\gamma}\right)(\sigma\gamma-1)(2\xi)(2(1-\xi))}{1+\left(1-\frac{\gamma}{\varphi+\gamma}\right)(\sigma\gamma-1)(2\xi)(2(1-\xi))}\right]$
Productivity shock	$\begin{pmatrix}\widehat{a}_t \\ \widehat{a}^*_t\end{pmatrix} \approx \begin{pmatrix}\delta_a & \delta_{a,a^*} \\ \delta_{a,a^*} & \delta_a\end{pmatrix}\begin{pmatrix}\widehat{a}_{t-1} \\ \widehat{a}^*_{t-1}\end{pmatrix} + \begin{pmatrix}\widehat{\varepsilon}^a_t \\ \widehat{\varepsilon}^{a*}_t\end{pmatrix}$ $\begin{pmatrix}\widehat{\varepsilon}^a_t \\ \widehat{\varepsilon}^{a*}_t\end{pmatrix} \sim N\left(\begin{pmatrix}0 \\ 0\end{pmatrix}, \begin{pmatrix}\sigma^2_a & \rho_{a,a^*}\sigma^2_a \\ \rho_{a,a^*}\sigma^2_a & \sigma^2_a\end{pmatrix}\right)$
Cost-push shock	$\begin{pmatrix}\widehat{u}_t \\ \widehat{u}^*_t\end{pmatrix} \approx \begin{pmatrix}\delta_u & 0 \\ 0 & \delta_u\end{pmatrix}\begin{pmatrix}\widehat{u}_{t-1} \\ \widehat{u}^*_{t-1}\end{pmatrix} + \begin{pmatrix}\widehat{\varepsilon}^u_t \\ \widehat{\varepsilon}^{u*}_t\end{pmatrix}$ $\begin{pmatrix}\widehat{\varepsilon}^u_t \\ \widehat{\varepsilon}^{u*}_t\end{pmatrix} \sim N\left(\begin{pmatrix}0 \\ 0\end{pmatrix}, \begin{pmatrix}\sigma^2_u & \rho_{u,u^*}\sigma^2_u \\ \rho_{u,u^*}\sigma^2_u & \sigma^2_u\end{pmatrix}\right)$
Monetary shock	$\begin{pmatrix}\widehat{m}_t \\ \widehat{m}^*_t\end{pmatrix} \approx \begin{pmatrix}\delta_m & 0 \\ 0 & \delta_m\end{pmatrix}\begin{pmatrix}\widehat{m}_{t-1} \\ \widehat{m}^*_{t-1}\end{pmatrix} + \begin{pmatrix}\widehat{\varepsilon}^m_t \\ \widehat{\varepsilon}^{m*}_t\end{pmatrix}$ $\begin{pmatrix}\widehat{\varepsilon}^m_t \\ \widehat{\varepsilon}^{m*}_t\end{pmatrix} \sim N\left(\begin{pmatrix}0 \\ 0\end{pmatrix}, \begin{pmatrix}\sigma^2_m & \rho_{m,m^*}\sigma^2_m \\ \rho_{m,m^*}\sigma^2_m & \sigma^2_m\end{pmatrix}\right)$

Finally, I define the intertemporal discount factor as β, the inverse of the intertemporal elasticity of substitution as γ, the inverse of the Frisch elasticity of labor supply as φ, and the Calvo (1983) price stickiness parameter as α. The deep structural parameters that determine the strength of the trade channel in the model are the degree of openness (the steady state import share) ξ and the trade elasticity of substitution between domestic and imported goods σ. The parameters that characterize the persistence of the underlying productivity shock process are δ_a with cross-country productivity spillovers (technological diffusion across countries) determined by δ_{a,a^*}. The volatility of the shock innovations is given by σ_a, while the cross-country correlation of the innovations is pinned down by ρ_{a,a^*}. Analogously, I define the parameters of the cost-push shock process and the monetary shock process. Finally, the policy weights on domestic inflation and the domestic output gap in the Taylor (1993) rule are given by ψ_π and ψ_x, respectively.

2.1 Implications from Theory

Productivity shocks capture the state of the economy and are the main drivers of the business cycle (see, e.g., Galí and Gambetti (2009) on the empirical evidence on the shrinking contribution of non-technology shocks to volatility during the Great Moderation). Then, it follows that the reduced-form solution for domestic inflation π_t conditional on productivity shocks that arises from the open-economy New Keynesian model (Table 1) can be represented with an ARMA(2,1) process of the following form:[4]

$$\pi_t = \chi_{\pi,1}\pi_{t-1} + \chi_{\pi,2}\pi_{t-2} + \eta_t + \theta_\pi \eta_{t-1}, \;\; \eta_t \sim N\left(0, \lambda_\pi^2\right). \tag{1}$$

which reduces to a simple AR(1) process:

$$\pi_t = \chi_{\pi,1}\pi_{t-1} + \eta_t, \;\; \eta_t \sim N\left(0, \lambda_\pi^2\right), \tag{2}$$

[4] To simplify notation, I drop the hat ($\hat{}$) on all variables from now onwards unless otherwise noted. For more details on the properties of the reduced-form solution of this model and the analytic derivation of the composite coefficients represented here, see Martínez-García (2017). A discussion of the open-economy Taylor principle that ensures existence and uniqueness of this solution can also be found in Martínez-García (2017).

whenever the cross-country productivity spillovers are set to zero, i.e., whenever $\delta_{a,a^*} = 0$. Here, the reduced-form composite coefficients $\chi_{\pi,1} \equiv \chi_{\pi,1}\left(\delta_a\right)$, $\chi_{\pi,2} \equiv \chi_{\pi,2}\left(\delta_a, \delta_{a,a^*}\right)$,
$\theta_\pi \equiv \theta_\pi\left(\xi, \sigma, \psi_\pi, \psi_x, \delta_a, \delta_{a,a^*}, \rho_{a,a^*}, \sigma_a^2; \beta, \varphi, \gamma, \alpha\right)$, and
$\lambda_\pi \equiv \lambda_\pi\left(\xi, \sigma, \psi_\pi, \psi_x, \delta_a, \delta_{a,a^*}, \rho_{a,a^*}, \sigma_a^2; \beta, \varphi, \gamma, \alpha\right)$ are nonlinear functions of the deep structural parameters of the model. A similar univariate time series characterizes foreign inflation (π_t^*).

Furthermore, domestic inflation and domestic and foreign output in response to productivity shocks must satisfy that:

$$\pi_t = \frac{\left(\frac{(1-\alpha)(1-\beta\alpha)}{\alpha}\right)(\varphi+\gamma)}{1-\beta\left(\delta_a + \delta_{a,a^*}\right)} \tfrac{1}{2}\left[\left(1+z^R\right)\left(y_t - \bar{y}_t\right) + \left(1-z^R\right)\left(y_t^* - \bar{y}_t^*\right)\right], \tag{3}$$

where $z^R \equiv z^R\left(\xi, \sigma, \delta_a, \delta_{a,a^*}; \beta, \varphi, \gamma\right)$. A similar trade-off characterizes the relationship between foreign inflation and domestic and foreign output. A bivariate VAR(1) stochastic process then closes the reduced-form solution of the model defining the dynamics of domestic and foreign output potential ($\bar{y}_t$ and $\bar{y}_t^*$) as follows:

$$\begin{pmatrix} \bar{y}_t \\ \bar{y}_t^* \end{pmatrix} = \begin{pmatrix} \delta_a & \delta_{a,a^*} \\ \delta_{a,a^*} & \delta_a \end{pmatrix} \begin{pmatrix} \bar{y}_{t-1} \\ \bar{y}_{t-1}^* \end{pmatrix} + \begin{pmatrix} \varepsilon_t \\ \varepsilon_t^* \end{pmatrix}, \quad \begin{pmatrix} \varepsilon_t \\ \varepsilon_t^* \end{pmatrix} \sim N\left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \lambda_{\bar{y}}^2 \begin{pmatrix} 1 & \rho_{\bar{y},\bar{y}^*} \\ \rho_{\bar{y},\bar{y}^*} & 1 \end{pmatrix}\right), \tag{4}$$

where ε_t and ε_t^* are domestic and foreign innovations, $\lambda_{\bar{y}} \equiv \lambda_{\bar{y}}\left(\xi, \sigma, \rho_{a,a^*}, \sigma_a^2; \varphi, \gamma\right)$, and $\rho_{\bar{y},\bar{y}^*} \equiv \rho_{\bar{y},\bar{y}^*}\left(\xi, \sigma, \rho_{a,a^*}; \varphi, \gamma\right)$. Furthermore, output dynamics can be inferred from (4) together with the conditional trade-off between inflation and slack and the inflation dynamics implied by (1)-(3) and its foreign counterpart as having a related univariate ARMA time series representation under standard time series aggregation results (Hamilton (1994)).

The dynamics implied by (1)-(4) can be enriched by incorporating monetary and cost-push shocks (as indicated in Martínez-García (2017)). The addition of monetary shocks does not fundamentally alter the equilibrium trade-offs in (4) but it can affect the unconditional persistence of the autoregressive coefficients as well as the macroeconomic volatility of π_t and y_t. In turn, the mixture of other shocks (particularly the addition of cost-push shocks which act as a shifter of the open-economy New Keynesian Phillips curve) introduces competing trade-offs for monetary policy, i.e., it leads to

$$\pi_t = -\frac{\left(1+\frac{1}{\gamma}\psi_x - \delta_\upsilon\right)}{\frac{1}{\gamma}\left(\psi_\pi - \delta_\upsilon\right)} \frac{1}{2}\left[\left(1+h^R\right)\left(y_t - \overline{y}_t\right) + \left(1-h^R\right)\left(y_t^* - \overline{y}_t^*\right)\right], \tag{5}$$

where $h^R \equiv h^R\left(\xi,\sigma,\psi_x,\delta_\upsilon;\gamma\right)$.

The mixture of shocks driving the business cycles affects the cyclicality of inflation because (5) shows that slack—a weighted average of Home and Foreign slack—is inversely related to domestic inflation in response to cost-push shocks while it is positively related in (3) in response to productivity shocks (and analogously for monetary shocks). Moreover, it can also impact the unconditional persistence and cross-country correlation of the key macro aggregates (π_t and y_t). Interestingly, this suggests that changes in the contribution of different shocks ("good luck" hypothesis) might result in shifts in the comovement between output and inflation over the business cycle (inflation cyclicality). Yet, this also shows the complexities of interpreting shifts in the observed business cycle moments because features like the cyclicality of inflation may change as a result of changes in other structural parameters (like the import share ξ and the policy parameters $\left(\psi_\pi,\psi_x\right)$ that affect (5) but not (3)) even if the dynamics of the different shocks remain unchanged.

More broadly, theory also suggests that the key parameters defining the trade channel (ξ,σ) can have a non-linear effect on reduced-form macroeconomic persistence as well as on volatility whenever business cycles are driven by a combination of shocks—the aim of the paper is to uncover and assess empirical evidence of such a relationship. Furthermore, the main message of the theory remains that a time series representation can capture well the macro data, so I rely on a linear TVP time series specification in my subsequent empirical strategy in order to identify shifts in international business cycles.

2.2 Empirical Approach

Martínez-García *et al.* (2012) and Martínez-García and Wynne (2014) show that there are significant challenges to identification and model selection that can prevent us from taking full advantage of well-known structural methods to estimate the workhorse open-economy New Keynesian model (even without assuming time-varying parameters). Instead, I approximate the reduced-form solution of the workhorse model for inflation and output growth, $z_t \in \{g_t, \pi_t\}$, with the following linear time-varying parameter (TVP) autoregressive specification with stochastic volatility:

$$
\begin{aligned}
z_t &= \chi_{0t} + \sum_{j=1}^{p} \chi_{jt} z_{t-j} + \lambda_t \varepsilon_t, \\
\chi_{jt} &= \chi_{jt-1} + c\nu_{jt}, \\
\ln\left(\lambda_t^2\right) &= \ln\left(\lambda_{t-1}^2\right) + u_t,
\end{aligned} \tag{6}
$$

where ε_t, $\{\nu_{jt}\}_{j=1}^{p}$ are i.i.d. $N(0,1)$. Furthermore, p determines the number of lags in the autoregressive conditional mean process, $\{\chi_{jt}\}_{j=0}^{p}$ are the corresponding time-varying autoregressive coefficients, and λ_t is the time-varying standard deviation of the innovations. I introduce a mixture-of-normals for u_t which is distributed independently of the other shocks, i.e., u_t is distributed $N\left(0,\tau_1^2\right)$ with probability q and $N\left(0,\tau_2^2\right)$ with probability $1-q$. The parameters c, τ_1, and τ_2 scale up the volatility on the innovations to the time-varying coefficients $\{\chi_{jt}\}_{j=0}^{p}$ and to λ_t.

I estimate (6) using the econometric modeling techniques of Stock and Watson (2003a,b)—related specifications can be found in Stock and Watson (2007), Teräsvirta (2012), and Amado and Teräsvirta (2008, 2013, 2017)—to flexibly capture the nonlinearities found in the macroeconomic data while approximating the reduced-form solution of the workhorse open-economy New Keynesian model (Martínez-García (2017)). In the spirit of Granger (2008), this specification allows time-variation in the conditional mean but also introduces (nonstationary) stochastic volatility whereby the log-volatility follows a random walk whose innovations are a mixture-of-normal distributions. The specification in (6) estimates a path for smoothed volatility (conditional variance) that is robust to shifts in the conditional mean of the process and allows for large jumps (or breaks) to occur.[5] For the estimation, I set $\tau_1 = 0.04$, $\tau_2 = 0.2$, $q = 0.95$, and $p = 4$. I also set $c = 7/T$, a value consistent with previous estimates of parameter drift in autoregressive processes (according to Stock and Watson (2003a)).

The quarterly time series data (z_t) includes: the annualized log-first difference of the real GDP and the real GDP subcomponents, and the annualized log-first difference of the GDP deflator expressed in percentages, i.e., for output Y_t this transformation means $g_t = 400 \times \ln\left(\frac{Y_t}{Y_{t-1}}\right)$ and similarly for the price level P_t is $\pi_t = 400 \times \ln\left(\frac{P_t}{P_{t-1}}\right)$.[6] The corresponding series $z_t \in \{g_t, \pi_t\}$ is then standardized before estimation. The instantaneous variance is computed as a function of the smoothed estimates of the time-varying term λ_t^2. The non-Gaussian smoother for the time-varying parameters is computed using Markov-chain Monte Carlo (MCMC) methods. The volatilities obtained are reported as four-quarter moving averages (MA(4)) computed via the temporal aggregation of the instantaneous autocovariance function. For additional technical details on prior selection, implementation, etc., see Stock and Watson (2003a, Appendix A).

The specification in (6) lets the data speak for itself largely unconstrained by the theoretical modeling assumptions, while providing a plausible approximation to the nonlinearities in the underlying data-generating process. The unconditional moments recovered from the estimation of (6)—macroeconomic volatility and persistence—vary, according to theory, due to shifts in a number

[5] As indicated by Shephard (1994), the specification of the error term u_t approximates non-gaussian distributions allowing for large jumps (sharp structural breaks) in the estimated variance λ_t^2.

[6] The specification in (6) includes a constant term to remove the mean of output growth and inflation—which otherwise are not part of the theory laid out in Section 2. The theoretical model does not account for the trend component of real GDP either. Therefore, as is customary, I use standard log-first differencing to filter out the trend component mapping the resulting observed growth (g_t) into the stationary output defined in the workhorse model (y_t).

of deep structural parameters including through the degree of openness ξ ("globalization"). I then provide evidence from OLS regressions showing that a polynomial function of the import share (ξ) explains much of the variation in the macroeconomic volatility, persistence, and in other features of the international business cycle—broadly consistent with the nonlinear impact that this measure is expected to have according to theory.

3. Shifting International Business Cycles

International business cycles have changed in a number of economically-relevant ways since the 1960s. I document these broad shifts with time series for the U.S., the U.K., France (FR), Germany (DE), Canada (CA), Italy (IT), Japan (JP), and Spain (ES) from the Organization for Economic Cooperation and Development (OECD). The series for volume estimates of Gross Domestic Product (in billions of US$, Purchasing Power Parity-adjusted) were taken directly from the OECD's Quarterly National Accounts database. The GDP deflator index (2009=100) was inferred by straightforward calculations using the OECD volume estimates and a comparable measure of GDP in nominal/current prices (expressed in billions of US$, Purchasing Power Parity-adjusted) also from the OECD's Quarterly National Accounts database. All series are reported as seasonally-adjusted and at an annual rate (SAAR).

3.1 Macroeconomic Volatility

Figures 1.A and 1.B illustrate the estimated time-varying standard deviation of quarterly real GDP growth and inflation (measured from the GDP deflator) for the U.S. and the other seven major advanced economies. The evidence in Figure 1.A shows a widespread decline in output growth volatility since the 1970s—characteristic of the Great Moderation period (see, e.g., Bernanke (2004)).[7] For the median advanced economy, the 1960s was a decade of elevated volatility, followed by a secular (and gradual) decline in volatility starting in the 1970s. The U.S. experience is characterized by a sharp fall around 1984 preceded by a period of elevated volatility during the 1970s. In turn, Figure 1.B shows a dramatic decline in inflation volatility occurring near-

[7] U.S. and international evidence on the Great Moderation includes: Kim and Nelson (1999), McConnell and Pérez-Quirós (2000), Blanchard and Simon (2001), Stock and Watson (2003a,b), Summers (2005), Cecchetti *et al.* (2005), Davis and Kahn (2008), Inoue and Rossi (2011), and Keating and Valcárcel (2017), among others.

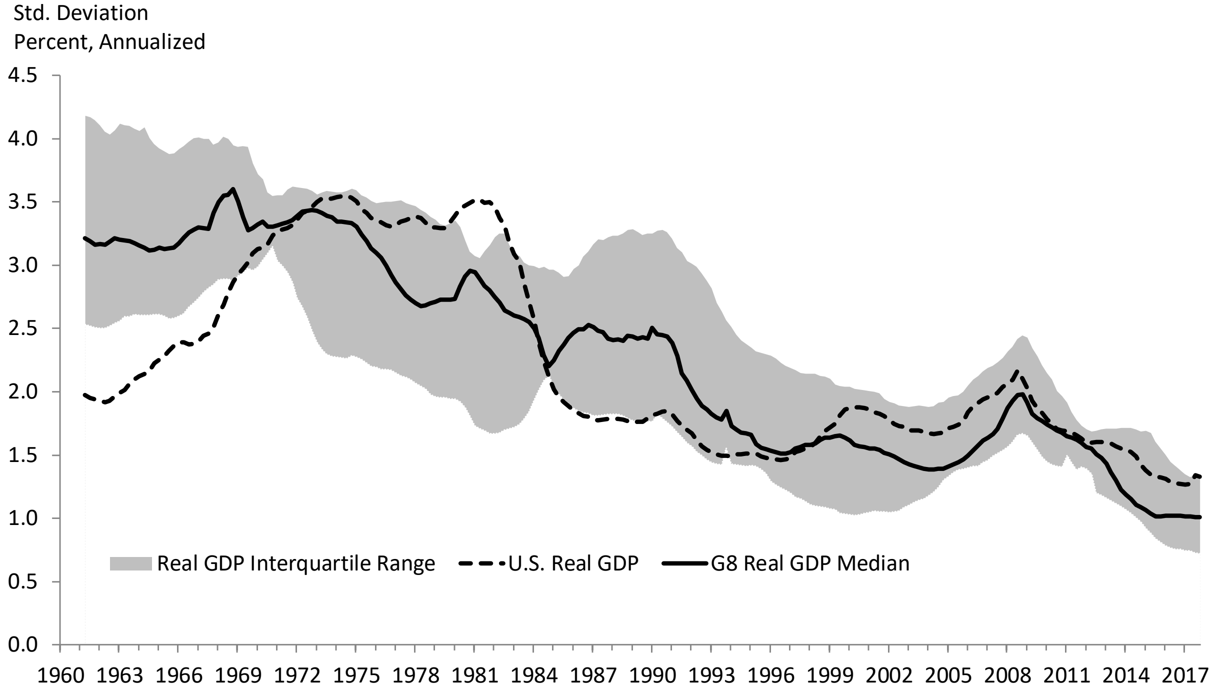
simultaneously in most advanced economies between the mid-1970s and the mid-1990s, followed by an equally notable—but uneven—rise afterwards. Balking at the trend, inflation volatility has remained fairly low in the U.S. since the mid-1990s until the present.

3.2 Macroeconomic Persistence

Figures 2.A and 2.B illustrate the persistence of a shock to real GDP growth and inflation (based on the GDP deflator), respectively. The sum of the time-varying autoregressive coefficients estimated from (6) is used to describe the persistence. Hence, an increase in this sum implies an increase in the persistence of a univariate innovation. The inverse of one minus this sum is the cumulative effect of a forecast error on the long-term forecast.

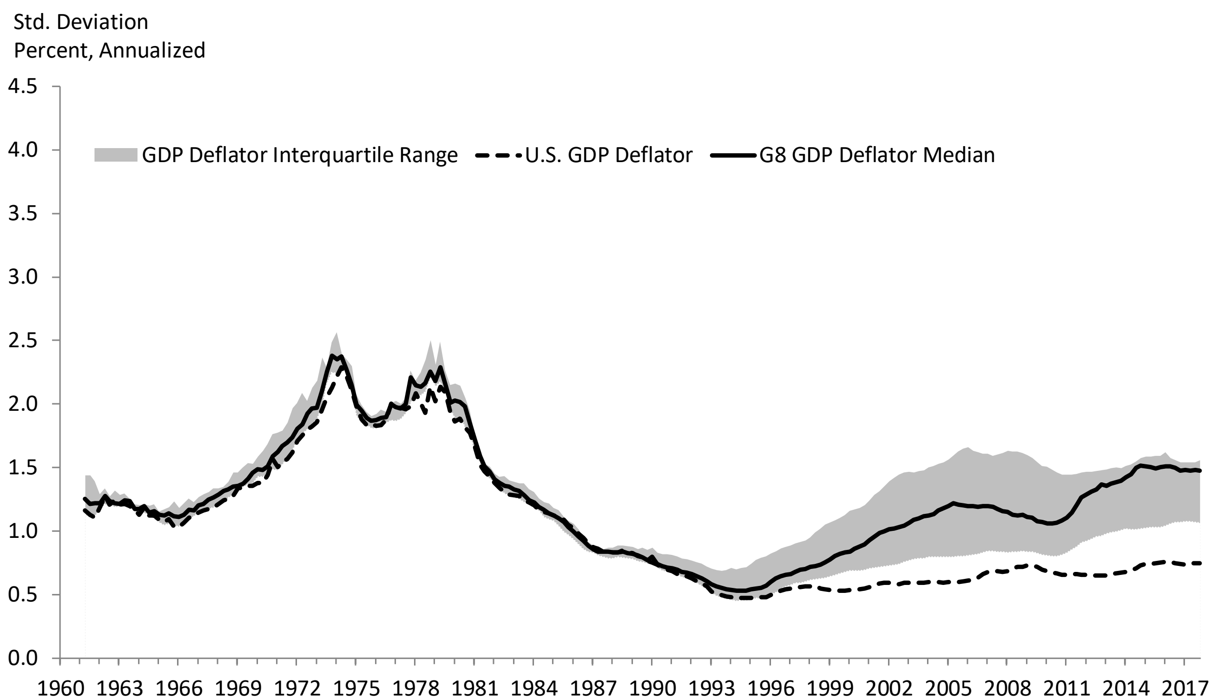
For the eight major advanced economies in my dataset, the evidence on persistence shows that: (a) real GDP growth persistence has remained fairly stable—less so in the U.S.—over time; (b) inflation persistence has been significantly higher than persistence on real GDP growth and much more similar across countries until the early-1980s when it declined—and became somewhat more dispersed—leveling off in the mid-2000s; (c) shifts in persistence appear more significant on inflation than on real GDP growth—not surprisingly, declining inflation persistence remains a major theoretical battleground in the business cycle literature (see, e.g., Benati and Surico (2008) and Carlstrom *et al.* (2009)).

