Has Globalization Changed the Inflation Process?*

By Kristin J. Forbes

MIT-Sloan School of Management, NBER and CEPR

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Abstract: The relationship central to most inflation models, between slack and inflation, seems to have weakened. Do we need a new framework? This paper uses three very different approaches—principal components, a Phillips curve model, and trend-cycle decomposition—to show that inflation models should more explicitly and comprehensively control for changes in the global economy and allow for key parameters to adjust over time. Global factors, such as global commodity prices, global slack, exchange rates, and producer price competition can all significantly affect inflation, even after controlling for the standard domestic variables. The role of these global factors has changed over the last decade, especially the relationship between global slack, commodity prices, and producer price dispersion with CPI inflation and the cyclical component of inflation. The role of different global and domestic factors varies across countries, but as the world has become more integrated through trade and supply chains, global factors should no longer play an ancillary role in models of inflation dynamics.

Key Words: inflation, Phillips curve, trend-cycle, price dynamics, globalization

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I. Introduction

Understanding and forecasting inflation is critically important for monetary policy. Recently, however, the basic framework and models central to forecasting inflation have not been performing very well. When growth collapsed in most countries during the global financial crisis—why didn't inflation fall further? More recently, as GDP growth has picked up, unemployment has fallen sharply, and output gaps have largely closed in many economies, why has inflation remained so low? Does the basic concept underlying most inflation models—of a "Phillips curve" tradeoff between slack and inflation—still apply? A google search for articles that include the terms "dead" and "Phillips curve" yields over 1000 hits. Has something changed so that the framework central to modelling inflation dynamics is no longer useful?

This paper suggests that our current framework for understanding inflation dynamics is not "dead," but does need an overhaul. More specifically, inflation models should more explicitly incorporate "globalization"—defined broadly as increased integration between individual countries and the rest of the world. Standard frameworks for modelling inflation have focused on the role of domestic variables, such as the degree of domestic slack and inflation expectations, often only allowing for global influences through a limited "supply shock" (such as a control for oil or import prices). The results in this paper suggest it is necessary to incorporate additional "global" factors in models of inflation dynamics, including global slack, non-fuel commodity prices (as well as oil prices), the exchange rate, and global price competition. These global factors can significantly improve the ability of simple models to predict inflation. The role of these different global variables, as well as those of the standard domestic variables, has also changed significantly over time, especially in models predicting CPI inflation or the cyclical component of inflation, suggesting key parameters in inflation models should be dynamic. Economists should not throw away the old models, but add a more comprehensive treatment of international factors whose role can vary over time.

"Has globalization changed inflation dynamics?" is not a new question. Soon after the Phillips curve relationship between unemployment and wage inflation gained prominence in the late 1960's, the oil shocks of the 1970's highlighted the need to supplement this framework to account for changes in global oil prices. In the mid-2000's, several prominent policymakers gave speeches questioning whether globalization, especially increased exports from low-wage economies, was moderating inflationary pressures at that time (Bean, 2006, Kohn, 2006, Yellen, 2006 and White, 2008). The corresponding discussion generally concluded that although globalization was an important phenomenon, and may have acted as a temporary "supply shock" reducing inflation, it had only had limited effects on the underlying inflation process. Ball (2006) summarized the current debate in an essay on whether "the "globalization of the U.S. economy has changed the behavior of inflation" and summarizes the results of his tests as "no, no, and no." The impact of globalization on inflation received less attention during and after the global financial crisis as most work attempting to explain the "missing deflation" in this period focused on domestic variables, such as the role of financial frictions (Gilchrist and Zakrajsek, 2015 and Gilchrist *et al.*, 2017). Only recently, as inflationary pressures have remained muted in a number of economies, despite minimal slack and a broad-based recovery, has the role of globalization in inflation dynamics begun to regain attention—especially the potential role of global slack (such as Borio and Filardo, 2007) and global supply chains (such as Auer, Levchenko and Sauré, 2016).

This paper assesses whether globalization should be included more comprehensively in the basic framework for understanding and forecasting inflation. It begins by discussing changes in the world economy that could cause global factors to have a greater role in the inflation process (and not just the level of inflation), and then surveys the limited literature testing for any such effects. Increased trade flows, the greater heft of emerging markets and their impact on commodity prices, the greater ease of using supply chains to shift parts of production to cheaper locations, and a corresponding reduction in local worker bargaining power could all affect inflation dynamics. These changes are not sufficiently captured in inflation models that only control for global influences through a single measure of import prices. Instead, controlling for variables such as the global output gap, the price of non-fuel commodities (as well as of oil), exchange rates, and the extent of competition in global producer pricing, could all go some way towards better capturing changes in the global economy—even in fairly simple frameworks.