Figure 1.A Real GDP Growth (Volatility)



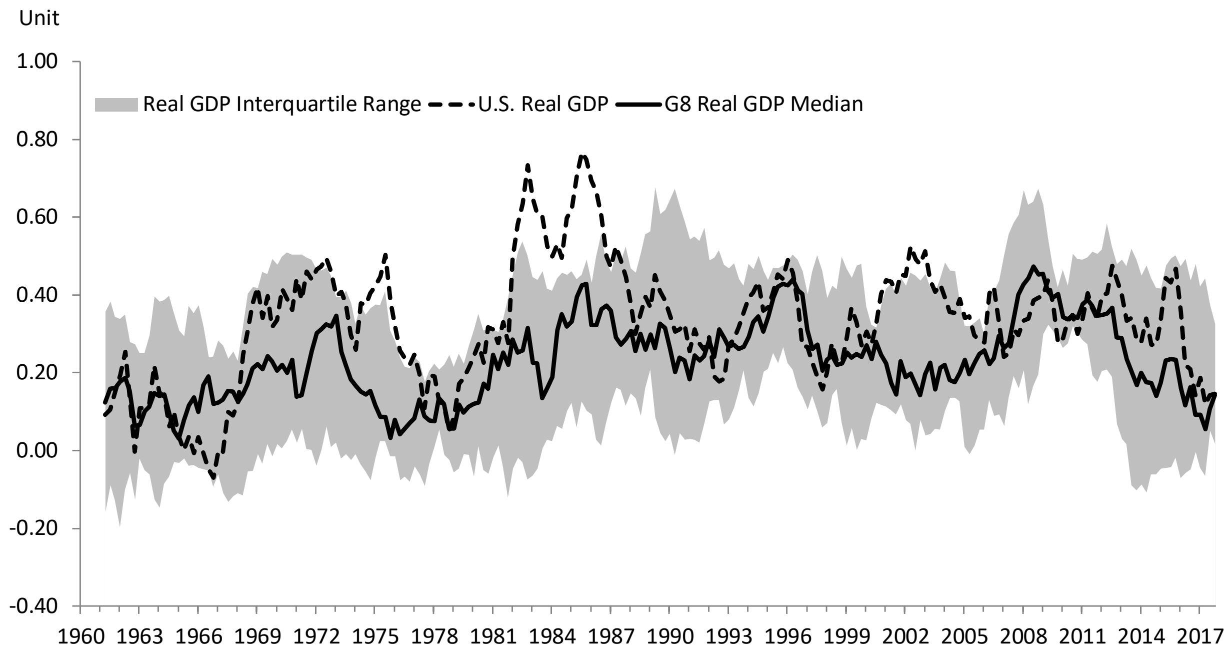
Note: Median and interquartile range include U.S., U.K., CA, FR, DE, JP, ES, and IT. The reported time-varying volatility is estimated from the annualized log-first differences in real GDP expressed in percentages.
Sources: Organization for Economic Cooperation and Development; author's calculations.

Figure 1.B GDP-Deflator-Based Inflation Rate (Volatility)



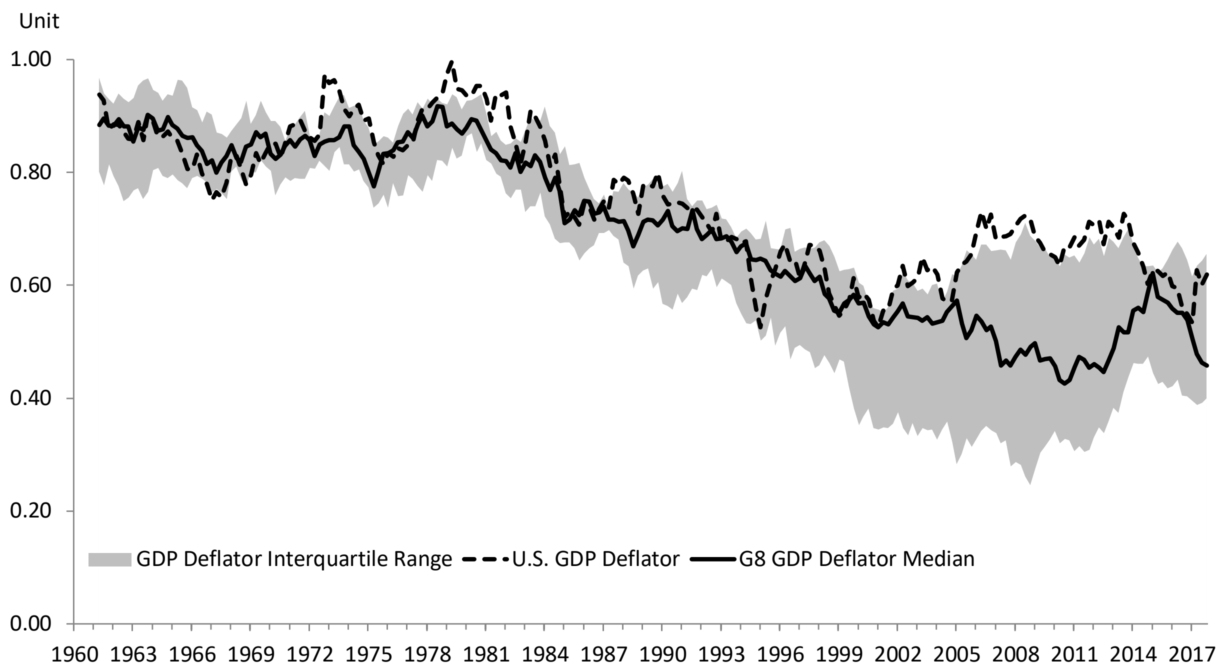
Note: Median and interquartile range include U.S., U.K., CA, FR, DE, JP, ES, and IT. The reported time-varying volatility is estimated from the annualized log-first differences in the implied GDP deflator expressed in percentages.
Sources: Organization for Economic Cooperation and Development; author's calculations.

Figure 2.A Persistence of Real GDP Growth



Note: Median and interquartile range include U.S., U.K., CA, FR, DE, JP, ES, and IT. The reported persistence is the sum of the time-varying autoregressive coefficients estimated from the annualized log-first differences in real GDP expressed in percentages.
Sources: Organization for Economic Cooperation and Development; author's calculations.

Figure 2.B Persistence of Inflation (GDP Deflator)



Note: Median and interquartile range include U.S., U.K., CA, FR, DE, JP, ES, and IT. The reported persistence is the sum of the time-varying autoregressive coefficients estimated from the annualized log-first differences in the implied GDP deflator expressed in percentages.
Sources: Organization for Economic Cooperation and Development; author's calculations.

3.3 Macroeconomic Forecastability

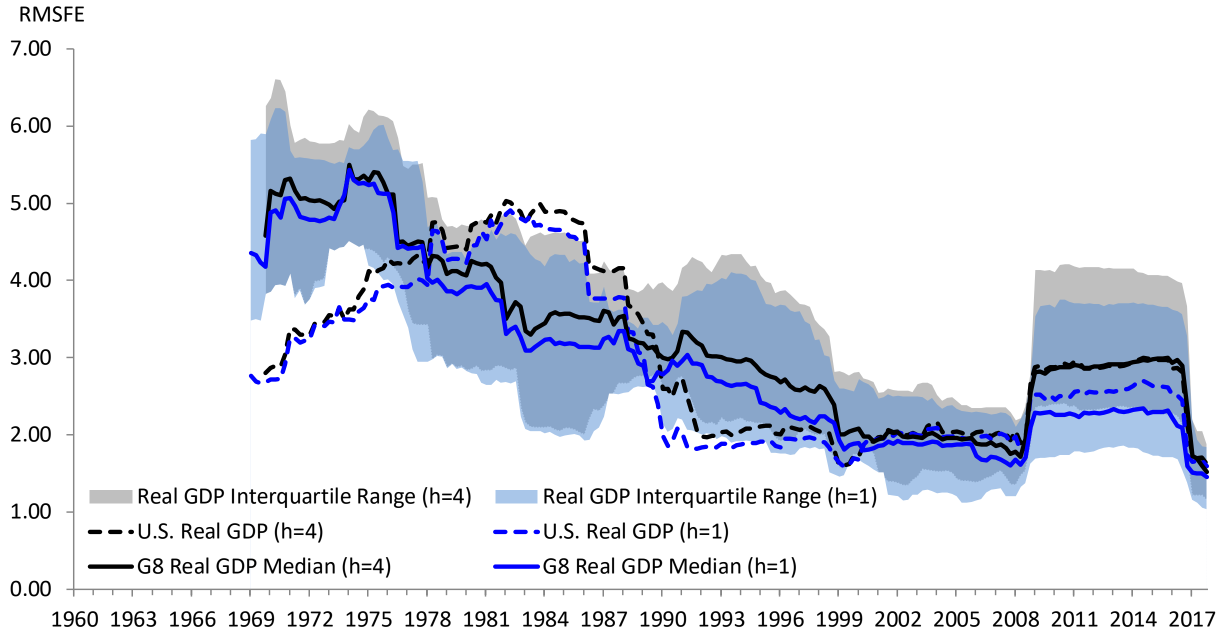
Figures 3.A and 3.B illustrate the uncertainty associated with one-period-ahead and four-periods-ahead forecasts of quarterly real GDP growth and inflation (derived from the GDP deflator) implied by the linear TVP model in (6) estimated over the full sample. Forecasts are constructed by the iterative method at different forecasting horizons. I measure forecasting uncertainty by the root mean squared forecasting error (RMSFE) of the resulting pseudo-out-of-sample forecasts implied by the estimated model over the preceding 8 years.[8]

The RMSFE for real GDP growth displays a secular trend decline similar to that of the conditional volatility estimates, which reverses itself only in the aftermath of the 2008 global recession—although temporarily. The differences at varying forecasting horizons are not too large. Similarly, the RMSFE for inflation shows the same broad shifts as the time-varying inflation volatility shown in Figure 1.B: a peak in the 1970s and a widespread fall up to the mid-1990s, followed by a divergent path afterwards. Differences in the RMSFE performance across forecasting horizons are more substantial for inflation than for real GDP growth.

Stock and Watson (2007), Duncan and Martínez-García (2015, 2018), and Kabukçuoglu and Martínez-García (2016, 2018), among others, document similar patterns across many countries and at multiple forecasting horizons. One mechanical interpretation of these findings is simply that forecasting either growth or inflation with simple univariate time series models becomes easier when the innovations become smaller (less volatile), as it largely happened during the Great Moderation (see Figures 1.A and 1.B).

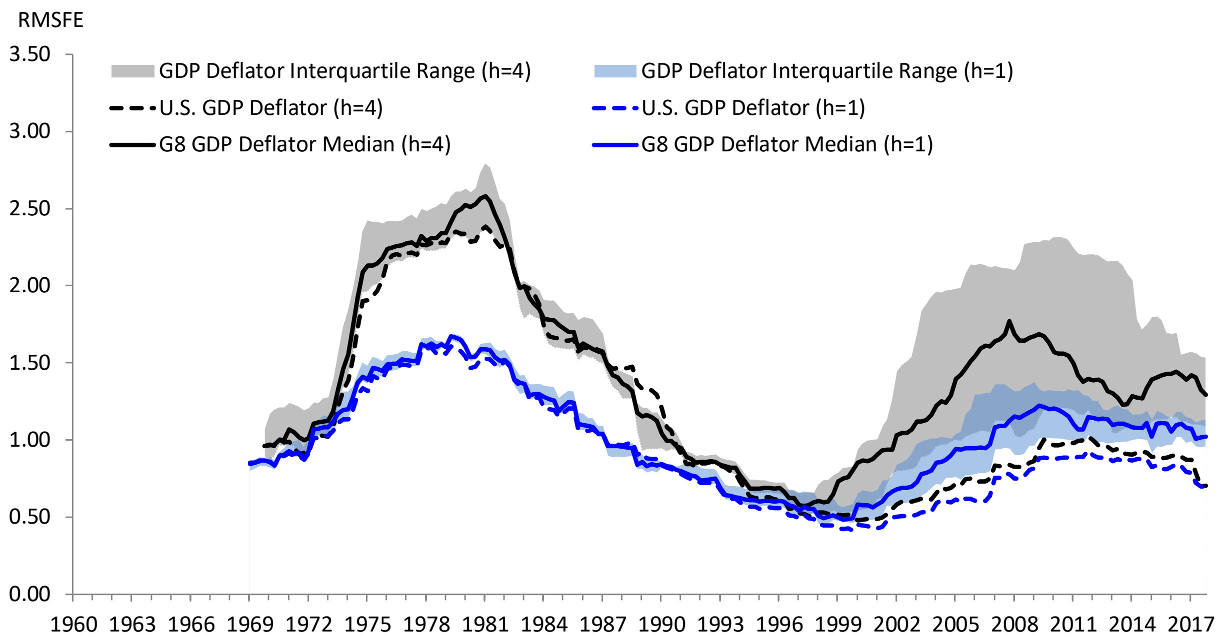
[8] These findings may be affected by revisions incorporated in the current series that were not available to forecasters in real time. For a more in-depth look at the role of data revisions, see Fernández *et al.* (2011).

Figure 3.A Root Mean Squared Forecast Error (RMSFE) on Real GDP Growth



Note: Median and interquartile range include U.S., U.K., CA, FR, DE, JP, ES, and IT. The reported root mean squared forecasting error (RMSFE) is the square root of the 8-year average of the one-step-ahead (h=1) and four-step-ahead (h=4) squared forecasting error obtained with the time-varying parameter model estimated on the annualized log-first differences in real GDP expressed in percentages.
Sources: Organization for Economic Cooperation and Development; author's calculations.

Figure 3.B Root Mean Squared Forecast Error (RMSFE) on Inflation (GDP Deflator)



Note: Median and interquartile range include U.S., U.K., CA, FR, DE, JP, ES, and IT. The reported root mean squared forecasting error (RMSFE) is the square root of the 8-year average of the one-step-ahead (h=1) and four-step-ahead (h=4) squared forecasting error obtained with the time-varying parameter model estimated on the annualized log-first differences in the implied GDP deflator expressed in percentages.
Sources: Organization for Economic Cooperation and Development; author's calculations.

3.4 Other International Business Cycle Features

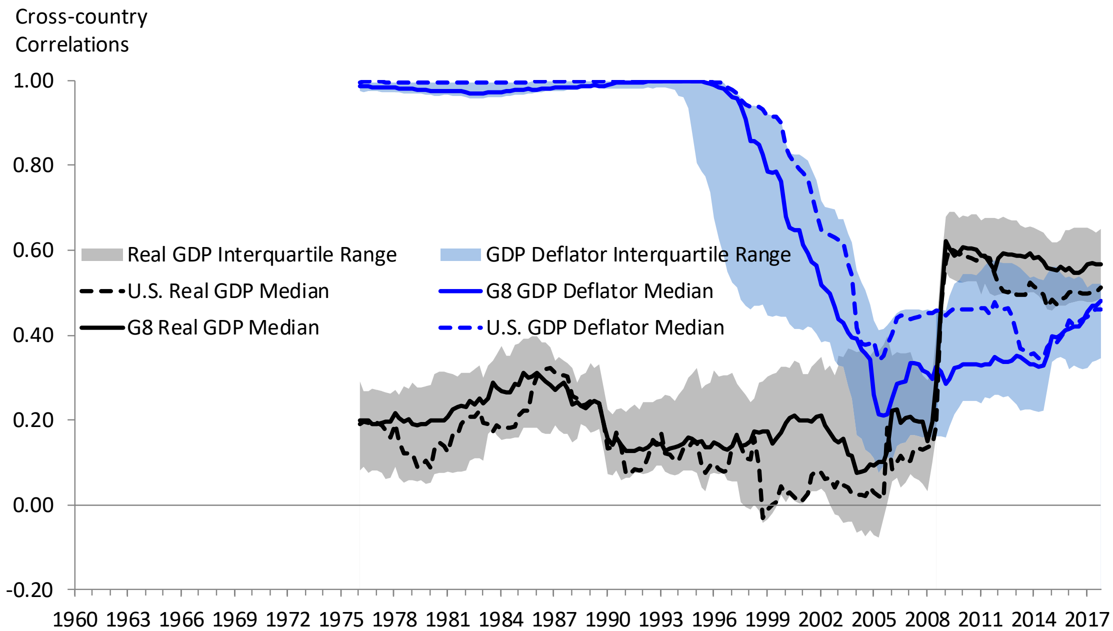
3.4.1 Synchronization and Cyclicality Patterns

Figure 4.A illustrates the empirical patterns of cross-country correlations among the eight major advanced economies for real GDP growth and the inflation rate (measured with the GDP deflator), respectively. The correlation of output growth across countries (or business cycle synchronization) did not change significantly until the 2008 global recession. The cross-country correlations of inflation among major advanced economies were very high and fairly tight up to the mid-1990s. From the mid-1990s up to the 2008 global recession, the cross-country inflation correlations declined by more than half and only moderately bounced back since then.

Figure 4.B illustrates the co-movement between inflation and output growth for the eight major advanced economies contemporaneously and at 4-quarters-ahead and 4-quarters-lagged. The striking finding is that these correlations (indicative of the cyclicality of inflation) switched from countercyclical to largely acyclical in the mid-1990s. For the U.S., the shift towards acyclicality does not appear to take a hold until 2008.[9] Such shifts as those observed in Figure 4.B are of particular importance for monetary theory (Kydland and Prescott (1990) and Brock and Haslag (2016)). They tend to be viewed as reflecting changes in the contributions of different shocks to the business cycle. (e.g., cost-push shocks vs. productivity or even monetary policy shocks).

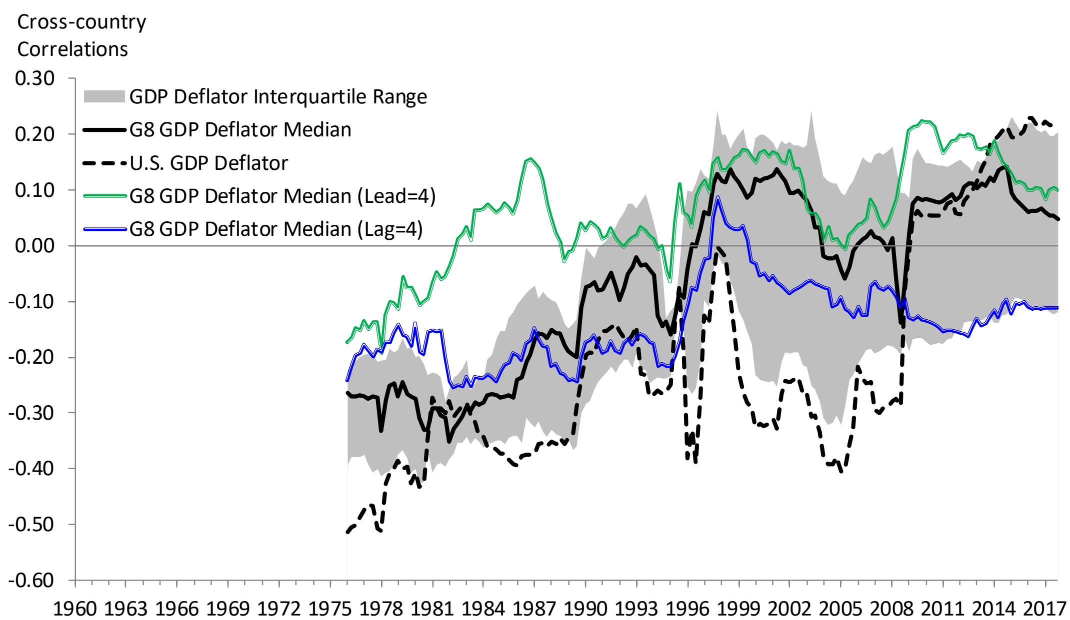
[9] These findings (Figures 4.A and 4.B) are robust when the bilateral correlation coefficients are aggregated following David (1949) and Camacho *et al.* (2006), as seen in the supplemental materials in the Appendix.

Figure 4.A Synchronization (Cross-Country Correlation) of Real GDP & Inflation



Note: Median and interquartile range include U.S., U.K., CA, FR, DE, JP, ES, and IT. The reported median and interquartile range are based on all possible bilateral cross-correlations between the countries calculated on a rolling window of 15 years. The reported median for the U.S. includes only the bilateral pairs between the U.S. and all other countries. Cross-correlations are calculated on the annualized log-first differences in real GDP and on the annualized log-first differences in the implied GDP deflator (expressed in percentages both).
Sources: Organization for Economic Cooperation and Development; author's calculations.

Figure 4.B Cyclicality (Cyclical Correlations) of Inflation at Different Leads and Lags



Note: Median and interquartile range include U.S., U.K., CA, FR, DE, JP, ES, and IT. The reported median and interquartile range are based on the contemporaneous correlation between the annualized log-first differences in real GDP and the annualized log-first differences in the implied GDP deflator (both expressed in percentages) of each country calculated on a rolling window of 15 years. The U.S. series is computed analogously. The median correlations of GDP growth with four-periods-ahead & four-periods-lagged inflation for all countries are added too.
Sources: Organization for Economic Cooperation and Development; author's calculations.

However, it should be noted that simple correlations may not accurately reflect the path of synchronization and cyclical variation when the data-generating process is also subject to shifts in the volatility (as seen in Figures 1.A and 1.B). In fact, much empirical work has been devoted to exploring how measured co-movements and correlations are affected during times of high/low volatility (see, e.g., King and Wadhwani (1990) and the contagion literature).[10]

3.4.2 Duration and Depth of Recessions

Grossman *et al.* (2014, 2015) investigate classical recessions in the spirit of Burns and Mitchell (1946) on the basis of a set of indicators of global economic activity that are broadly available across countries and over time.[11] They use the well-known Bry and Boschan (1971) algorithm to consistently characterize periods of expansion and contraction. I find that looking at real GDP alone is often sufficient to identify major turning points (in the classical sense) on the level of economic activity at quarterly frequency among the eight major advanced economies under consideration here. Table 2 summarizes my findings about the duration and depth of (classical) business cycles based on the real GDP of the eight major advanced economies relying—as Grossman *et al.* (2014, 2015) do—on the Bry and Boschan (1971) methodology.

[10] For illustration purposes, consider domestic and foreign growth are related as follows: $g_t = \mu_0 + \mu_1 g_t^* + e_t$, where $E\left(e_t\right) = 0$, $E\left(e_t^2\right) = c < \infty$, and $E\left(g_t^* e_t\right) = 0$. Hence, the standard correlation coefficient can be re-written as: $\rho\left(g, g^*\right) \equiv \frac{\sigma\left(g, g^*\right)}{\lambda^* \lambda} = \mu_1 \frac{\lambda^*}{\lambda}$. As a result, an increase in the relative volatility across countries, $\frac{\lambda^*}{\lambda}$, may result in a higher measured output cross-correlation, $\rho\left(g, g^*\right)$, even when the underlying structural relationship—given by μ_1—remains unchanged. There are good reasons to suspect autocorrelated residuals and $E\left(g_t^* e_t\right) \neq 0$—hence, this further complicates the empirical recovery of the true structural relationship μ_1 and the interpretation of $\rho\left(g, g^*\right)$.

[11] Business cycles are patterns of alternating expansions and contractions in real economic activity. There are at least three conceptually-different definitions of business cycles. The concept of "growth rate cycle" refers to fluctuations in the growth rate of economic activity while the "growth cycle" concept refers to fluctuations in economic activity around its long-run potential/trend. The "classical business cycle" à la Burns and Mitchell (1946) refers to fluctuations in the level of economic activity. Accordingly, classical contractions are periods of decline in the level of economic activity which is what the Bry and Boschan (1971) algorithm used in Table 2 aims to identify.

Table 2. Properties of the Classical Cycles

CLASSICAL CYCLES: CONTRACTIONS

	1960:Q1-1983:Q4			1984:Q1-2017:Q4		
	Frequency (%)	Duration	Growth (%)	Frequency (%)	Duration	Growth (%)
US	19.8	3.0	-2.5	7.4	5.0	-2.3
UK	21.9	8.0	-1.9	8.8	6.0	-2.2
FR	7.3	3.5	-1.8	9.6	4.0	-1.1
DE	20.8	4.0	-2.0	24.3	4.5	-1.1
IT	16.7	4.0	-1.4	28.7	5.5	-1.3
CA	14.6	4.0	-2.7	8.8	4.0	-3.6
JP	0.0	0.0	--	22.8	4.0	-2.6
ES	10.4	3.0	-0.6	19.1	7.0	-2.4
G8 Median	15.6	3.8	-1.9	14.3	4.8	-2.2

CLASSICAL CYCLES: EXPANSIONS

	1960:Q1-1983:Q4			1984:Q1-2017:Q4		
	Frequency (%)	Duration	Growth (%)	Frequency (%)	Duration	Growth (%)
US	80.2	14.0	3.9	92.6	34.0	3.0
UK	78.1	12.5	2.8	91.2	34.0	2.6
FR	92.7	19.0	3.8	90.4	26.0	2.1
DE	79.2	11.5	4.3	75.7	13.0	2.8
IT	83.3	16.0	5.7	71.3	14.0	1.7
CA	85.4	11.5	4.5	91.2	22.5	2.8
JP	100.0	96.0	5.7	77.2	10.0	2.5
ES	89.6	10.5	3.9	80.9	24.5	3.3
G8 Median	84.4	13.3	4.1	85.7	23.5	2.7

Note: Classical cycles are dated using the Bry and Boschan (1971) algorithm on real GDP data in levels for the U.S., U.K., CA, FR, DE, JP, ES, and IT.
Each subsample is treated as a separate period and both complete and incomple cycles are included. Duration and Growth (log-first differenced, annualized, %) refer to the corresponding median of each cycle phase within each subsample.
Sources: Organization for Economic Cooperation and Development; author's calculation.

Table 2 shows that periods of contraction have become somewhat less frequent since the mid-1980s as most advanced economies entered a prolonged period of low volatility. Japan recorded no identifiable contraction in real GDP before the mid-1980s but those episodes have become frequent occurrences afterwards. The median duration and depth (in terms of the median real GDP growth) of contractions for the advanced economies have increased during the period starting around 1984:Q1 (at the onset of the Great Moderation), but only if I take into account the prolonged contractionary impact of the 2008 global recession. Excluding this last contractionary phase, recessions appear both shorter and shallower during the Great Moderation than in the preceding period up to 1984:Q1. In turn, the frequency of expansions has increased, its median duration has lengthened, and median growth has notably declined since 1984:Q1.

The Great Moderation period up to the 2008 global recession, indeed, has been characterized by low volatility and longer periods of sustained (albeit more moderate) increases in the level of economic activity. The reduction in output volatility is related to some extent to the changes in the length and frequency of classical business cycles shown in Table 2. If the conditional growth rate of real GDP remains stable but the standard deviation of the innovations falls (Figure 1.A), then, *ceteris paribus*, periods of declining output become both shorter and less frequent while expansions become longer and more frequent. On top of that, Table 2 also suggests a concurrent slowdown in growth since the mid-1980s. All of this, indeed, seems consistent with the evidence for the major advanced economies before the 2008 global recession.[12]

4. Globalization Hypothesis

Economic theory (the workhorse model laid out in Section 2) suggests that key features of the international business cycle—volatility and persistence, as seen in Figures 1.A, 1.B, 2.A, and 2.B—might be non-linearly related to measures of increased openness across countries. Here, I investigate whether there is indeed empirical evidence that greater economic integration and openness to trade (globalization) is non-linearly related to the volatility and persistence of real GDP growth and inflation (measured with the GDP deflator) as predicted by theory.

To do this empirical exercise, I isolate the impact of the real import goods and services share over real GDP (Figure 5) as this ratio relates to the structural parameter ξ that describes the degree of openness in the two-country workhorse model of Section 2.[13] Consistent with the model's implicit assumptions, I work with the median import share as it describes the cross-country central tendency of the path of trade openness for the eight major advanced economies in my dataset and because the median is less sensitive to outliers than the mean. Motivated by the workhorse New Keynesian model, I also use a second-order polynomial with intercept (a second-order Taylor approximation) in the right-hand side of my regressions to flexibly allow for non-linearities in the relationship between the time-varying median import share and the main time-varying business cycle moments.

The theory laid out in Section 2 is primarily concerned with the common business cycle patterns that arise across countries. I approximate those with the median of business cycle moments of the eight countries in the dataset (in order to wash out shifts that are likely idiosyncratic) as the dependent variable in my regressions. At the same time, though, I also consider the potential (non-linear)

[12] A further structural evaluation of the linkages between volatility transfers and the duration, frequency, and depth of business cycles through the lens of the New Keynesian model can be found in Crowley and Hallett (2018).
[13] Volume estimates of Gross Domestic Product by expenditure type (market prices in local currency) were taken from the OECD's Outlook database. These series are not PPP-adjusted and are reported as seasonally-adjusted and at an annual rate (SAAR).

relationship between the dispersion of those business cycle moments across countries—as measured by the interquartile range—and the median import share.

Finally, I should note that the theoretical model in Section 2 that motivates my analysis is predicated on the assumption that the world economy is subject to an *active* monetary policy (i.e., the open-economy counterpart of the Taylor principle is satisfied and ensures the existence and uniqueness of the solution). Hence, I include a dummy variable for the 1970:Q1-1983:Q4 period—which largely corresponds with the so-called Great Inflation era of the 1970s, prior to the onset of the Great Moderation—as this period is often viewed as having resulted from having moved away from *active* and into *passive* monetary policy territory in many advanced countries (particularly the U.S.) (see, e.g., Lubik and Schorfheide (2004)).

My empirical findings are summarized in Table 3 and Figure 6.[14] The existing empirical evidence is mixed on whether the greater trade openness is (linearly) correlated with the changing international business cycles (Barrell and Gottschalk (2004), Cecchetti *et al.* (2005), Bianchi and Civelli (2015)). Figure 6, in turn, shows that to a large extent most of the time-series variation on the median path of international volatility and persistence can be attributed—albeit in non-linear form—to the import share and presumably to globalization. The evidence of such a relationship is weakest for median real GDP growth persistence, while achieving R-squares above 0.80 for all other moments (Table 3).

Economic integration and openness to trade (measured by the import share) have notably increased over time—yet, it has had a heterogeneous and diverse impact across countries. As suggested by the empirical evidence presented in Table 3, the path of the median import share has sizeable explanatory power to account for the cross-country dispersion (interquartile range) on the key business cycle moments—except only marginally on real GDP growth persistence.

[14] The model ties the steady state import share to the parameter ξ, while short-run imports are endogenously determined and varies over the business cycle. This raises the possibility of endogeneity in the regressions using the contemporaneous import share for each given quarter. However, using four-period lags or even historical averages as instruments does not affect the results reported in Table 3 much. Qualitatively similar results supporting a role for the increasing import share on business cycle movements can be found with quantile regressions on the pooled panel of the eight countries in my dataset.

Table 3. OLS Regression Estimates: A Closer Inspection at the Import Share (Median)

VOLATILITY

	Real GDP Growth		Inflation (GDP Deflator)	
	Median	Interquartile Range	Median	Interquartile Range
Import Share (Median)	-0.20***	0.03**	-0.17***	-0.01*
$((\text{Import Share (Median)})^2)/100$	0.31***	-0.16***	0.48***	0.10***
Dummy (1970:Q1-1983:Q4)	0.42***	-0.13***	0.96***	0.04***
Intercept	4.59***	1.05***	2.22***	0.12***
R-squared	0.89	0.52	0.80	0.78

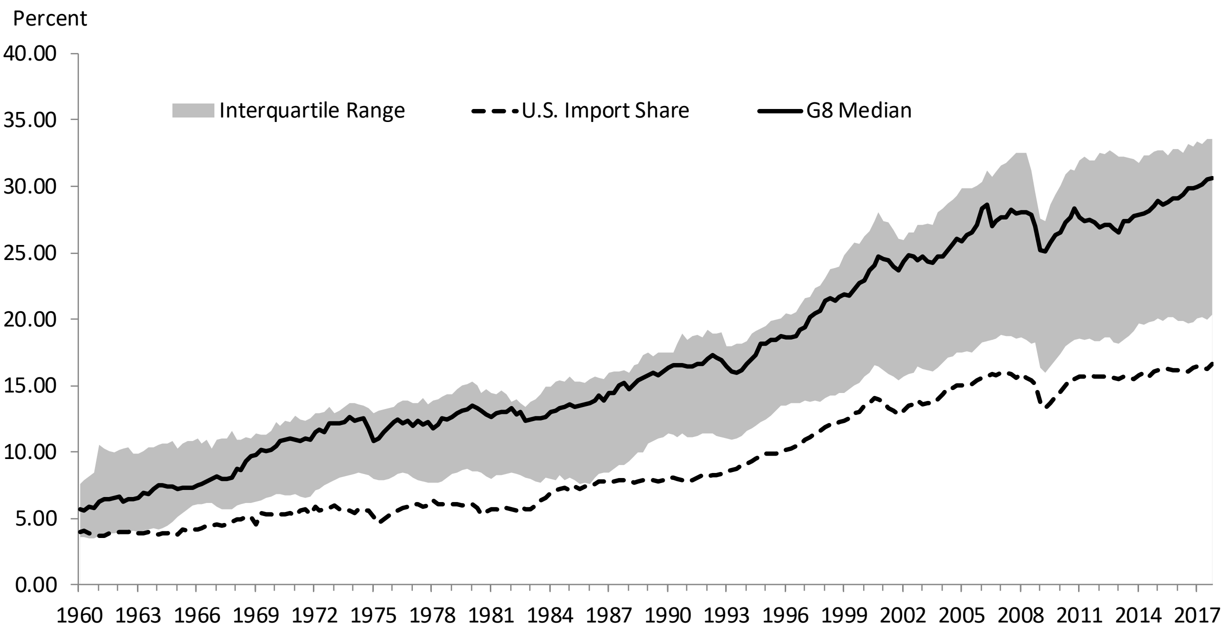
PERSISTENCE

	Real GDP Growth		Inflation (GDP Deflator)	
	Median	Interquartile Range	Median	Interquartile Range
Import Share (Median)	0.04***	-0.01**	-0.03***	-0.01***
$((\text{Import Share (Median)})^2)/100$	0.11***	0.03**	0.03***	0.04***
Dummy (1970:Q1-1983:Q4)	-0.08***	-0.001	0.09***	-0.03***
Intercept	-0.11***	0.45***	1.06***	0.15***
R-squared	0.36	0.03	0.94	0.65

Note: *, **, and *** denote statistical significance at the 10, 5, and 1 percent significance levels respectively. Median and Interquartile range are computed for the corresponding variables including data for the U.S., U.K., CA, FR, DE, JP, ES, and IT.

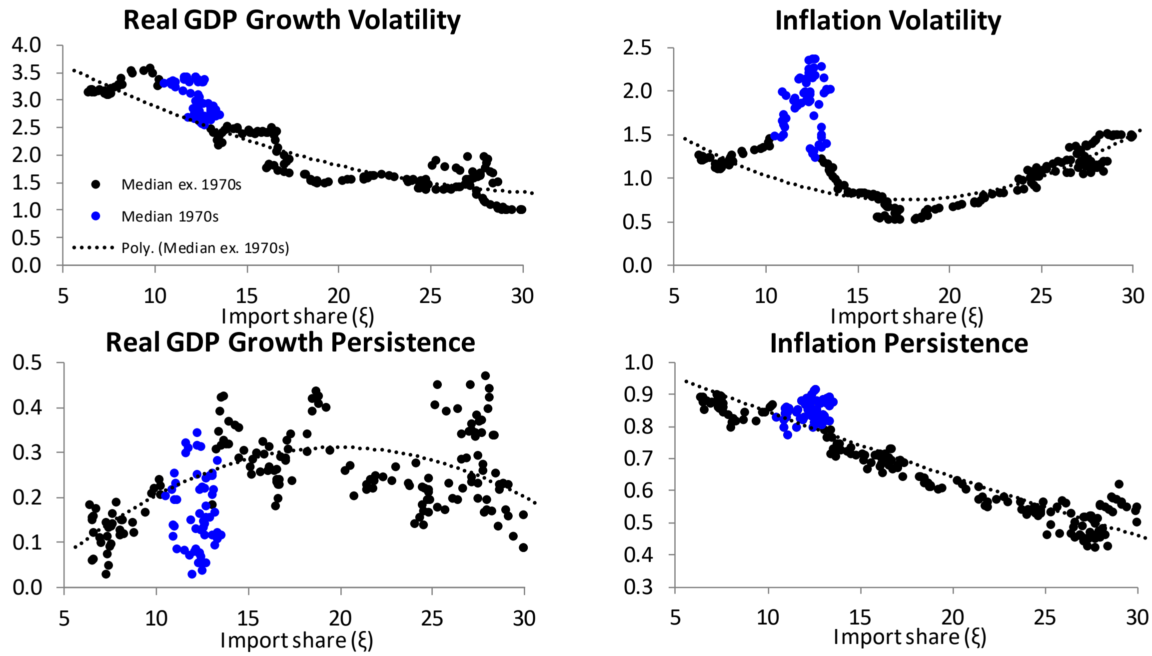
Sources: Organization for Economic Cooperation and Development; author's calculation.

Figure 5. Ratio of Real Imports (of Goods and Services) Over Real GDP



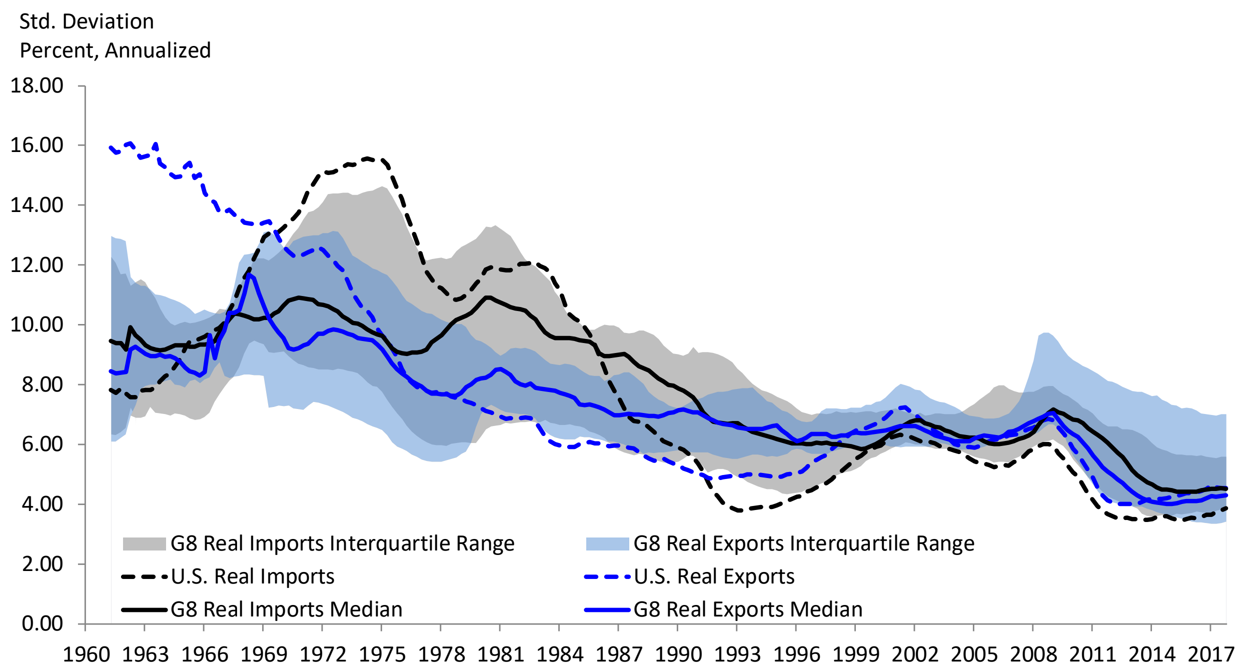
Note: Includes U.S., U.K., CA, FR, DE, JP, ES, and IT. Canada data in levels starts in 1961:Q1 and Germany data starts in 1969:Q1. The ratio is defined as real imports of goods and services expressed in percentages over real GDP. The chained volume series are not additive, so imports must be proportionally scaled such that the sum of the subcomponents by expenditures is equal to real GDP.
Sources: Organization for Economic Co-operation and Development; author's calculations

Figure 6. Macroeconomic Volatility and Persistence vs. Import Share (G8 Median)



Note: Includes U.S., U.K., CA, FR, DE, JP, ES, and IT. The reported time-varying volatilities are estimated from the annualized log-first differences in real GDP and the annualized log-first differences in the implied GDP deflator expressed in percentages. The reported persistence is the sum of the time-varying autoregressive coefficients estimated on the same data series. The import share is defined as the ratio of real imports of goods and services in percentage over real GDP.
Sources: Organization for Economic Cooperation and Development; author's calculations.

Figure 7. Volatility of Real Imports and Real Exports



Note: Includes U.S., U.K., CA, FR, DE, JP, ES, and IT. Canada data starts in 1961:Q2 and Germany data starts in 1969:Q2. The reported time-varying volatility is estimated from the annualized log-first differences in real exports and real imports of goods and services expressed in percentages.
Sources: Organization for Economic Co-operation and Development; author's calculations

I also observe significant changes in volatility in exports and imports suggesting that "mechanically" the trade channel has been a major source of volatility spillovers in the economy during the Great Moderation (Figure 7)—in line with the increase in globalization of trade (and supported by a gradual capital account liberalization) experienced since the 1970s.[15]

To my knowledge, all these stylized facts have not been documented before in the literature. Consistent with the workhorse New Keynesian model, these findings suggest that globalization and trade may have played an important role in explaining the changes in business cycles witnessed over the past 58 years. Moreover, I would also argue that these facts are an important milestone as they open up international macroeconomics to new research that help us understand these empirical relationships more deeply and how globalization may interact with shifting monetary policy, "good luck", other forms of structural transformation, etc.

5. Rethinking the Empirical Evidence

If shifts in international business cycles are partly accounted for by greater trade openness as suggested by the evidence in Table 3 and Figure 6, does this imply causal relationship? The short answer to that is no. A number of reasons can be cited for this including that:

First, the role of the trade channel is—even in the stylized workhorse model of Section 2—more complex than just the import share (ξ). Economic theory suggests that a shift in the trade elasticity σ (relative to a given inverse of the intertemporal elasticity of substitution γ) can alter the effects of increasing trade integration (increasing trade openness) on key international business cycles.

Second, the trade channel permits intratemporal consumption smoothing and risk-sharing across countries but its actual impact depends in complex ways on other features of the economy. For example, changes in labor markets—due to labor market deregulation and declining costs on labor

[15] The theory laid out in Section 2 implicitly assumes complete domestic and international asset markets and perfect risk-sharing across countries. The evolution of capital markets is definitely an important dimension of globalization that needs to feature more prominently in future research on the different channels through which globalization affects the international business cycles. Building on the workhorse open-economy New Keynesian model, the trade-offs between intra-temporal consumption smoothing through trade and intertemporal smoothing through capital accumulation (in Martínez-García and Søndergaard (2009, 2013)) and the degree of international risk-sharing (Martínez-García (2016)) are shown to be quite important structural features too.

mobility within and across countries since the 1960s—can alter the effects of trade openness ξ on the business cycle. In fact, the workhorse New Keynesian model suggests that shifts in the (Frisch) elasticity of labor supply pinned down by φ (relative to the inverse of the intertemporal elasticity of substitution γ) as well as changes in the pricing power of workers on wages (cost-push shocks) play a role on international business cycle moments. The interaction between changes in labor institutions and greater openness therefore contributes to explain some of the non-linearities found in Table 3. Moreover, institutional differences across countries may explain not just the business cycle dispersion across countries but also the relationship between dispersion and trade openness (particularly when these types of changes in labor markets go hand in hand with increasing trade openness).