To test if global factors have played a more important role in inflation dynamics, this paper uses three very different approaches—all of which have their advantages and disadvantages: a principal components analysis, a Phillips-curve based framework, and a trend-cycle decomposition. The principal components analysis finds an important shared principal component in inflation around the world—but a striking divergence in how this global component has evolved over time for different inflation measures. Over the last 25 years the shared global component of CPI inflation has more than doubled (from 27% in 1990-94 to almost 57% in 2015-17), but for core inflation it has fallen (from about 43% to 26% over the same periods). This would be consistent with global factors playing a more important role for CPI inflation over time, while having less impact on core inflation, although there are other possible explanations and this framework does not provide any information on what is driving these patterns.

Next, to better understand this divergence and the changes over time in this global component of inflation, the next section of the paper shifts to using the most common approach for analyzing inflation—a Phillips curve model. It augments a standard model (which includes lagged inflation, inflation expectations, and the domestic output gap) with a set of global factors: exchange rates, the world output gap, oil prices, commodity prices, and a measure of global producer price dispersion. When the model is estimated for a cross-section of countries from 1990 to 2017, all of the domestic and global variables have the expected sign and are significant. Results when the model is estimated for individual countries are more varied, and the significance of different coefficients fluctuates, although global variables are significant in just over half of the individual country regressions.

Moreover, when the same model is estimated using rolling regressions over eight-year windows, it is clear that the role of many of these factors, and especially the global factors, has changed significantly over time. The patterns in the graphs of the rolling coefficients are supported by more formal regression analysis, which allows the impact of different variables to change over the last decade. More specifically, currency depreciations and higher oil prices are both significantly correlated with higher CPI and core inflation over the full period. Over the last decade, however, the world output gap and world commodity prices have had a significant (and positive) impact on CPI inflation, while producer price dispersion appears to have played a smaller role than before the global financial crisis (although the impact of producer price competition appears to be remerging at the end of the sample). The domestic variables traditionally believed to drive inflation are still important and significant, although there is some evidence that the relationship between the domestic output gap and core inflation has weakened. Overall, adding the global variables to Phillips curve models and allowing the coefficients to change over time can significantly improve the ability of these simple models to explain inflation.

Given the instability in the coefficient estimates, however, it is also useful to model inflation dynamics using a less structured approach. The last section of the paper shifts to an atheoretical framework that decomposes inflation into two components: a slow-moving trend and shorter-term cyclical movements. It uses the "ARSV" approach developed in Forbes, Kirkham and Theodoridis (2017), which is grounded in the unobserved component stochastic volatility model (UCSV) developed by Stock and Watson (2007), but allows the deviations in trend inflation to have an autoregressive component (as suggested in Chan, Koop, and Potter, 2013 and Cecchetti *et al*., 2017). This ARSV approach has previously been applied to the UK, but not the broader set of countries analyzed in this paper. The resulting estimates show substantial differences across countries in how much of their inflation volatility is driven by short-term cyclical movements relative to changes in their slower-moving trend. These estimates also suggest that underlying trend inflation is somewhat above 2% in some countries today (such as the UK), at 2% in other countries (such as the US), and well below 2% in many advanced economies (primarily members of the euro zone, but also Sweden, Switzerland and Japan).

The paper then attempts to explain these different patterns in the estimated cyclical and trend components of inflation in countries around the world, using the same domestic and global variables included in the earlier Phillips curve analysis. The results suggest that the standard domestic variables (inflation expectations and the domestic output gap) are significantly correlated with both the cyclical and trend components of inflation, as are some global variables, and the role of the global variables has changed more over time. More specifically, over the last decade increases in world commodity prices have had a greater impact on the cyclical component of inflation, and the world output gap may have had a greater impact on both the cyclical and trend components of inflation. Producer price dispersion has also affected both components of inflation. There is some evidence (albeit mixed) that the impact of domestic slack on trend core inflation has decreased over the last decade, especially for advanced economies outside the euro zone.

This series of results, obtained using very different approaches, yields a fairly consistent set of conclusions. Global factors can play a significant role in the inflation process. The role of these global factors appears to have increased over the last decade—especially for CPI inflation and the cyclical component of inflation—largely driven by a greater impact of changes in the world output gap and commodity prices. Global factors, and especially exchange rate movements (which are driven partly by domestic and partly by foreign factors), can also play an important role in driving core inflation and the trend component of inflation. The standard "Phillips curve" domestic variables—such as the domestic output gap and inflation expectations—are also consistently significant in these different inflation models, albeit with some evidence that the domestic output gap has been less correlated with inflation over the last decade—especially in advanced economies outside the euro zone. These results are consistent with the divergence in the estimated global principal components of different inflation series over time; global factors are playing a substantially greater role in driving inflation dynamics for CPI inflation, albeit with less change in their role explaining core inflation.