Exploring the evidence on competing (and possibly complementary) hypotheses for the shifting international business cycles to disentangle their structural linkages with trade openness goes beyond the scope of this paper. However, the additional evidence presented in the remainder of the paper suggests that improved monetary policy and "good luck" likely also played a major role on the observed changes in international business cycles.

5.1 Monetary Policy Framework

The workhorse New Keynesian model in Section 2 is consistent with the view that globalization does not necessarily imply a weakening of the ability of national central banks to influence domestic output and inflation, as long as countries retain flexible exchange rates (see, e.g., Woodford (2010), among others). However, in theory, the impact of the monetary policy rule parameters on the dynamics of output and inflation can be very significant. Apart from the volatility "smile" of inflation relative to the import share bottoming in the mid-1990s and the declining persistence since the early 1980s (Figure 6), the significant shifts in the cyclicality of inflation and the cross-country synchronization (that have partly reversed since the 2008 global recession) point at monetary policy as a prime suspect.

The evidence reported among others by Stock and Watson (2003a,b) suggests that the contribution of policy to the Great Moderation period may have been modest in its contributions on volatility. Stock and Watson (2003a,b)'s assessment of a diverse collection of models shows that improved monetary policy brought inflation down, yet accounts for a small fraction of the observed reduction in macro volatility. However, looking at a broader set of countries—the eight largest advanced economies—including the aftermath of the 2008 global recession and considering a broader set of business cycle moments and their changes, the role of monetary policy is harder to ascertain.

Monetary policy is generally thought to have been too accommodative during the 1960s, leading to the collapse in the early 1970s of the Bretton Woods system of managed exchange rates (tied to Gold) upon which the international monetary system was rebuilt after WWII. The new post-Bretton Woods era of fiat money and flexible exchange rates did not come with tight monetary policy to quell the raising inflation (monetary policy, in fact, has been characterized as *passive* prior to the Great Moderation by Lubik and Schorfheide (2004), among others).

The more accommodative monetary policy of the 1960s and 1970s was replaced by a stronger commitment towards low inflation and central bank independence—which took hold in the 1980s. It also coincided with the onset of the Great Moderation period. In some of these advanced countries, this ultimately led to outright inflation targeting (Canada in 1991, United Kingdom in 1992). European countries pushed through the creation of the euro (monetary union) in the 1990s. Finally, the 2008 recession challenged the price-based monetary policy implementation based on the short-term nominal interest rate that prevailed in the 1980s over monetary aggregates targeting and instead ushered a new monetary policy approach (including unconventional policies: quantitative easing, forward guidance) at the zero-lower bound.

Hence, it is indeed difficult to ignore that many of these changes in the monetary policy framework, indeed, coincided in time with major breaks in key business cycle moments—particularly relating to inflation. The question on the role of monetary policy, therefore, might have more to do with changes to the framework rather than on improvements in policy within a given framework (a point recently noted, among others, by Borio, Disyatat, Juselius and Rungcharoenkitkul (2017)).

5.2 Other Aspects of Structural Transformation

If the Great Moderation was partly the result of "good luck", then the favorable output and inflation volatility of the Great Moderation period may worsen whenever macroeconomic shocks become large again. This argument gained further stock in the aftermath of the 2008 global recession. But, what may lie behind the shifts around the 2008 global recession? I would argue that the potential causes of the changes in the international business cycle around the 2008 global recession—where some of the patterns of the Great Moderation continued (e.g. in regards to volatility) while others were partly reversed or change notably (specially the cross-country synchronization of real GDP growth in Figure 4.A)—may be more complex than just a reversal of the preceding good fortunes.

One structural-transformation explanation relies on the hypothesis that the Great Moderation reflects to a certain extent a compositional shift in the sectoral shares of economic activity detected among advanced economies. Simply put, as advanced economies develop, more of their economic activity shifts towards the generally less volatile tertiary sector (services). Interestingly, housing and residential investment still explain most of the uptick in macro volatility during the 2008 global recession in spite of their small sectoral share. Another hypothesis supported by the data includes the possibility that financial innovations (and deregulation) may have relaxed the liquidity constraints and allowed households and firms to better smooth shocks—until the 2008 global recession exposed the other side of the coin (excessive risk-taking, contagion, etc.).

5.2.1 The Sectoral Composition Hypothesis

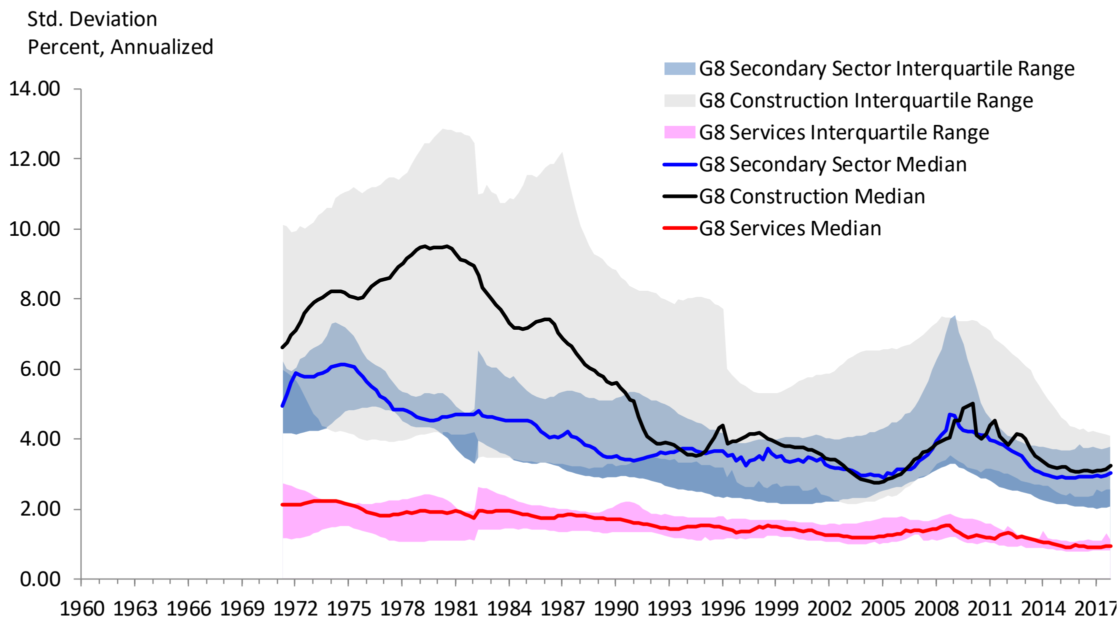
Stock and Watson (2003a,b) argue that secular changes in the composition by industry resulting from on-going development likely explains only a modest fraction of the shifting volatility observed in the data—at least until the 2000s. However, while the reduction in macro volatility is widespread, I find that the decline is not uniform across sectors of the economy (Figure 8).[16] Among the measures of real activity, the largest relative decline in volatility occurred in the cyclically-sensitive construction sector (within the secondary sector)—in the construction sector, the post-1984 standard deviation is approximately half of its pre-1984 estimate.

Even though the share of construction in real GDP is fairly small, because its variance is so large, the reduction in volatility mechanically "accounts for" a nontrivial fraction of the output volatility reduction during the Great Moderation. Most interestingly, it accounts in part for the increased

[16] The series for real Gross Domestic Product (chained, in local currency) by industry were taken directly from official sources from each country. All series are reported as seasonally-adjusted and are not PPP-adjusted. This panel is noticeably unbalanced—there is no quarterly data for Japan and the US series is fairly short (starting only in 2005:Q1).

volatility observed during the 2008 global recession as well. The impact of this on other business cycle moments—particularly on the synchronization of real GDP growth—is less clear, though.

Figure 8. Volatility of Real GDP by Industry



Note: Includes UK, CA, FR, DE, ES, and IT. Not all series are complete back to 1960. JP is excluded due to lack of quarterly data, while the US quarterly series starts in 2005 and only the tertiary sector can be estimated precisely. Estimates of volatility for the primary sector which are notably volatile are omitted as the sector accounts for a very small and declining share of real GDP (around 2 percent or less), but are available upon request.
Sources: Bureau Economic Analysis; Office National Statistics; Institut National Statistique Economique; Statistisches Bundesamt; Istituto Nazionale Statistica; Statistics Canada; Instituto Nacional Estadistica; author's calculations.

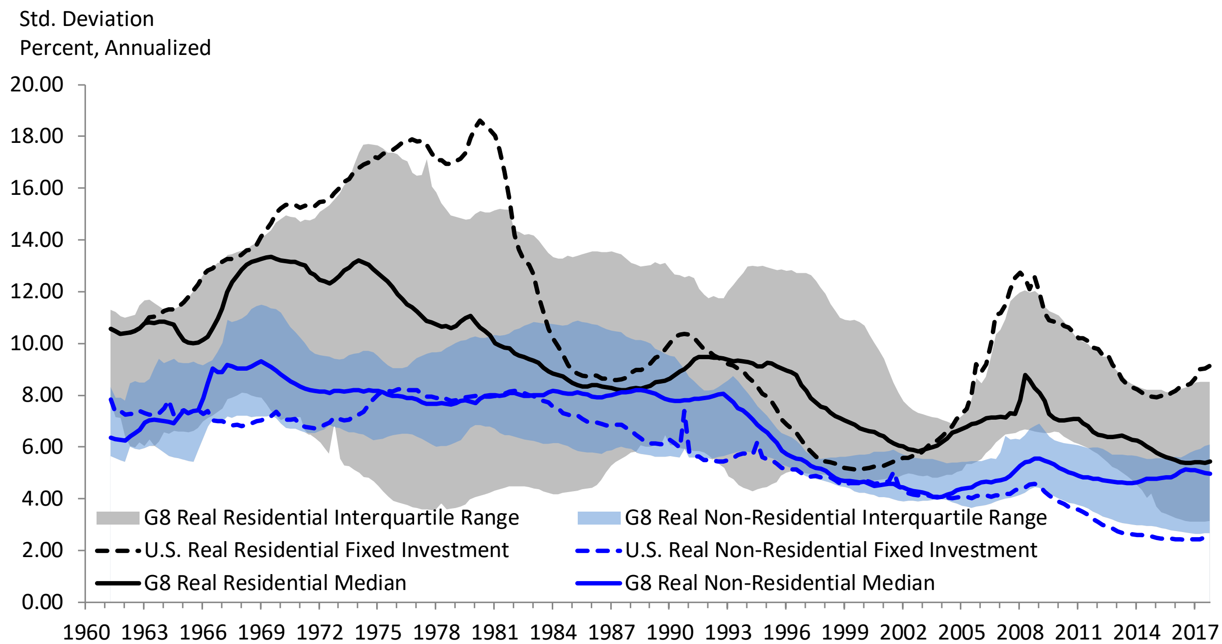
5.2.2 The Financial Globalization Hypothesis

Capital account liberalization, new financial industry technologies, and financial deregulation have led to major changes in the functioning of financial markets, especially internationally (but also domestically) over the past six decades. Although the net contribution of this change to shifting international business cycles is difficult to quantify, some evidence suggests that financial developments may have played a role in the partial reversal seen in some business cycle moments in the aftermath of the 2008 global recession. Not surprisingly, one expenditure type that experienced really large declines in volatility during the Great Moderation and a substantial spike during the 2008 global recession is residential fixed investment—notably for the U.S. (Figure 9). However, the volatility uptick around 2008 appears to have been mostly temporary.

In turn, there has been little apparent change in the degree of synchronization in international business cycles among major advanced economies. In this context, whether international growth synchronization remains what it was since the 1960s or will stay elevated—the new normal since 2008—may depend on the path of the underlying shocks going forward, but also on the impact that financial technologies and regulation continue to have on the transmission mechanism through which shocks propagate.

To the extent that greater economic integration induces specialization, then industry-specific shocks can become concentrated in a few economies and synchronization could decrease again. However, integrated financial markets facilitate international flows of capital. Hence, difficulties in one financial market can more easily spill-over into foreign financial markets (contagion) through liquidity, wealth, or other contagion effects resulting in more permanent effects and a shift towards higher growth synchronization too. Indeed, this remains an open question in the literature.

Figure 9. Volatility of Residential and Non-Residential Fixed Investment



Note: Includes U.S., U.K., CA, FR, DE, JP, ES, and IT. Canada data starts in 1961:Q2 for non-residential fixed investment and U.K. data starts in 1967:Q2 for both series. The reported time-varying volatility is estimated from the annualized log-first differences in real housing and in real private non-residential and government fixed capital formation (main components of gross fixed capital formation) expressed in percentages.
Sources: Organization for Economic Co-operation and Development; author's calculations

6. Concluding Remarks

In this paper I propose a time-varying parameter (TVP) autoregressive model with stochastic volatility in the spirit of Stock and Watson (2003a,b). This helps me approximate nonlinearities in the conditional mean and in the stochastic volatility of the data generating process for real GDP growth and inflation (as indicated by Granger (2008)). Time-variation therefore allows for the possibility that key features of the underlying data-generating process shift over time and theory suggests that the path towards greater trade openness observed from the 1960s might be part of the explanation for the changing international business cycles.

The broad stylized facts that emerge from the empirical evidence since the 1960s collected across eight major advanced economies shows that:

1. The Great Moderation from the mid-1980s to the onset of the 2008 global recession was a period of relative calm after the high volatility of the 1970s (the Great Inflation period). Inflation volatility has strikingly diverged across countries since the mid-1990s.
2. Persistence on inflation has been higher than on real GDP growth, and also much more similar across countries until the 1980s when it started to gradually decline.
3. The correlation of output (or synchronization) across countries does not appear to have changed significantly until the 2008 global recession. Until the mid-1990s, the cross-correlation of inflation is pretty high and tight across countries—weakening a lot afterwards but bouncing back modestly since the 2008 recession.
4. The cyclicality of inflation shifted from countercyclical to acyclical in the mid-1990s.
5. The forecastability of macro aggregates with naïve time series forecasts tends to improve in periods where volatility is low. The Great Moderation period up to the 2008 global recession has been characterized by longer periods of sustained increases in the level of economic activity and less frequent recessions.

Some of these shifts could be permanent, the result of an improved ability to smooth shocks because of greater financial deepening, capital account liberalization, deregulation, innovation (technology), etc. There are reasons to suspect that part of the observed shifts in business cycles might be due to a period of benign macroeconomic shocks too—prolonged over time, yet transitory. The improvements in monetary policy resulting in the conquest of inflation (to use Sargent (1999)'s term) receive credit for a modest part of these changes (Stock and Watson (2003b)) but the changes in the monetary policy framework could play a more significant role.

While acknowledging all of that, this paper shows that a sizeable part of the common component of the changes in international business cycles seems to be (non-linearly) related to greater trade openness (globalization)—a pattern that is broadly consistent and motivated by the economic theory (the workhorse open-economy New Keynesian model). Hence, structural transformation relating to globalization appears as an important force in international business cycles. Yet more research is needed to flesh out the causal linkages and the interactions between globalization and other structural features of the economy that explain the evidence reported here.

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Appendix: Supplementary Materials

A.1 On the Flattening of the Phillips Curve

An important part of the debate on globalization has to do with its potential effect on the pricing behavior of firms, on marginal costs, and on the degree of market competition (Sbordone (2007), Martínez-García and Wynne (2010), Benigno and Faia (2016)). A key empirical observation that has emerged as central to much of this debate is the perceived "flattening" of the short-run Phillips curve.[17] Roberts (2006), among others, identified a flattening of the Phillips curve for the U.S. starting around 1984 at the onset of the Great Moderation. Figure I.A illustrates the sort of estimates of the coefficient on the domestic output gap that can be found in this strand of the literature, for the eight major advanced economies.

To construct Figure I.A, I use a reduced-form representation of the closed-economy Phillips curve that augments the univariate time series autoregressive specification with domestic output gap (slack), i.e., $\pi_t = \sum_{j=1}^{4} \chi_j \pi_{t-j} + \theta x_{t-1} + u_t$ where u_t is the estimation residual. The domestic output gap x_t is proxied with the one-sided Hodrick-Prescott (1997)-filtered domestic real GDP, while inflation π_t is derived as the annualized log-first differences of the GDP deflator (expressed in percentages). Figure I.A summarizes the slope coefficient θ obtained from OLS estimates of the reduced-form Phillips curve on a rolling-window basis using the previous 15 years of data.[18]

In an increasingly more integrated world economy, domestic firms can charge more for their output when they face increases in world demand even if domestic slack remains invariant (a point extensively argued in Martínez-García and Wynne (2010, 2013)). Therefore, globalization weakens the relationship between inflation and domestic slack. Consistent with that, the empirical evidence shown in Figure I.A indicates that over time inflation has become less responsive to fluctuations in the domestic output gap (θ has declined).[19] The slope estimates appear to have bounced-back since the 2008 global recession—and even earlier for the U.S.

However, Martínez-García and Wynne (2010) and Martínez-García (2017) as well as the theory laid out in this paper also suggest that one should not expect the flattening of the New Keynesian Phillips curve to be linearly related to measures of increased openness. Interestingly, consistent with the predictions of New Keynesian theory, I find that the estimated slope on the domestic output gap tends to decline with the import share—at least until the data for the post-2008 period gets factored in (as can be seen in Figure I.B).

Inferences based on a reduced-form specification—while often used in practice—are neither very precise nor structural *per se* and should be taken with a grain of salt. First, data mismeasurement and misspecification problems matter when exploring the relationship between inflation and the output

[17] Phillips (1958) is credited for identifying the empirical inverse relationship between nominal wage changes and unemployment that bears his name. However, the idea has a much earlier precedent in Fisher (1926).

[18] I also consider alternative filtering methods for detrending output—including using a quadratic trend and a trend-cycle decomposition motivated by economic theory such as in Crucini and Shintani (2015)—with similar findings about the slope of the Phillips curve coefficient θ.

[19] The sacrifice ratio measures the reduction in output required for a given reduction in inflation. Therefore, a flattening of the Phillips curve may imply that the sacrifice ratio has shifted as well.

gap (see, e.g., Martínez-García and Wynne (2010) on the impact of filtering output, Ihrig *et al.* (2010) on trend inflation, Kabukçuoglu and Martínez-García (2016, 2018) on the reliability of global slack indicators, Borio, Disyatat and Juselius (2017) on unmodeled shifts in potential, etc.).

For example, using the Hodrick-Prescott (1997) filter on real GDP to compute the output gap—as conventionally done (including for Figures I.A and I.B)—implicitly imposes a local-linear trend specification on potential and assumes the output gap to be purely transitory white noise.[20] However, those assumptions are inconsistent with the analytic reduced-form solution of the New Keynesian model derived in Section 2. Hence, estimating the flattening of the slope of the Phillips curve poses in practice a joint hypothesis testing problem since it cannot be separated from other modeling assumptions (like those imposed on the unobservable output potential).

Second, there is a body of evidence supportive of the global slack hypothesis both in reduced-form and in more structural settings whereby the relevant trade-off arises between domestic inflation and the global output gap (see, e.g., Borio and Filardo (2007), Binyamini and Razin (2007), Martínez-García and Wynne (2010), Eickmeier and Pijnenburg (2013), Bianchi and Civelli (2015), Duncan and Martínez-García (2015, 2018), and Kabukçuoglu and Martínez-García (2016, 2018)). Hence, to the extent that globalization is a significant force influencing the dynamics of inflation, Phillips-curve-based specifications relying on the domestic output gap alone might be subject to omitted variable biases. Not too surprisingly, Atkeson and Ohanian (2001) and more recently Kabukçuoglu and Martínez-García (2016) and Duncan and Martínez-García (2018) show that backward-looking Phillips curve forecasts of domestic inflation based on domestic output gaps are often found to be inferior against a naïve or univariate time series forecasting benchmark across many different countries—notably during the Great Moderation period.

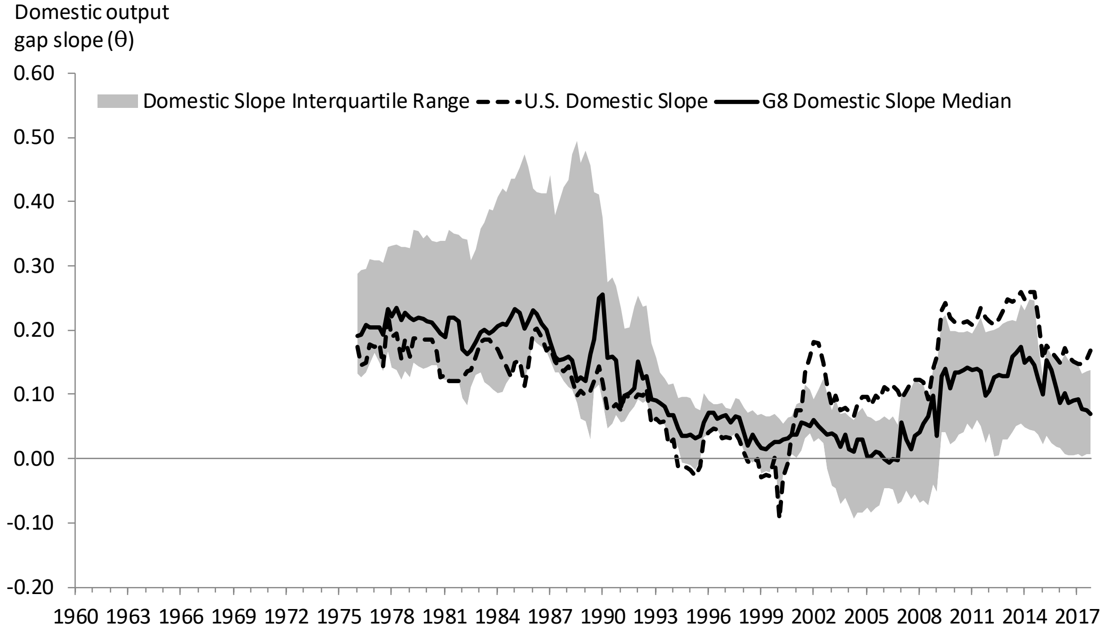
Third, a number of empirical studies from very early on have challenged the notion that the flattening of the Phillips curve is much related to globalization—reporting mixed results on the relationship between openness and the sensitivity of inflation to the domestic (and even global) output gap over different time periods and across countries (see, e.g., IMF (2006, 2013), Ball (2006), Pain *et al.* (2006), Ihrig *et al.* (2010), and Milani (2010, 2012)). Figure I.B illustrates this same point suggesting that the inverse comovement between the import share and the slope of the Phillips curve on domestic slack implied by theory has leveled off or even reversed since 2008.

[20] The Hodrick-Prescott (1997) filter can be recast as a state space model,

$$y_t = \tau_t + c_t,\ \tau_t = \tau_{t-1} + \omega_{t-1},\ \omega_t = \omega_{t-1} + \varepsilon_t,\ c_t \overset{iid}{\sim} N\left(0, \sigma_c^2\right),\ \varepsilon_t \overset{iid}{\sim} N\left(0, \sigma_\varepsilon^2\right),$$

where y_t is the observed time series, τ_t is the trend component (which takes the form of a local linear trend) and c_t is the (purely transitory) cyclical component. This system contains two unknown parameters to be estimated, σ_c^2 and σ_ε^2, which together define the signal-to-noise ratio $q \equiv \frac{\sigma_c^2}{\sigma_\varepsilon^2}$. Harvey and Jaeger (1993) show that when the restrictions $\sigma_c^2 = 1$ and $\sigma_\varepsilon^2 = \frac{1}{1600}$ are imposed on the signal-to-noise ratio on this state-space model, the smoothed estimator of the trend component obtained by the Kalman filter is numerically identical to that obtained from the conventional Hodrick-Prescott (1997) filter. It can be shown that normalizing $\sigma_c^2 = 1$ and estimating the signal-to-noise ratio q by Maximum Likelihood often performs better in fitting to the data. The statistical framework based on the local linear trend model has multiple practical uses in the literature—for instance, a special case of this is the random walk plus noise or local level specification postulated by Stock and Watson (2007) to model inflation albeit augmented with stochastic volatility. The local linear trend model framework has been generalized to incorporate financial variables in Borio, Disyatat and Juselius (2017).

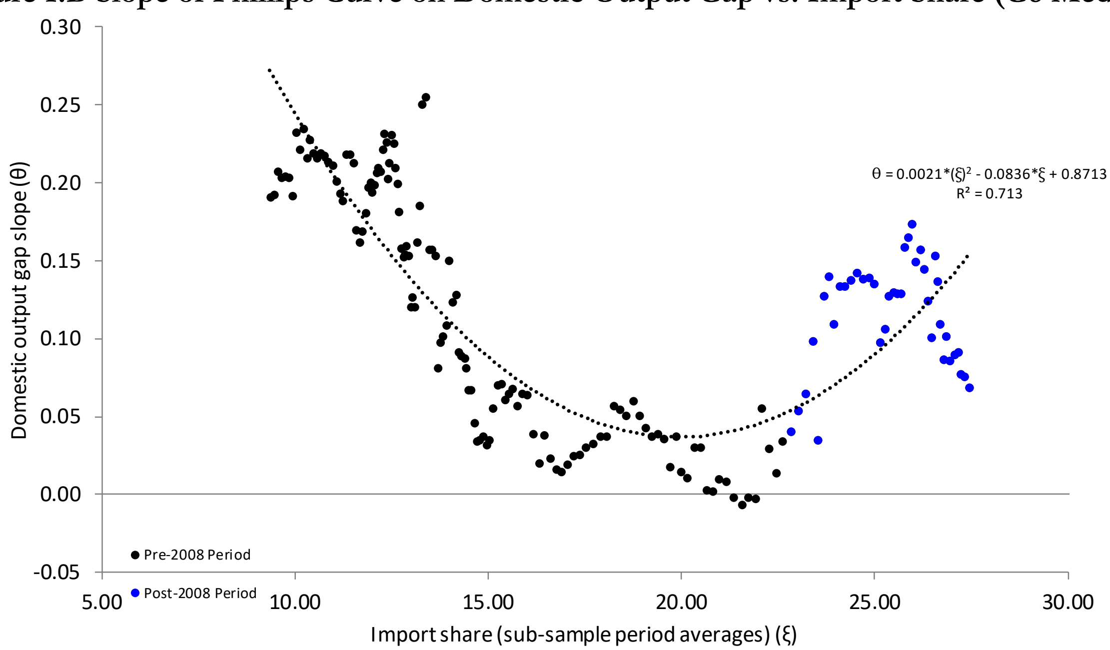
Figure I.A Phillips Curve Estimated Coefficient on Domestic Output Gap



Note: Median and interquartile range include U.S., U.K., CA, FR, DE, JP, ES, and IT. The figure is based on OLS estimates obtained on a rolling-window basis using the previous 15 years of data and a conventional (closed-economy) reduced-form Phillips curve specification with four lags on inflation and lagged domestic output gap. The domestic output gap is calculated with the one-sided Hodrick-Prescott filter on log real GDP index in units, expressed in percentages.

Sources: Organization for Economic Cooperation and Development; author's calculations.

Figure I.B Slope of Phillips Curve on Domestic Output Gap vs. Import Share (G8 Median)



Note: Includes U.S., U.K., CA, FR, DE, JP, ES, and IT. The OLS estimates for θ are obtained on a rolling-window basis using the previous 15 years of data and a conventional (closed-economy) reduced-form Phillips curve specification with four lags on inflation and lagged domestic output gap. The domestic output gap is calculated with the one-sided Hodrick-Prescott filter on log real GDP index in units, expressed in percentages. The import share is defined as the average over the estimation period of the ratio of real imports of goods and services in percentage over real GDP.

Sources: Organization for Economic Cooperation and Development; author's calculations.

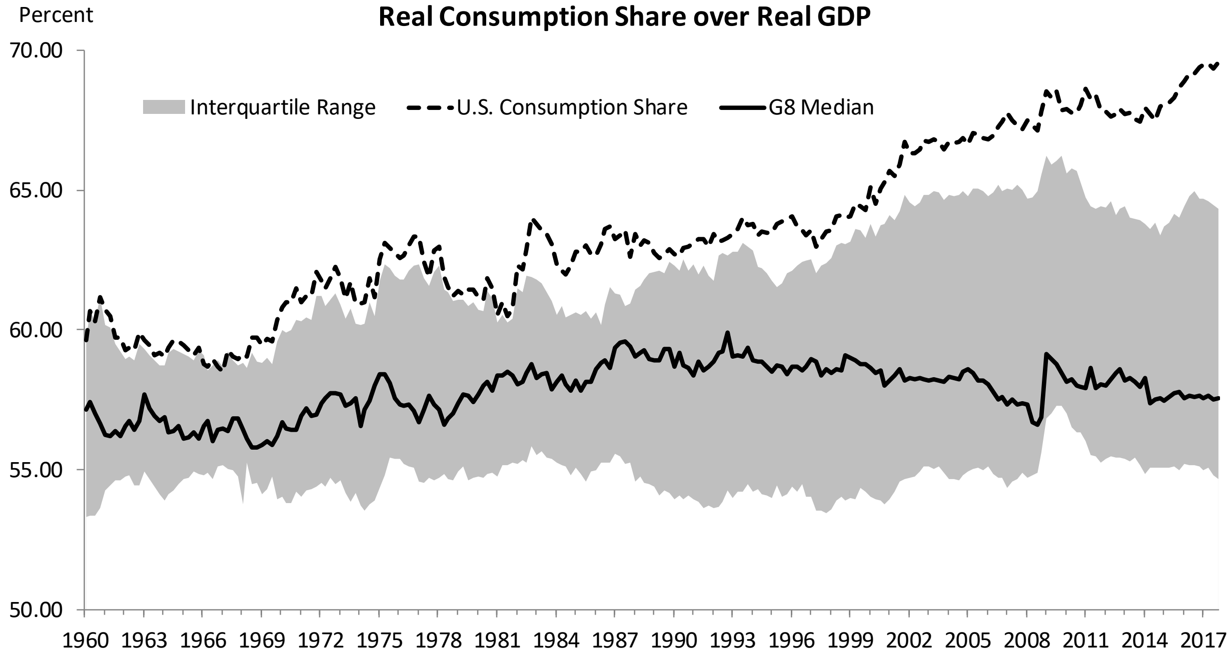
A more structural approach is warranted because the relationship between the observed variables does not map directly into the slope of the Phillips curve. In fact, the theory laid out in Section 2 suggests a reversal in the correlation between inflation and the output gap can result from a shift towards cost-push shocks (and away from other structural shocks). To conclude, while greater openness can diminish the slope of the Phillips curve on domestic slack as predicted by theory, the nonlinear relationship found in the data is suggestive of other economic forces at play, including possibly shifts in the contribution of the different shocks and even shifts in monetary policy.

A.2 Additional Results on Macroeconomic Volatility

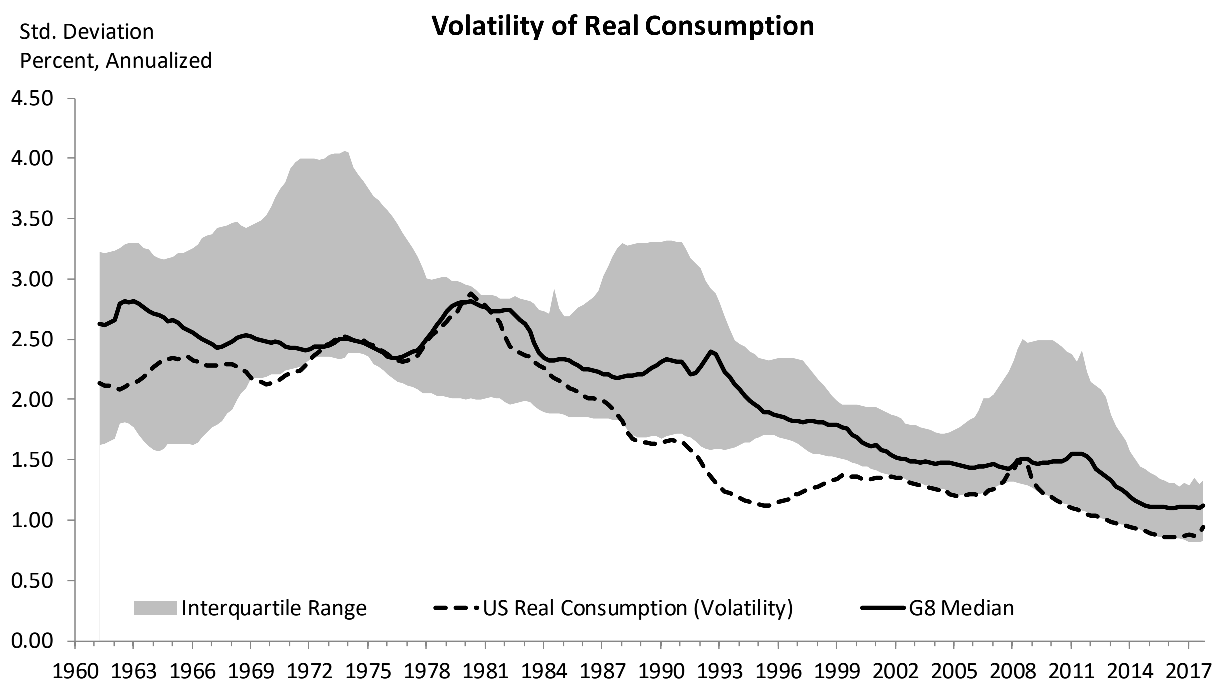
The series for volume estimates of Gross Domestic Product (market prices, in local currency) by expenditure type or sector were taken directly from the OECD's Outlook database. All series are reported as seasonally-adjusted and at an annual rate (SAAR) and are not PPP-adjusted.

The evidence across the eight major advanced economies for the estimated instantaneous volatility on real GDP subcomponents by expenditure (real consumption, real fixed investment, real residential fixed investment, real non-residential fixed investment, real government expenditures, real imports, and real exports) and by production sector (primary, secondary (excluding construction), construction, and tertiary) is summarized in the figures below:

Figure S.1 Shares and Volatility of Real GDP Subcomponents by Expenditure

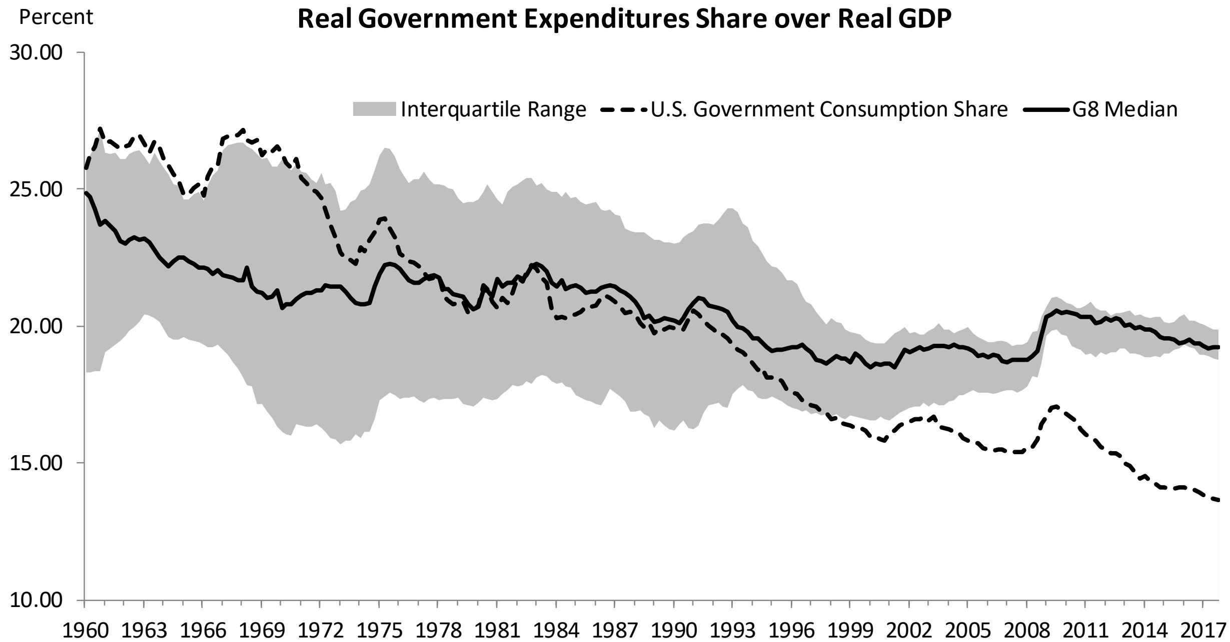


Note: Includes U.S., U.K., CA, FR, DE, JP, ES, and IT. Canada data in levels starts in 1961:Q1. The ratio is defined as real private final consumption expenditures expressed in percentages over real GDP. The chained volume series are not additive, so consumption must be proportionally scaled such that the sum of the subcomponents by expenditures is equal to real GDP.
Sources: Organization for Economic Co-operation and Development; author's calculations



Note: Includes U.S., U.K., CA, FR, DE, JP, ES, and IT. Canada data starts in 1961:Q2. The reported time-varying volatility is estimated from the annualized log-first differences in real private final consumption expenditures expressed in percentages.
Sources: Organization for Economic Co-operation and Development; author's calculations

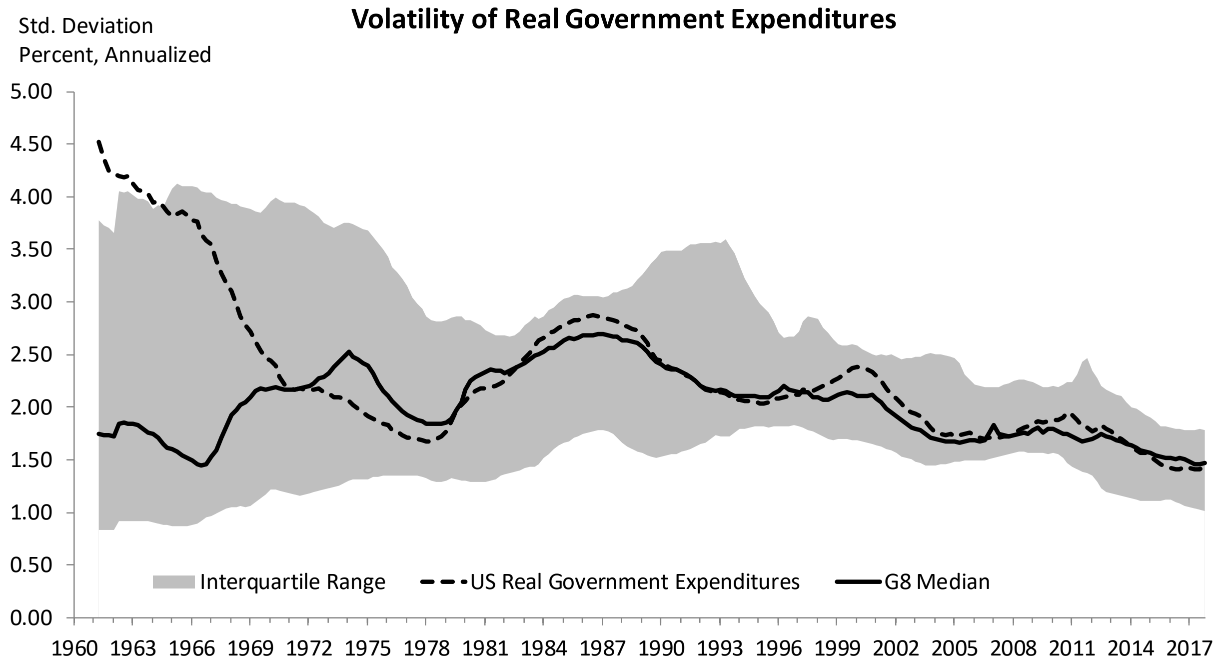
Real Government Expenditures Share over Real GDP



Note: Includes U.S., U.K., CA, FR, DE, JP, ES, and IT. Canada data in levels starts in 1961:Q1. The ratio is defined as real government final consumption expenditures expressed in percentages over real GDP. The chained volume series are not additive, so government consumption must be proportionally scaled such that the sum of the subcomponents by expenditures is equal to real GDP.

Sources: Organization for Economic Co-operation and Development; author's calculations

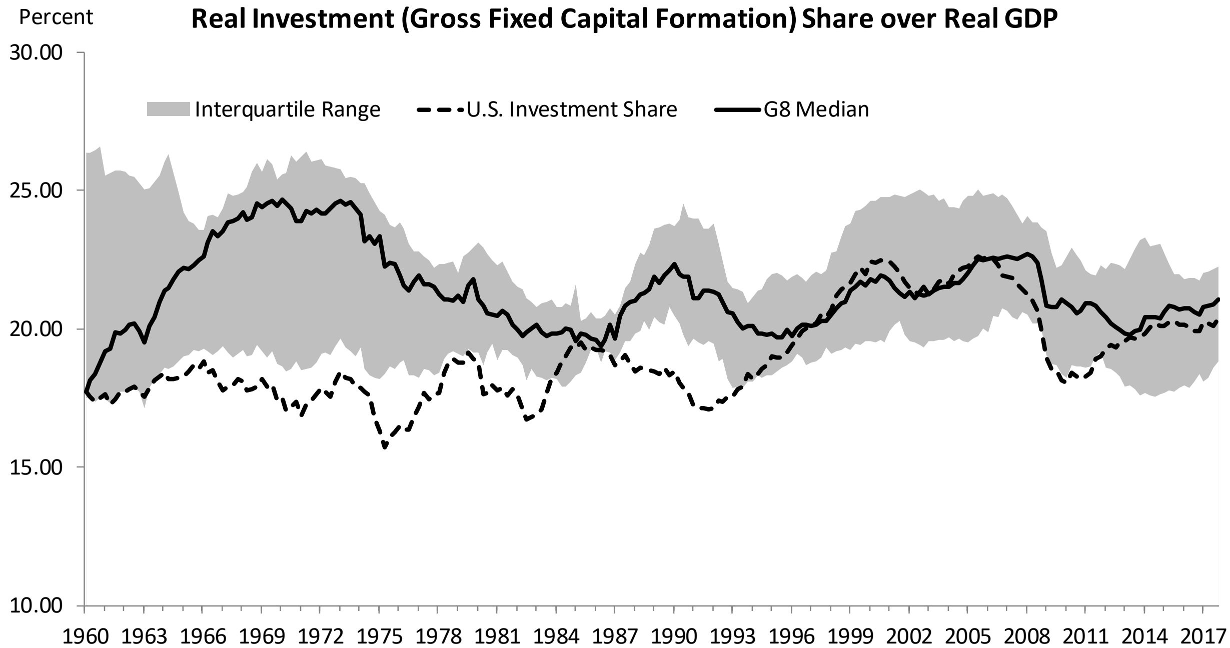
Volatility of Real Government Expenditures



Note: Includes U.S., U.K., CA, FR, DE, JP, ES, and IT. Canada data starts in 1961:Q2. The reported time-varying volatility is estimated from the annualized log-first differences in real government final consumption expenditures expressed in percentages.