While these patterns apply across the sample of advanced economies and several emerging markets, it is important to note that the results vary when the models are estimated for individual countries. For some economies, global factors play a dominant role in explaining the variation in different inflation measures, while in other countries domestic variables are more important. Even in the countries for which the global variables are jointly significant, different global factors drive their joint significance. Controlling for changes in the global economy can significantly improve our understanding of inflation dynamics, but exactly what global measures are most important varies based on the country's characteristics and the period.

The remainder of the paper is as follows. Section II discusses key changes in the global economy and how they could affect inflation dynamics, including a brief survey of previous literature. Section III uses principal components to assess the shared global component of different inflation measures, including how the global components have evolved over time. Section IV uses a Phillips curve framework augmented with global variables to evaluate the factors driving inflation over the full sample period, over rolling regression windows, and then over the last decade relative to earlier years. Section V breaks inflation into a trend and cyclical component, studies the role of each in inflation dynamics in different countries, and then evaluates the role of the same set of domestic and global factors—both over the full period as well as in the last decade compared to earlier years. Section VI concludes.

II. Globalization and Inflation Dynamics: The Arguments and Previous Evidence

The academic literature modelling inflation—and the continual stream of proposals to improve on these frameworks to solve new puzzles—is lengthy.[1] At the core of most of these models, from the simplest Phillips curve equations to the most complicated DSGE models, is a central role for domestic slack, as well as domestic inflation expectations in the New Keynesian versions. Although many papers and frameworks have attempted to incorporate the rest of the world by adding a control for import prices (and in a few cases adding a control for global slack, or adjusting for import competition in firm markups), domestic variables remain central.[2] Global interactions play a minor, ancillary role—and in some simple models are completely ignored (albeit not in the more complicated DSGE models used by central banks, which include a fuller treatment of the international economy). A common justification is that any changes in the global economy should be captured in measures of domestic slack and import prices (if the latter is included), so that these variables are "sufficient statistics" to control for changes in

[1] For excellent overviews that capture the key issues, see Stock and Watson (2010), Gordon (2013), Ball and Mazumder (2015), Berganza *et al.*, (2016), Miles *et al.* (2017), and Blanchard (2018).

[2] Papers studying the role of globalization in inflation include: Ball (2006), Borio and Filardo (2007), Ihrig *et al.* (2010), Berganza *et al.* (2016), Mikolajun and Lodge (2016), Auer *et al.* (2016, 2017), and Borio (2017).

the global economy and adding any additional global factors is superfluous.[3] This secondary role for global effects and global interactions is surprising given the extensive literature on globalization and evidence of how increased integration through trade and capital flows has affected an array of economic variables.

There are, however, a range of channels by which globalization could be affecting inflation dynamics—channels which would not be captured in measures of domestic slack or import prices. This discussion (and paper) focuses on channels by which globalization may have affected the inflation process, and not just caused temporary shifts in the level of inflation for a period. For example, the paper does not focus on how the rapid growth in exports from low-wage economies affected the prices of manufactured goods during the 2000's after China entered the WTO. This can be interpreted as a supply shock that lowered inflation during this period, and has been analyzed in detail elsewhere.[4] Instead, the discussion below focuses on how globalization may have changed the relationships between key global factors and inflation. More specifically, it focuses on channels that roughly correspond to four changes in the global economy: increased global trade flows, increased role of emerging markets, increased use of supply chains, and reduced worker bargaining power. These changes in the global economy could influence several variables relevant to the inflation process: the roles of global slack, commodity markets, firm markups and domestic slack. Many of these changes in the global economy, and their effects on variables relevant to the inflation process, are closely related and interact in important ways.

The first of these changes in the global economy, increased trade around the world, is well documented. Total trade (imports plus exports) has increased notably, from about 39% of GDP in 1990 to 56% of GDP in 2016.[5] As the share of exports to GDP increases for a given economy, demand in global markets will likely have a greater impact on national income and on price setting by domestic firms. Similarly, as the share of imports to GDP increases for a given economy, domestic inflation will be more affected by the prices of imported goods simply due to their higher share in the price basket—and these imported goods prices will at least partially be determined by foreign demand conditions, foreign markups, and foreign marginal costs (assuming there is not complete pricing-to-market). Closely related,

[3] See Eickmeier and Pijnenbrug (2013) as an example of this line of reasoning.
[4] See Gamber and Hung (2001), Ball (2006), Auer and Fischer (2010), and Auer, Degen and Fischer (2013). Gamber and Hung (2001) also highlights that it is not just increased import penetration, but the combination of increased trade integration with global slack that is important.
[5] Data from World Bank, *World Development Indicators.* Includes trade in goods and services.

as the share of traded goods to GDP increases, a given exchange rate movement could have a larger impact on prices—both through the effect on the imported component of any domestic inflation index, as well as on exporters' competitiveness, margins and pricing decisions.