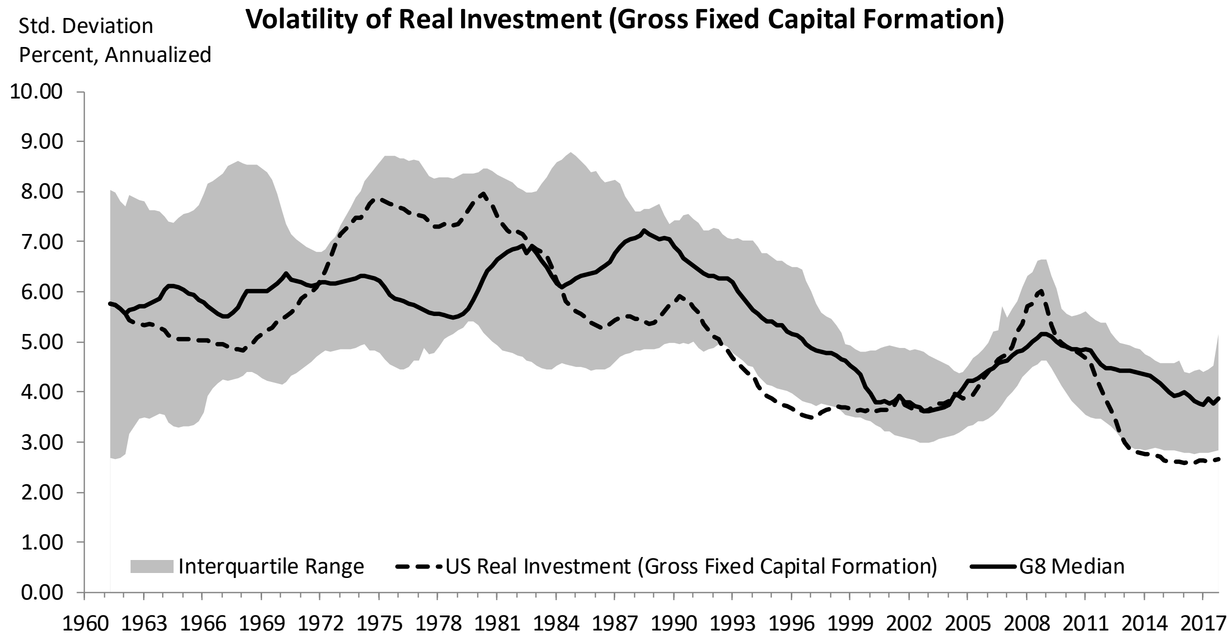
Sources: Organization for Economic Co-operation and Development; author's calculations

Real Investment (Gross Fixed Capital Formation) Share over Real GDP

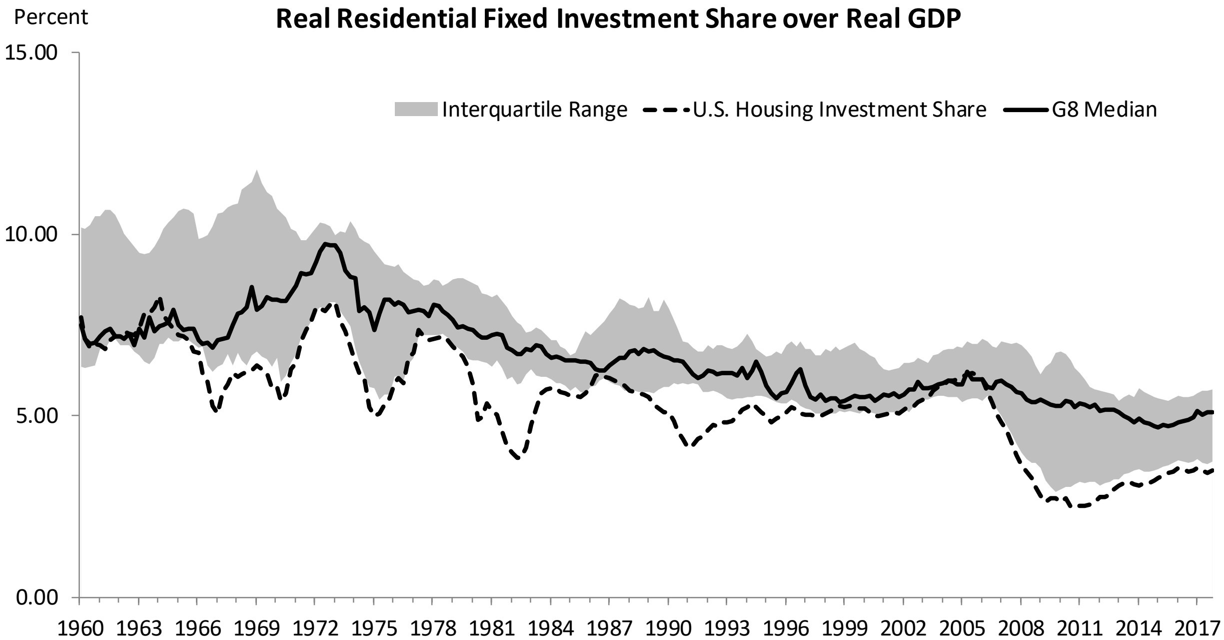


Note: Includes U.S., U.K., CA, FR, DE, JP, ES, and IT. Canada data in levels starts in 1961:Q1. The ratio is defined as real gross fixed capital formation expressed in percentages over real GDP. The chained volume series are not additive, so investment must be proportionally scaled such that the sum of the subcomponents by expenditures is equal to real GDP.
Sources: Organization for Economic Co-operation and Development; author's calculations

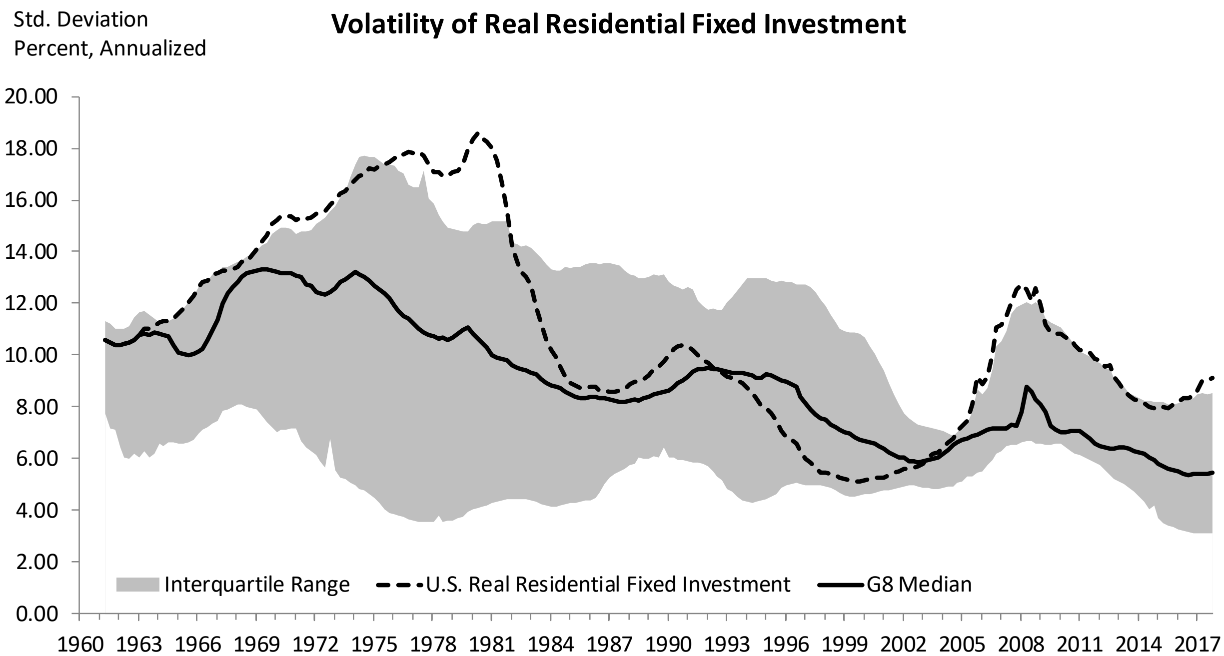
Volatility of Real Investment (Gross Fixed Capital Formation)



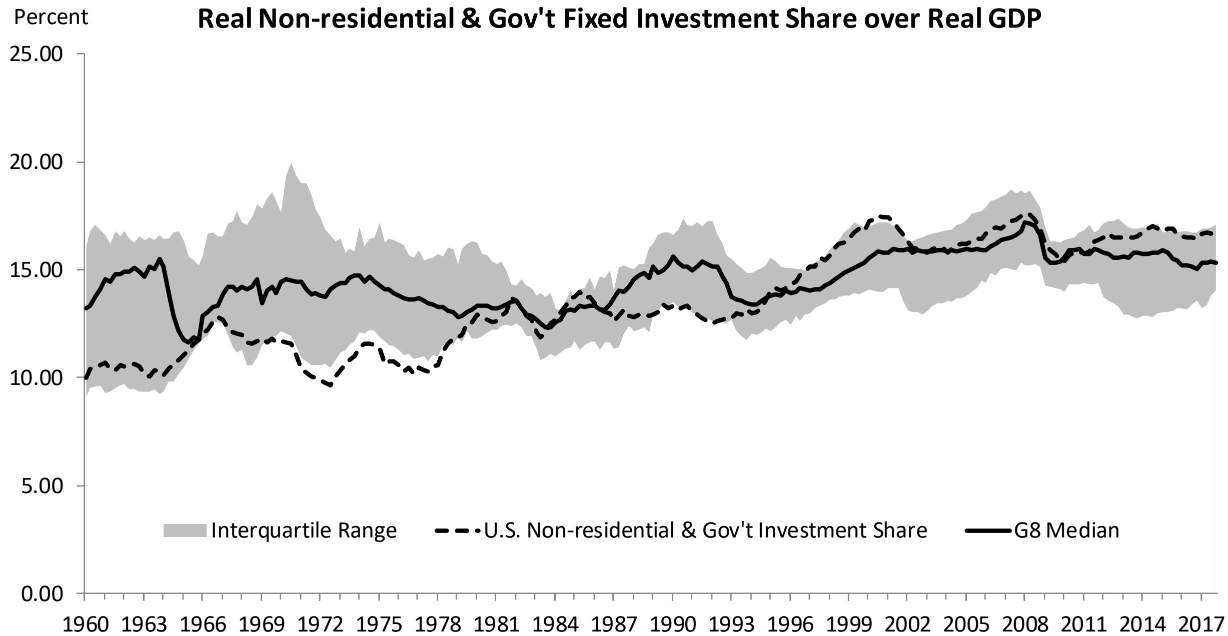
Note: Includes U.S., U.K., CA, FR, DE, JP, ES, and IT. Canada data starts in 1961:Q2. The reported time-varying volatility is estimated from the annualized log-first differences in real gross fixed capital formation expressed in percentages. Gross fixed capital formation excludes net changes in inventories and acquisitions less disposals of valuables for a unit or sector from gross capital formation.
Sources: Organization for Economic Co-operation and Development; author's calculations



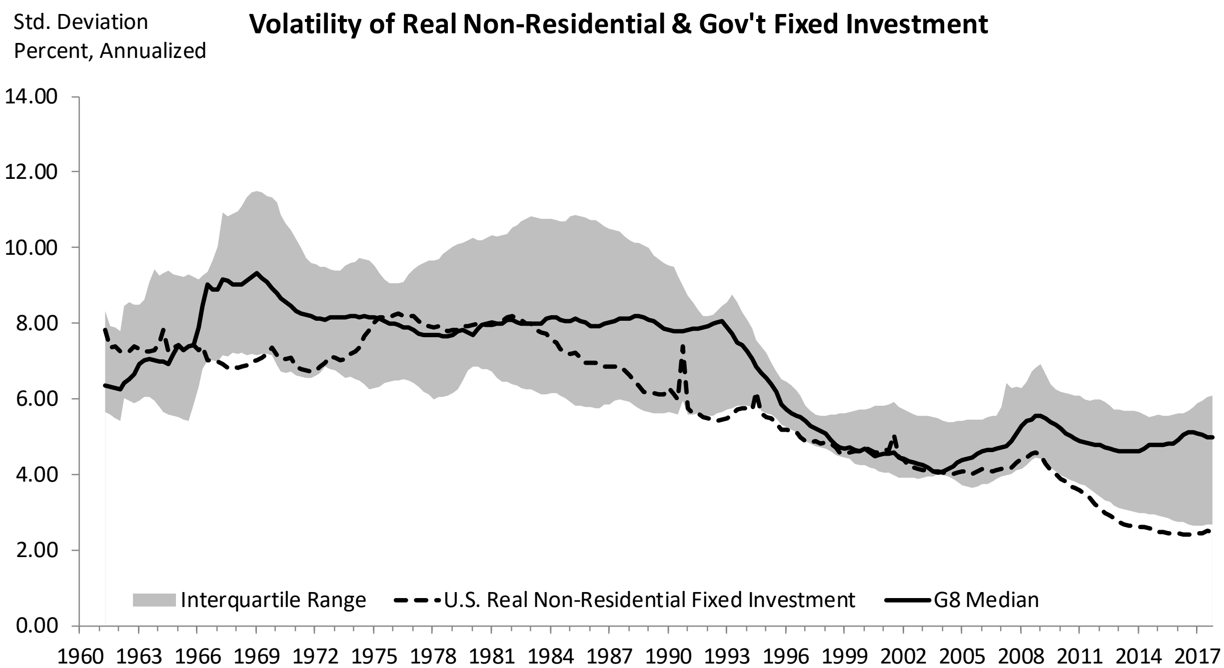
Note: Includes U.S., U.K., CA, FR, DE, JP, ES, and IT. U.K. data in levels starts in 1967:Q1. The ratio is defined as real housing (a component of gross fixed capital formation) expressed in percentages over real GDP. The chained volume series are not additive, so housing investment must be proportionally scaled such that the sum of the subcomponents by expenditures is equal to real GDP.
Sources: Organization for Economic Co-operation and Development; author's calculations



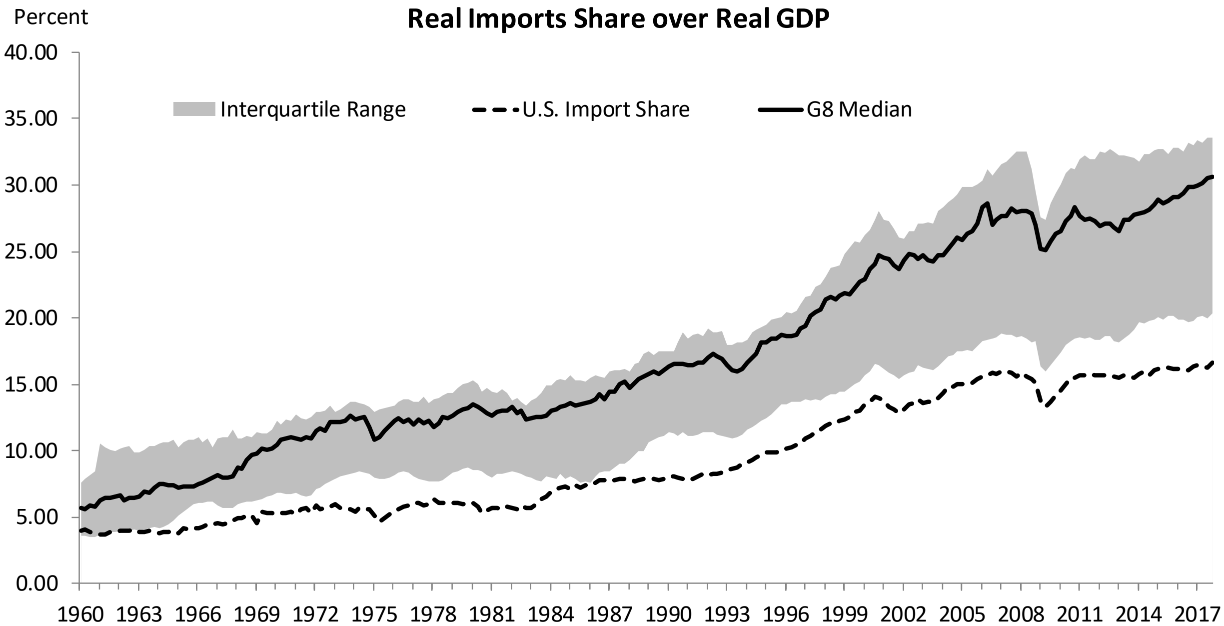
Note: Includes U.S., U.K., CA, FR, DE, JP, ES, and IT. U.K. data starts in 1967:Q2. The reported time-varying volatility is estimated from the annualized log-first differences in real housing (a component of gross fixed capital formation) expressed in percentages.
Sources: Organization for Economic Co-operation and Development; author's calculations



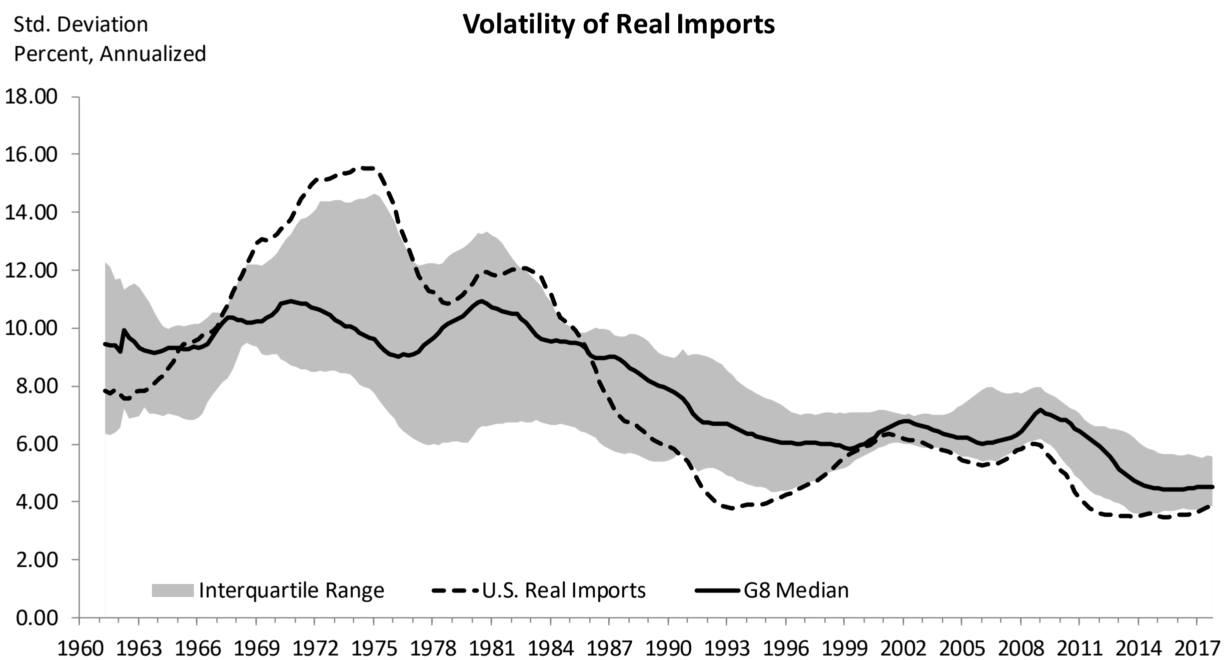
Note: Includes U.S., U.K., CA, FR, DE, JP, ES, and IT. Canada data in levels starts in 1961:Q1 and U.K. data starts in 1967:Q1. The ratio is defined as real non-residential and government investment (a component of gross fixed capital formation) expressed in percentages over real GDP. The chained volume series are not additive, so non-residential and government investment must be proportionally scaled such that the sum of the subcomponents by expenditures is equal to real GDP.
Sources: Organization for Economic Co-operation and Development; author's calculations



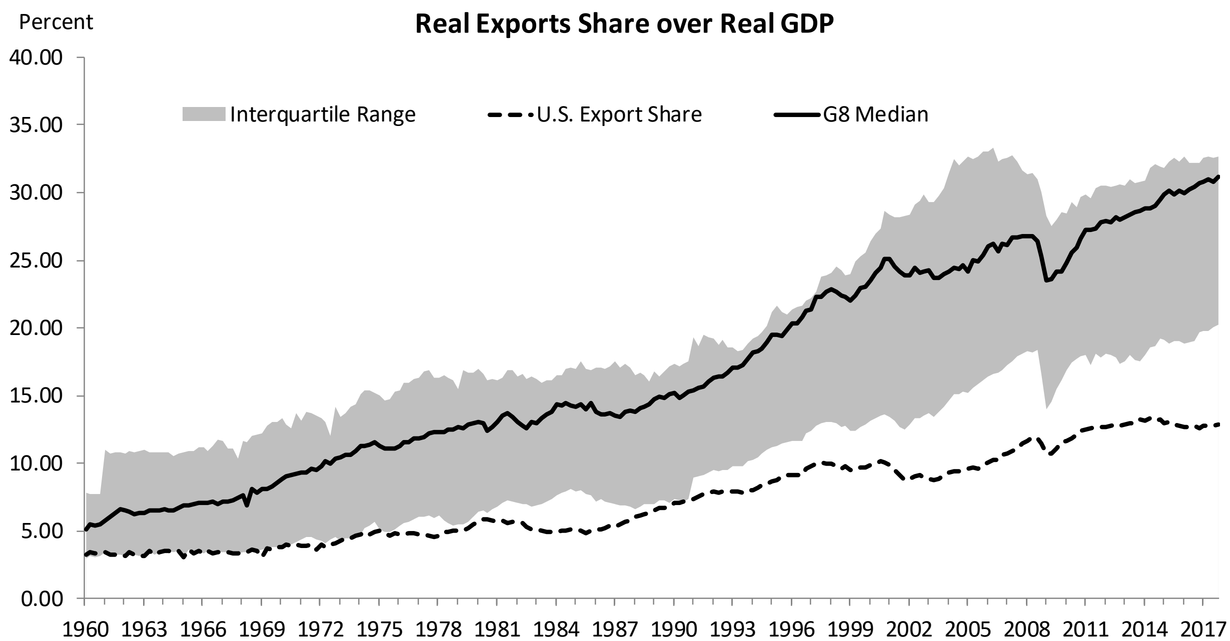
Note: Includes U.S., U.K., CA, FR, DE, JP, ES, and IT. Canada data starts in 1961:Q2 and U.K. data starts in 1967:Q2. The reported time-varying volatility is estimated from the annualized log-first differences in real private non-residential and government fixed capital formation (a component of gross fixed capital formation) expressed in percentages.
Sources: Organization for Economic Co-operation and Development; author's calculations



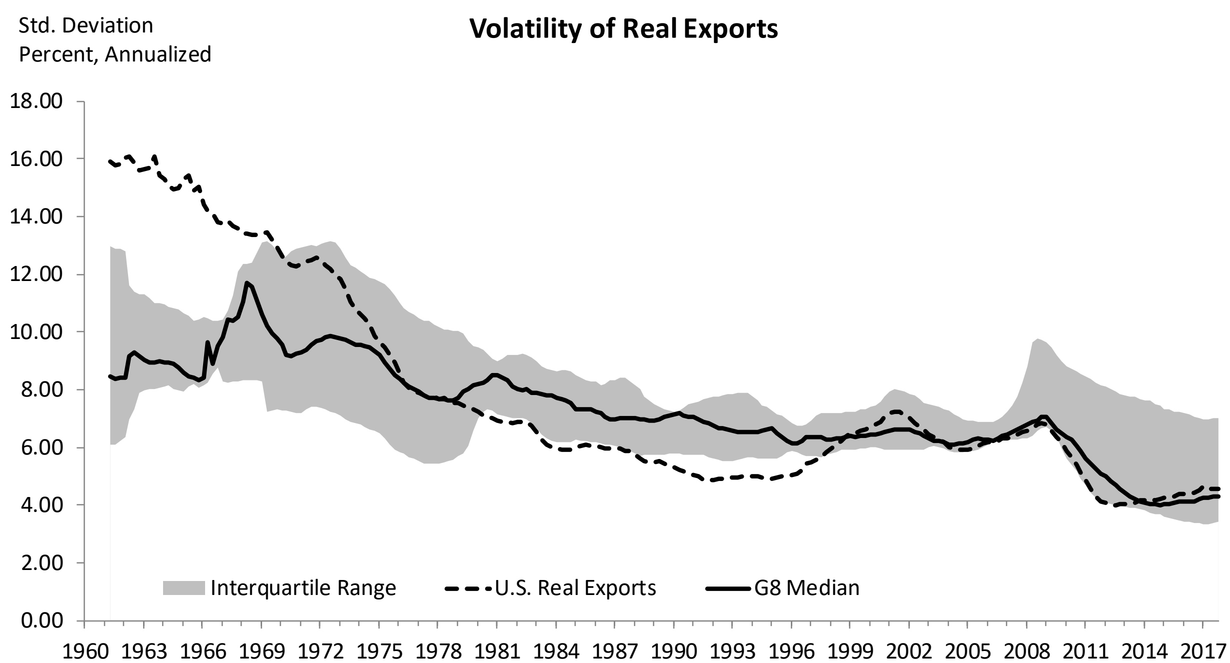
Note: Includes U.S., U.K., CA, FR, DE, JP, ES, and IT. Canada data in levels starts in 1961:Q1 and Germany data starts in 1969:Q1. The ratio is defined as real imports of goods and services expressed in percentages over real GDP. The chained volume series are not additive, so imports must be proportionally scaled such that the sum of the subcomponents by expenditures is equal to real GDP.
Sources: Organization for Economic Co-operation and Development; author's calculations



Note: Includes U.S., U.K., CA, FR, DE, JP, ES, and IT. Canada data starts in 1961:Q2 and Germany data starts in 1969:Q2. The reported time-varying volatility is estimated from the annualized log-first differences in real imports of goods and services expressed in percentages.
Sources: Organization for Economic Co-operation and Development; author's calculations

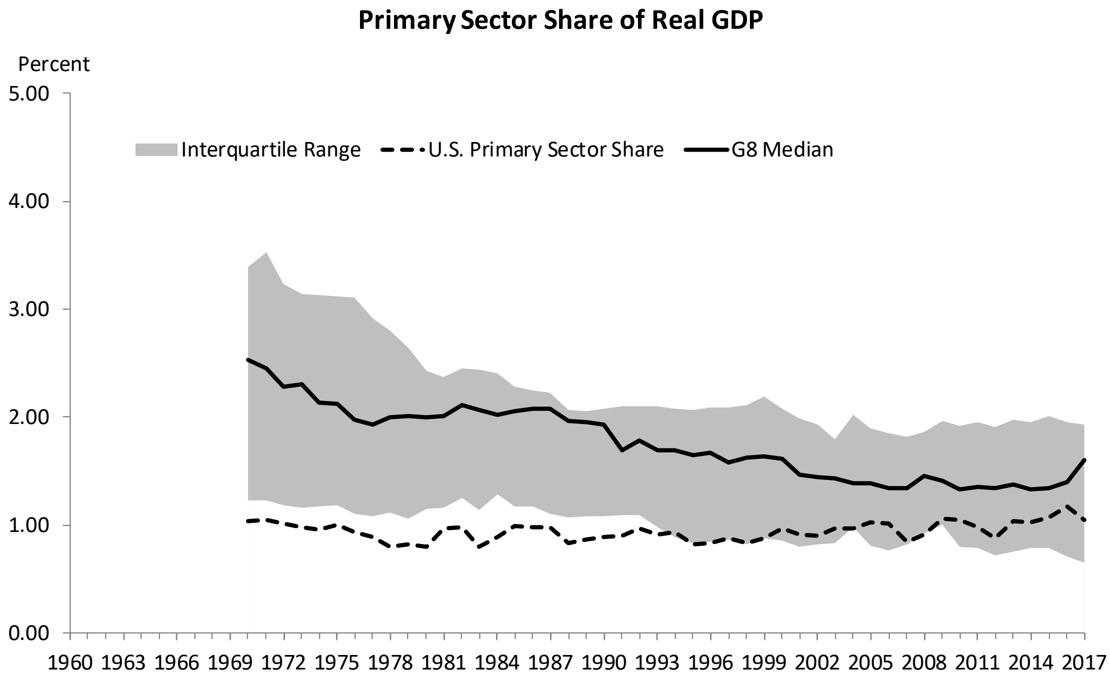


Note: Includes U.S., U.K., CA, FR, DE, JP, ES, and IT. Canada data in levels starts in 1961:Q1 and Germany data starts in 1969:Q1. The ratio is defined as real exports of goods and services expressed in percentages over real GDP. The chained volume series are not additive, so exports must be proportionally scaled such that the sum of the subcomponents by expenditures is equal to real GDP.
Sources: Organization for Economic Co-operation and Development; author's calculations

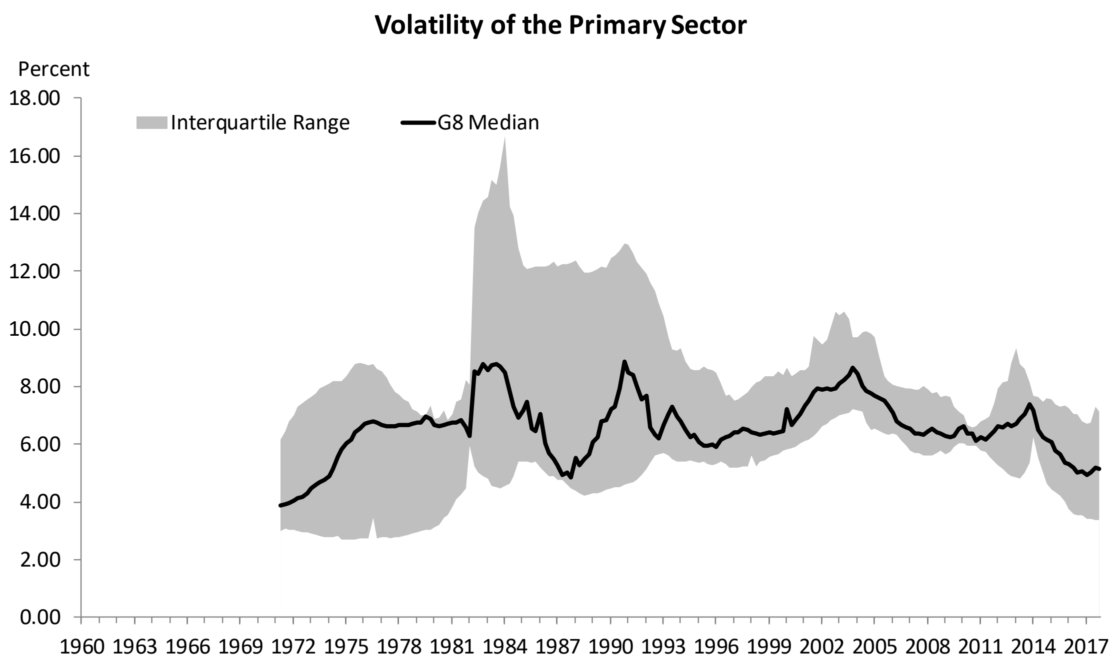


Note: Includes U.S., U.K., CA, FR, DE, JP, ES, and IT. Canada data starts in 1961:Q2 and Germany data starts in 1969:Q2. The reported time-varying volatility is estimated from the annualized log-first differences in real exports of goods and services expressed in percentages.
Sources: Organization for Economic Co-operation and Development; author's calculations

Figure S.2 Volatility on Real GDP by Production Sector

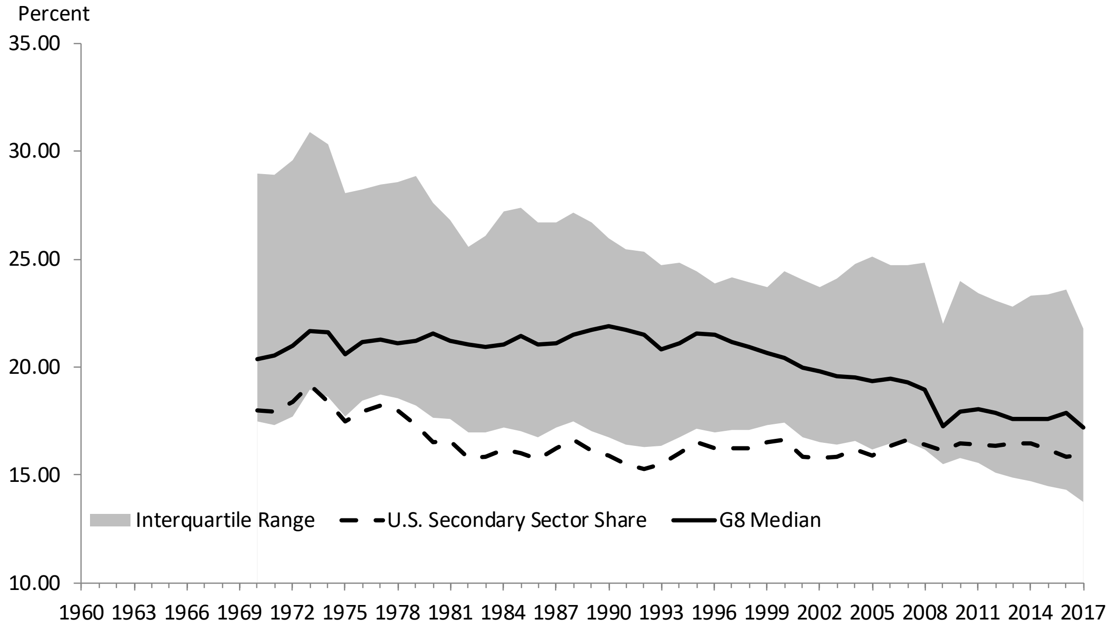


Note: Includes U.S., U.K., CA, FR, DE, JP, ES, and IT. Not all series are complete back to 1960.
Sources: Organization for Economic Co-operation and Development; Bureau of Economic Analysis; Office for National Statistics; Institut National de la Statistique/Economique; Deutsche Bundesbank; Statistisches Bundesamt; Istituto Nazionale di Statistica; Statistics Canada; Instituto Nacional de Estadistica; author's calculations.



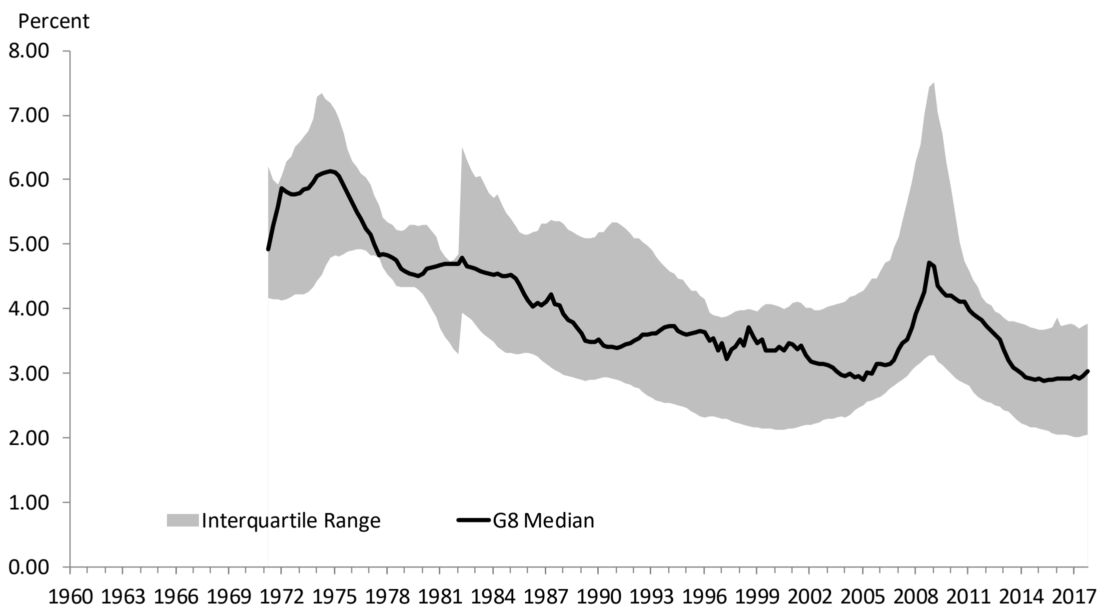
Note: Includes U.K., CA, FR, DE, ES, and IT. Not all series are complete back to 1960. U.S. and JP are excluded due to lack of quarterly data.
Sources: Bureau of Economic Analysis; Office for National Statistics; Institut National de la Statistique/Economique; Deutsche Bundesbank; Statistisches Bundesamt; Istituto Nazionale di Statistica; Statistics Canada; Instituto Nacional de Estadistica; author's calculations.

Secondary Sector (ex. Construction) Share of Real GDP



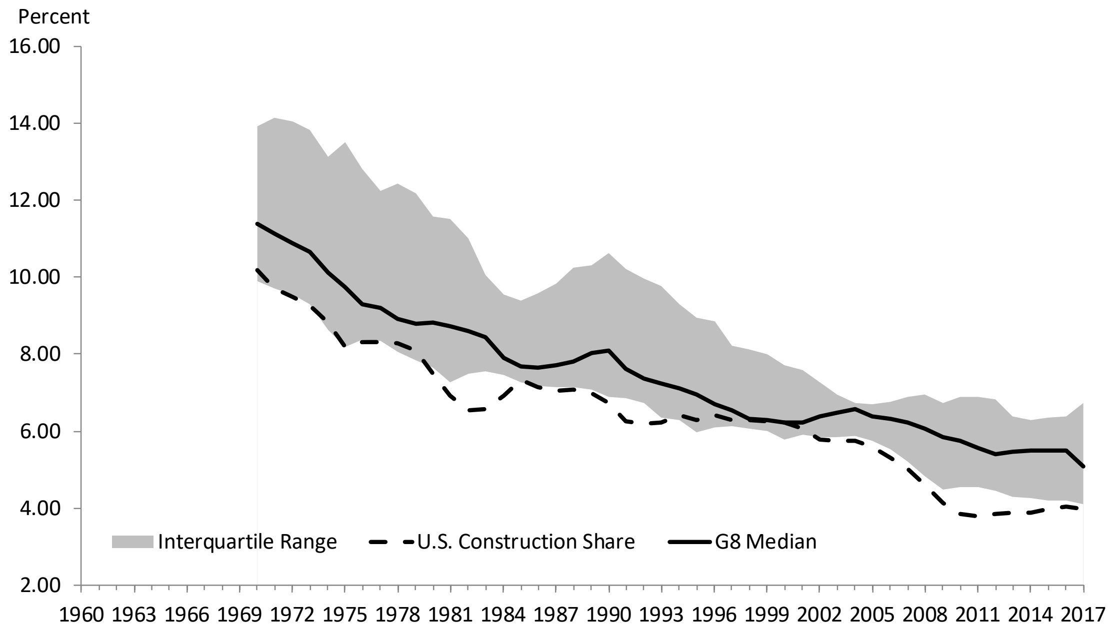
Note: Includes U.S., U.K., CA, FR, DE, JP, ES, and IT. Not all series are complete back to 1960.
Sources: Organization for Economic Co-operation and Development; Bureau of Economic Analysis; Office for National Statistics; Institut National de la Statistique/Economique; Deutsche Bundesbank; Statistisches Bundesamt; Istituto Nazionale di Statistica; Statistics Canada; Instituto Nacional de Estadistica; author's calculations.

Volatility of the Secondary Sector (ex. Construction)



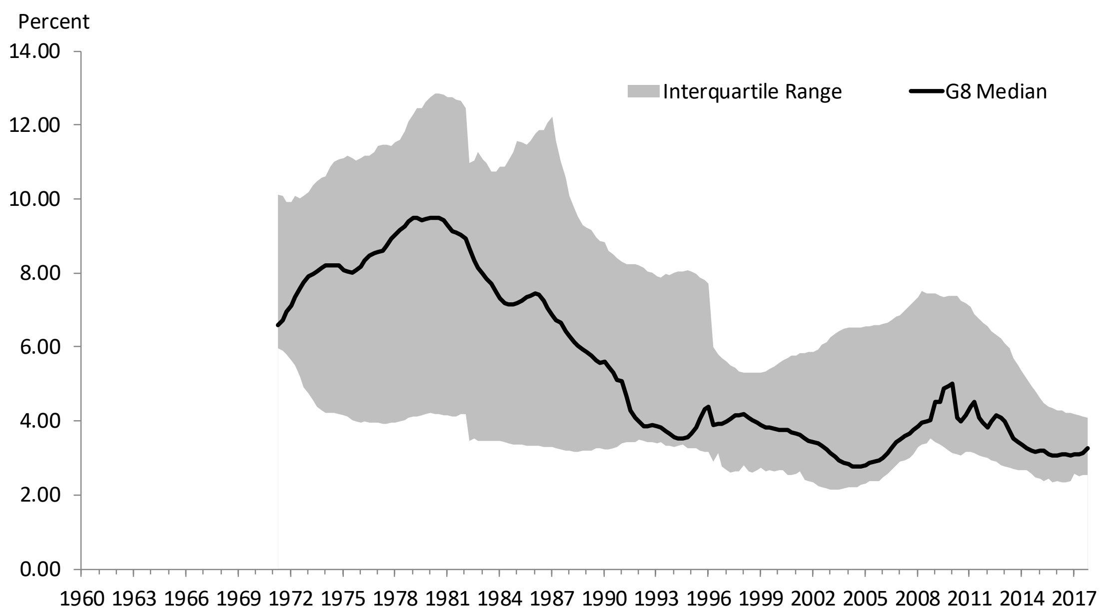
Note: Includes U.K., CA, FR, DE, ES, and IT. Not all series are complete back to 1960. U.S. and JP are excluded due to lack of quarterly data.
Sources: Bureau of Economic Analysis; Office for National Statistics; Institut National de la Statistique/Economique; Deutsche Bundesbank; Statistisches Bundesamt; Istituto Nazionale di Statistica; Statistics Canada; Instituto Nacional de Estadistica; author's calculations.

Secondary Sector (Construction) Share of Real GDP



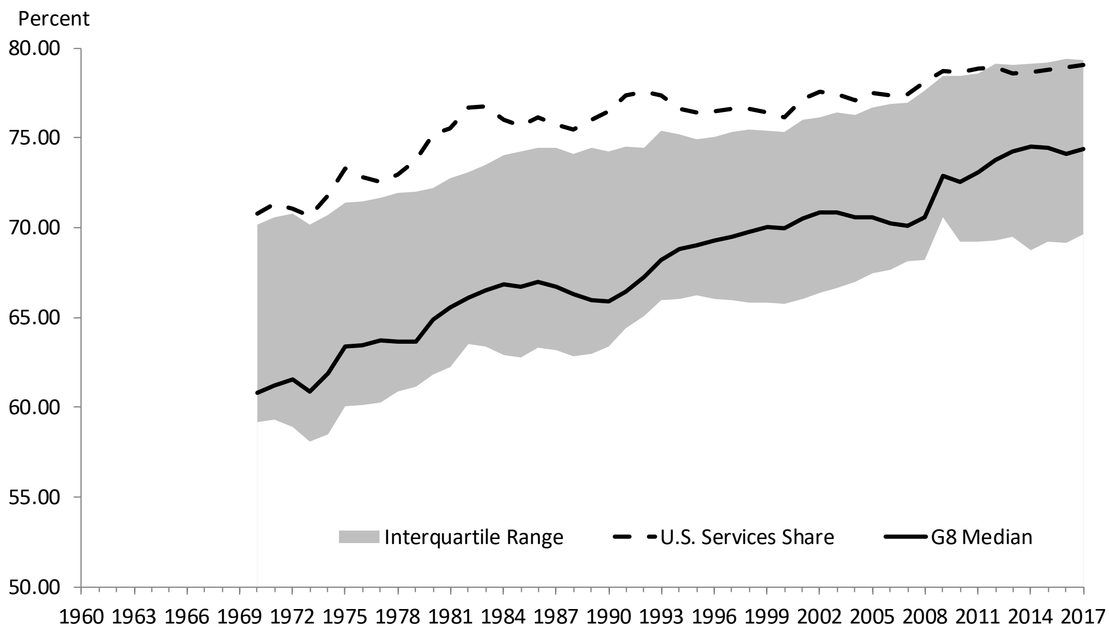
Note: Includes U.S., U.K., CA, FR, DE, JP, ES, and IT. Not all series are complete back to 1960.
Sources: Organization for Economic Co-operation and Development; Bureau of Economic Analysis; Office for National Statistics; Institut National de la Statistique/Economique; Deutsche Bundesbank; Statistisches Bundesamt; Istituto Nazionale di Statistica; Statistics Canada; Instituto Nacional de Estadistica; author's calculations.

Volatility of the Secondary Sector (Construction)



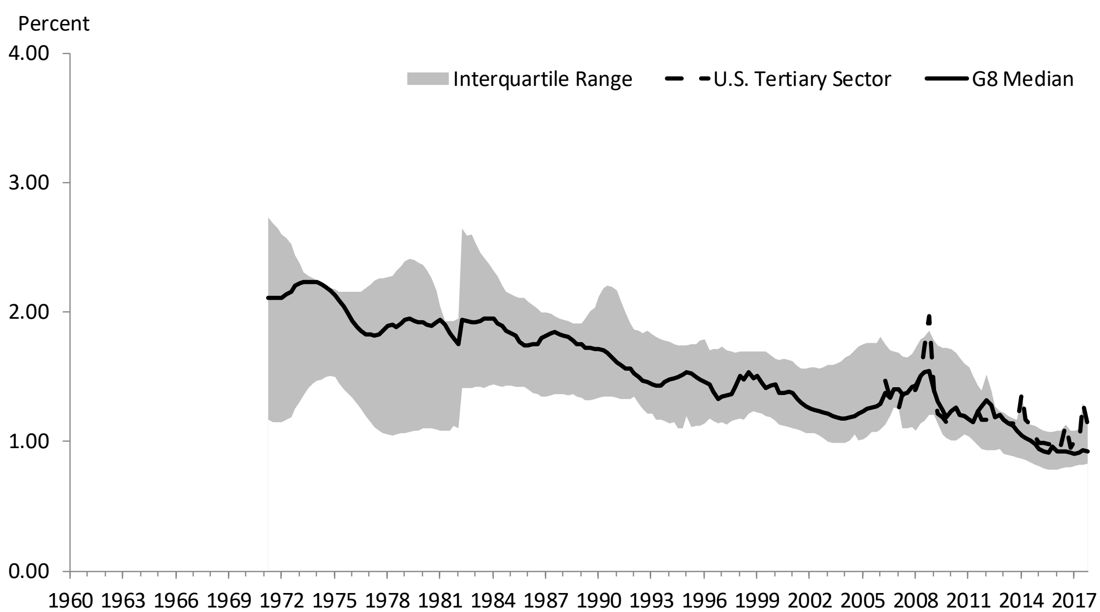
Note: Includes U.K., CA, FR, DE, ES, and IT. Not all series are complete back to 1960. U.S. and JP are excluded due to lack of quarterly data.
Sources: Bureau of Economic Analysis; Office for National Statistics; Institut National de la Statistique Economique; Deutsche Bundesbank; Statistisches Bundesamt; Istituto Nazionale di Statistica; Statistics Canada; Instituto Nacional de Estadistica; author's calculations.

Tertiary Sector Share of Real GDP



Note: Includes U.S., U.K., CA, FR, DE, JP, ES, and IT. Not all series are complete back to 1960.
Sources: Organization for Economic Co-operation and Development; Bureau of Economic Analysis; Office for National Statistics; Institut National de la Statistique/Economique; Deutsche Bundesbank; Statistisches Bundesamt; Istituto Nazionale di Statistica; Statistics Canada; Instituto Nacional de Estadistica; author's calculations.

Volatility of the Tertiary Sector



Note: Includes U.K., CA, FR, DE, ES, and IT. Not all series are complete back to 1960. JP is excluded due to lack of quarterly data.
Sources: Bureau of Economic Analysis; Office for National Statistics; Institut National de la Statistique/Economique; Deutsche Bundesbank; Statistisches Bundesamt; Istituto Nazionale di Statistica; Statistics Canada; Instituto Nacional de Estadistica; author's calculations.

A.3 A Note on the Consumption Correlation Puzzle

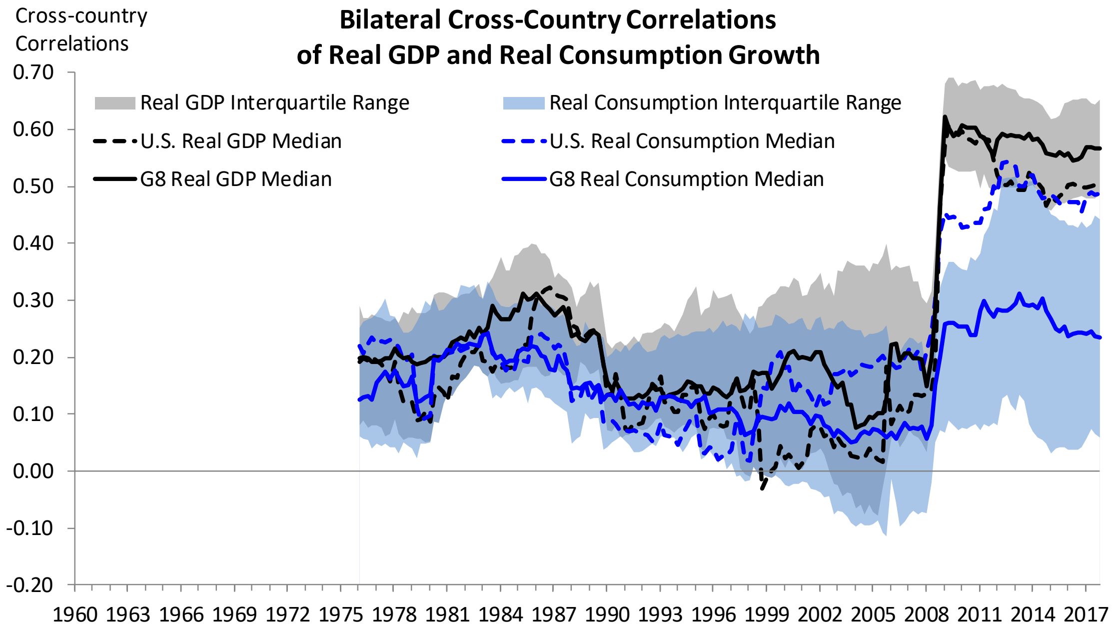
Figure S.3 illustrates the empirical patterns of cross-country correlations among the eight major advanced economies for four-quarter real GDP growth and four-quarter real consumption growth. Figure S.3, in particular, illustrates the well-known 'puzzle' in the international macro literature which arises because—unlike in theory—cross-country output correlations tend to be higher than cross-country consumption correlations in the data (Backus *et al.* (1992), Obstfeld and Rogoff (2001)).[21] The correlation of output growth (or synchronization) across countries as well as the cross-correlation of real consumption growth did not change significantly until the 2008 global recession according to the first panel in Figure S.3. For the U.S. in particular, it is worth noting that the cross-country correlations of output and consumption weakened somewhat during the 1990s.

Given that I compute pairwise correlation coefficients, I also consider David (1949)'s alternative approach to compute a combined (or aggregated) correlation across several correlation coefficients ($\rho_i,\ i=1,...,N$). For that, I apply Fisher's transformation to each correlation coefficient (i.e., $\zeta_i = \tanh^{-1}(\rho_i) = \frac{1}{2}\left(\ln(1+\rho_i) - \ln(1-\rho_i)\right),\ i=1,...,N$, where $\tanh^{-1}(.)$ is the inverse hyperbolic tangent function). Then, the coefficient that summarizes the correlations is calculated as $\zeta = \tanh^{-1}(\rho) = \sum_{i=1}^{N} \frac{T_i}{\sum_{j=1}^{N} T_j} \tanh^{-1}(\rho_i)$ which is approximately normally distributed with variance $\frac{1}{\sum_{j=1}^{N} T_j}$. From here, the combined correlation coefficient is recovered as $\rho = \tanh(\zeta)$.

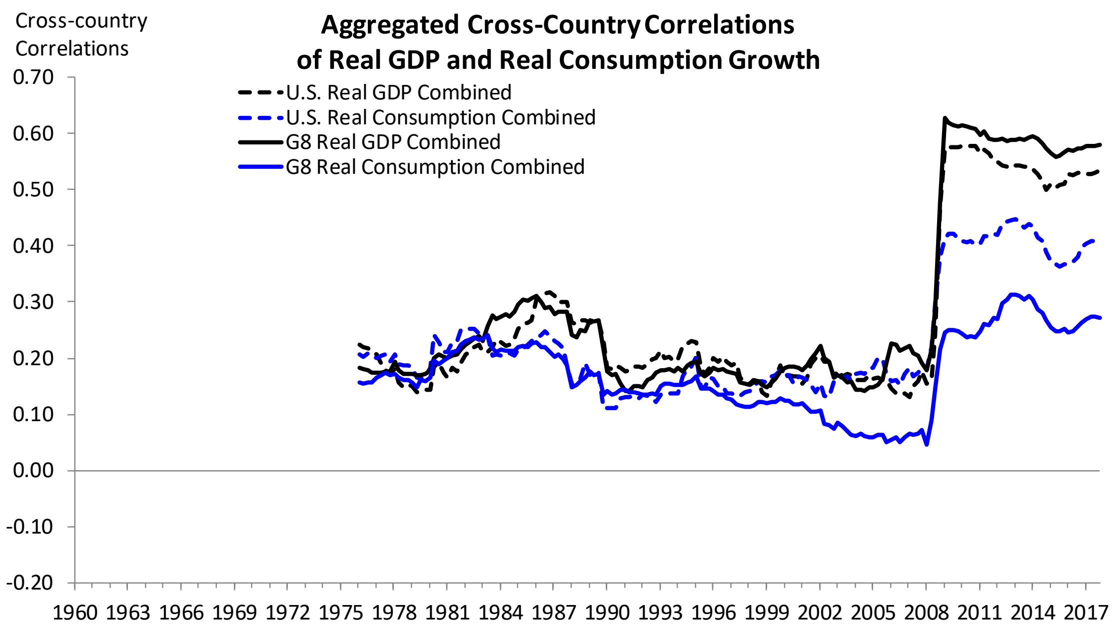
The relevant findings from this aggregated correlation coefficient are reported in the lower panel of Figure S3. The evidence obtained is largely consistent (both qualitatively as well as quantitatively) with that reported in the upper panel. It not only confirms the evidence of a consumption correlation puzzle, but it also suggests that the gap has widened as correlations abruptly grew after the 2008 global recession.

[21] Obstfeld and Rogoff (2001) show that international trade costs can help reconcile international business cycle models with the data on the consumption correlation puzzle and on other major international macro puzzles. An alternative (yet complementary) view puts the emphasis on the functioning of domestic and international capital markets—building on the workhorse open-economy New Keynesian model, the trade-offs between intra-temporal consumption smoothing through trade and intertemporal smoothing through capital accumulation (Martínez-García and Søndergaard (2009, 2013)) and the degree of international risk-sharing whenever international asset markets are incomplete (Martínez-García (2016)) are shown to be quite important too.

Figure S.3 Consumption Correlation Puzzle



Note: Median and interquartile range include U.S., U.K., CA, FR, DE, JP, ES, and IT. The reported median and interquartile range are based on all possible bilateral cross-correlations between the countries calculated on a rolling window of 15 years. The reported median for the U.S. includes only the bilateral pairs between the U.S. and all other countries. Cross-correlations are calculated on the annualized log-first differences in real GDP and on the annualized log-first differences in real private consumption expenditures (expressed in percentages both).
Sources: Organization for Economic Cooperation and Development; author's calculations.



Note: Includes U.S., U.K., CA, FR, DE, JP, ES, and IT. The combined series uses David (1949) approach based on all possible bilateral cross-correlations between the countries calculated on a rolling window of 15 years. The series for the U.S. includes only the bilateral pairs between the U.S. and all other countries. Cross-correlations are calculated on the annualized log-first differences in real GDP and on the annualized log-first differences in real private consumption expenditures (expressed in percentages both).
Sources: Organization for Economic Cooperation and Development; author's calculations.

A.4 A Note on the Synchronization and Cyclicality of Inflation

I document the cross-country correlations of the inflation rate (based on the GDP deflator) and the corresponding four-quarter real GDP growth in Figure S.4.[22] Up to the mid-1980s, the cross-correlation of real GDP growth is low while the cross-correlation of inflation is very high and much less dispersed across countries. Between the mid-1980s and the mid-1990s, both cross-correlations are pretty stable as can be seen in Figure S.4. From the mid-1990s up to the 2008 global recession, the cross-country correlation of inflation declines by about half while the cross-country correlation of real GDP growth remains largely unchanged.

In the aftermath of the 2008 global recession, the measures of inflation synchronization across countries has regained some ground. However, what is most notable is the abrupt increase in the cross-correlation of real GDP growth and the reversal in the ordering (with real GDP growth becoming more synchronized than inflation). The U.S. data does not appear to behave too differently than the G8 data. While these shifts are stark, these are to my knowledge lesser-studied (and lesser-understood) empirical regularities in international macroeconomics.

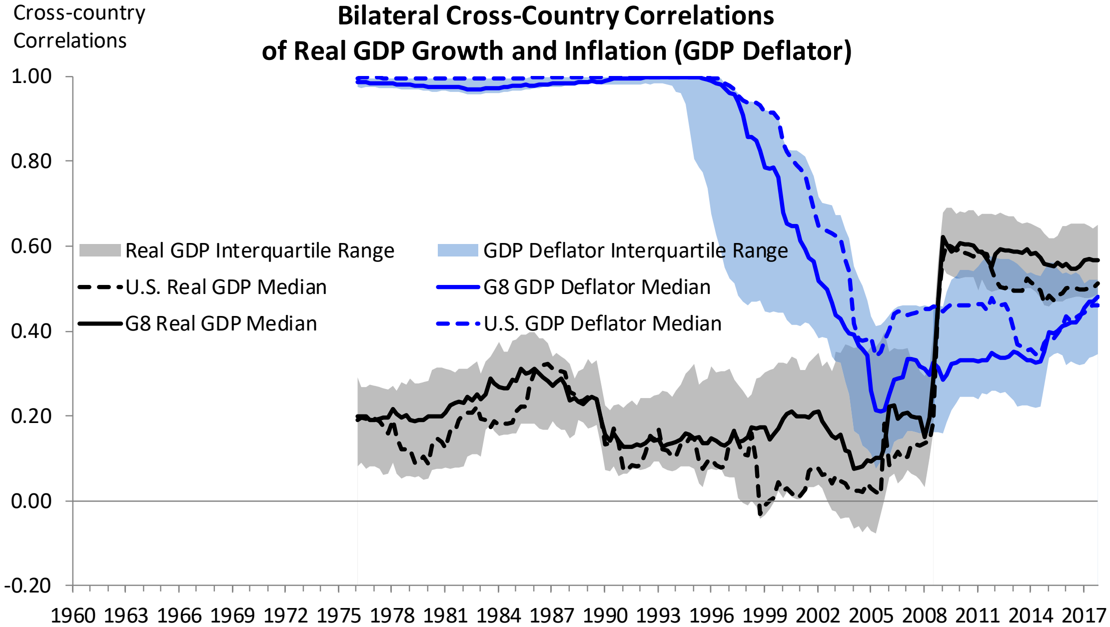
Another important regularity on inflation to pay attention to is its cyclicality pattern. Kydland and Prescott (1990) showed that after filtering for the business-cycle component (that is, detrending the data), the U.S. price level had been negatively correlated with output over the post-WWII period. Cooley and Ohanian (1991) extended the sample confirming Kydland and Prescott (1990)'s countercyclical result in the post-WWII period, but showing instead that the price level had been procyclical prior to WWII (particularly during the interwar period). Cooley and Ohanian (1991) looked at the inflation rate as well and found that it was procyclical during the post-WWII period.

Brock and Haslag (2016) and Kydland and Prescott (1990) note that the cyclical behavior of the price level and that of inflation are of particular importance for theorists to evaluate the current class of monetary models. For example, the perception that the movements in the price level are procyclical largely accounts for the prevalence of monetary policy shocks as a major source of fluctuations. Brock and Haslag (2016) further state that "given the deterministic relationship between the price level and the inflation rate, the qualitative difference [the countercyclicality of the price level and the procyclicality of the inflation rate] deserves attention."[23]

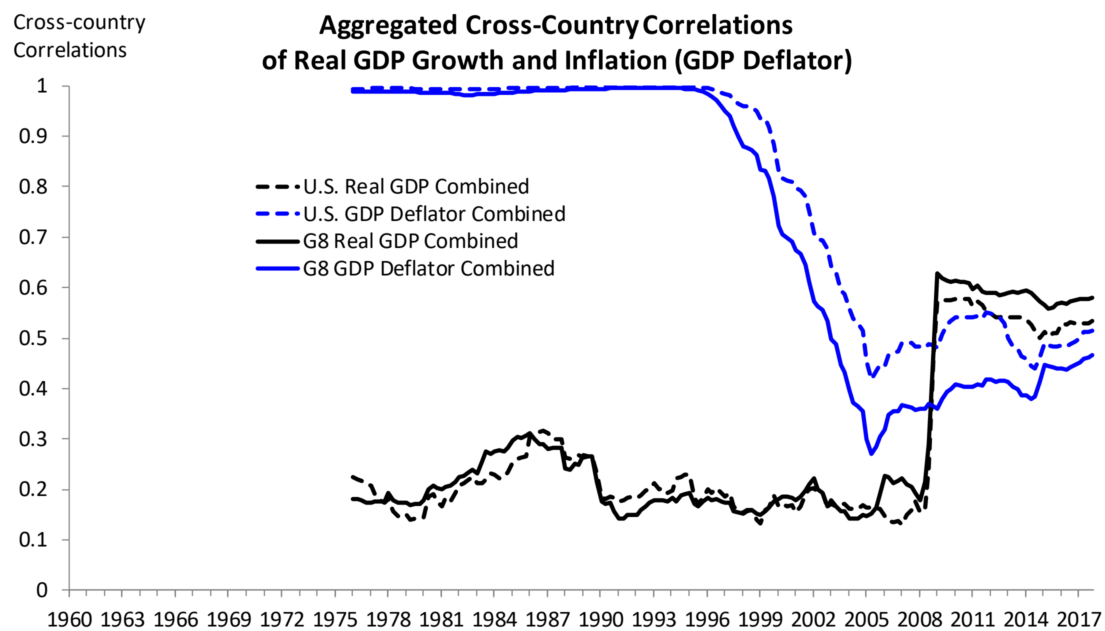
[22] As in Figure S.3, I construct Figures S.4 and S.5 to illustrate the patterns of synchronization and cyclicality of inflation using both the bilateral correlation coefficients (top panel) as well as the aggregated correlation coefficients (lower panel) based on David (1949)'s approach to compute a combined (or aggregated) correlation.

[23] Inflation is by definition equal to the direction of change over time in the price level.

Figure S4. Synchronization (Cross-Correlations): Inflation vs. Real GDP Growth

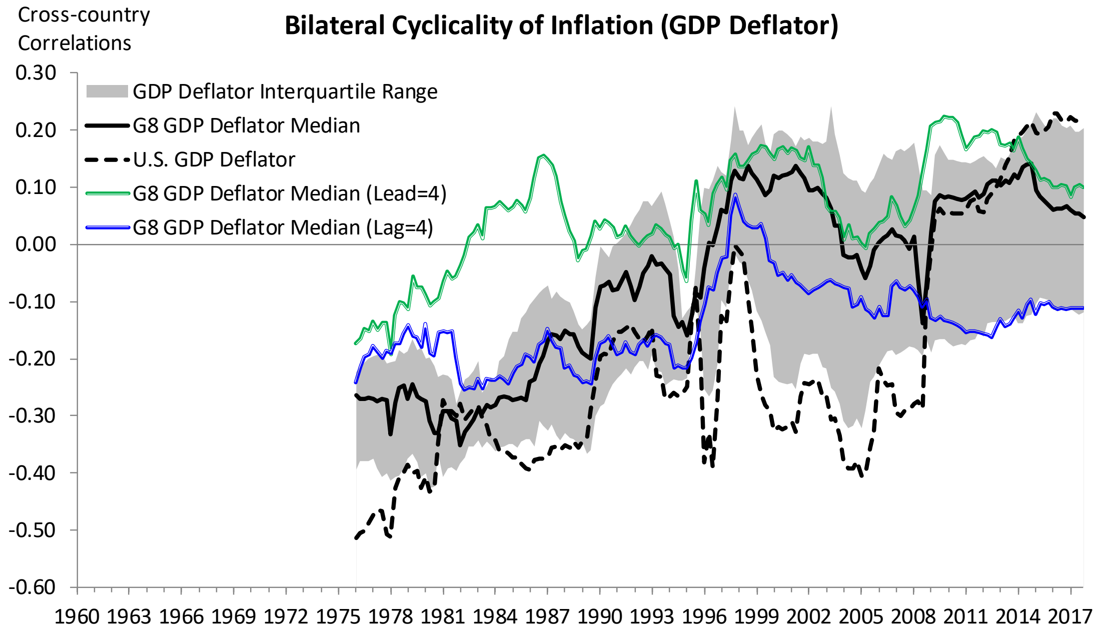


Note: Median and interquartile range include U.S., U.K., CA, FR, DE, JP, ES, and IT. The reported median and interquartile range are based on all possible bilateral cross-correlations between the countries calculated on a rolling window of 15 years. The reported median for the U.S. includes only the bilateral pairs between the U.S. and all other countries. Cross-correlations are calculated on the annualized log-first differences in real GDP and on the annualized log-first differences in the implied GDP deflator (expressed in percentages both).
Sources: Organization for Economic Cooperation and Development; author's calculations.

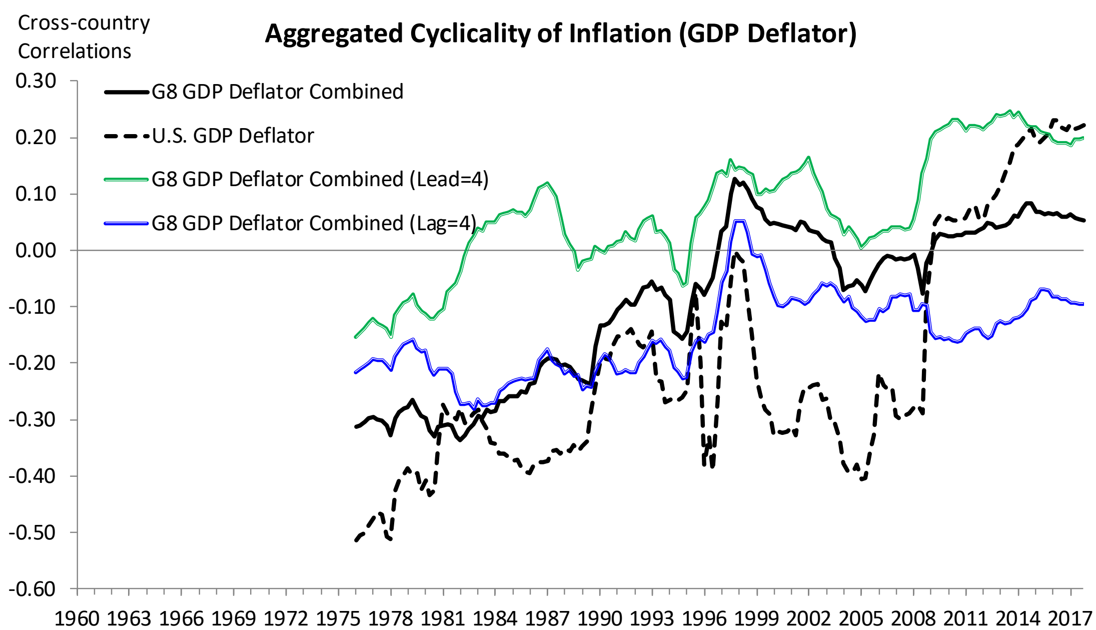


Note: Includes U.S., U.K., CA, FR, DE, JP, ES, and IT. The combined series uses David (1949) approach based on all possible bilateral cross-correlations between the countries calculated on a rolling window of 15 years. The series for the U.S. includes only the bilateral pairs between the U.S. and all other countries. Cross-correlations are calculated on the annualized log-first differences in real GDP and on the annualized log-first differences in the implied GDP deflator (expressed in percentages both).
Sources: Organization for Economic Cooperation and Development; author's calculations.

Figure S5. Cyclicality of Inflation (Correlation with Real GDP) at Different Leads and Lags



Note: Median and interquartile range include U.S., U.K., CA, FR, DE, JP, ES, and IT. The reported median and interquartile range are based on the contemporaneous correlation between the annualized log-first differences in real GDP and the annualized log-first differences in the implied GDP deflator (both expressed in percentages) of each country calculated on a rolling window of 15 years. The U.S. series is computed analogously. The median correlations of GDP growth with four-periods-ahead & four-periods-lagged inflation for all countries are added too.
Sources: Organization for Economic Cooperation and Development; author's calculations.



Note: Includes U.S., U.K., CA, FR, DE, JP, ES, and IT. The combined series uses David (1949) approach based on the contemporaneous correlation between the annualized log-first differences in real GDP and the annualized log-first differences in the implied GDP deflator (both expressed in percentages) of each country calculated on a rolling window of 15 years. The U.S. series is computed analogously. The median correlations of GDP growth with four-periods-ahead & four-periods-lagged inflation for all countries are added too.
Sources: Organization for Economic Cooperation and Development; author's calculations.

Figure S.5 illustrates the evolution of the co-movement of inflation with the corresponding business cycle of the eight major advanced economies in the dataset at different leads and lags. To be more specific, Figure S.4 illustrates the contemporaneous correlation and leads/lags of up to four quarters between the inflation rate computed from the GDP deflator and the four-quarter growth rate of real GDP. In the face of substantial declines in inflation volatility, the striking finding is that the cyclical correlation for inflation has changed only modestly.

The most significant change I find in the cyclical correlation is that it has turned from negative in the earlier part of the sample to largely acyclical since the 2000s. The switch for the median advanced economy occurred in the mid-1990s—particularly among European countries—but only appears clearly in the U.S. data in the aftermath of the 2008 global recession. This is another important regularity in the data worth keeping in mind when developing consistent monetary models.