A second and even more striking change in the global economy since the early 1990's has been the increased role of emerging markets. In 1990, advanced economies produced about 64% of global GDP and emerging markets about 36%.[6] In 2018, this is expected to almost reverse—with advanced economies producing only about 40% of global GDP and emerging markets about 60%. Emerging markets have accounted for over 75% of global growth since the global financial crisis. Emerging markets have also been the key source of demand for commodities, with just the seven largest emerging markets accounting for almost all of the increase in the global consumption of metals and two-thirds of the increase for energy over the last 20 years.[7] As a result, global commodity prices have become more tightly linked to growth dynamics in emerging markets—particularly in China. This link has contributed to sharp swings in commodity prices—as highlighted in Miles *et al*. (2017)—potentially increasing the role of these types of commodity price shocks to movements in inflation around the world.[8] This increased volatility in commodity prices could explain a greater share of the variance in inflation due simply to the larger price movements, but if the effects of commodity price movements on inflation are nonlinear (and larger after larger price movements), the impact of a given change in commodity prices on inflation could also have increased.[9] This would occur, for example, in a sticky-price model in which firms are more likely to adjust prices after larger shocks (Ball and Mankiw, 1995). Working in the other direction, however, the reduced reliance of most advanced economies on natural resources as they shift to less commodity-intensive forms of production could lessen the impact of commodity price movements on inflation in these economies.

A third change in the global economy that could affect inflation dynamics is greater pricing competition and pressure on firm markups, resulting from the greater ease in purchasing final goods from their cheapest locations and/or using global supply chains to shift production to where it can be

[6] Based on data from the IMF's *World Economic Outlook* database (April 2018) and using IMF definitions for advanced and emerging economies. GDP measures are adjusted for purchasing power parity.
[7] See World Bank (2018) for a detailed discussion of the role of emerging markets in driving global commodity demand and corresponding price movements.
[8] Coibion and Gorodnichenko (2015) highlight another way this volatility in energy prices could affect inflation dynamics—through the sensitivity of household inflation expectations to changes in oil prices, and the role of household inflation expectations in setting firm inflation expectations.
[9] For a summary of evidence of these nonlinear effects, see Hamilton (2010).

done at the lowest cost. [10] This development is linked to the previous two—of the increased ability to trade across borders and greater role of emerging economies. For companies that export or compete with imports, decisions on markups must take greater account of prices from foreign competitors. Even holding trade flows constant, greater "contestability" from global markets reduces the pricing power of companies and lowers markups, especially in sectors with less differentiated goods (Grossman and Rossi-Hansberg, 2008, Burstein *et al.*, 2008, and Benigno and Faia, 2010).[11] As it becomes easier to shift activities abroad—even just small stages of the production process—domestic costs will be more closely aligned with foreign costs.[12] Auer, Levchenko and Sauré (2016) develop these arguments in detail, showing how global supply chains have increased the synchronization of producer prices across countries—roughly doubling the global component of the producer price index in their sample. A greater use of supply chains could also reduce the sensitivity of prices to exchange rate movements (*i.e.*, reduce exchange rate pass-through)—as more integrated supply chains that involve both importing and exporting can better allow firms to absorb exchange rate movements at various stages of production without adjusting final prices (Bank of International Settlements, 2015).

Finally, each of these changes in the global economy could simultaneously reduce the labor share and bargaining power of workers, dampening the key Phillips curve relationship between domestic slack and wage (and price) inflation.[13] More specifically, if there is some substitution between labor and energy costs as firms attempt to keep margins constant, the greater volatility in commodity prices could weaken the relationship between wage growth and slack (Bean, 2006). Increased imports from low-wage countries and competition in traded goods could make it more difficult for domestic firms to raise prices in response to tight labor markets and worker demands for higher pay (Auer, Degen and Fischer, 2013). The increased use of supply chains and ease of shifting parts of the production process to cheaper locations could further reduce the ability of domestic workers to bargain for higher wages (Auer, Borio and Filardo, 2017). Moreover, the increased mobility of workers (such as in the euro zone), or even just the possibility of increased immigration to fill any vacancies, could further reduce worker bargaining power. Although there are many other domestic developments which are also likely

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[10] Potentially counteracting some of these effects of increased global pricing competition, however, is the trend toward greater concentration in some markets, especially in the U.S. See Guilloux-Nefussi (2018) and Autor *et al.* (2017) for a discussion of how greater concentration may have increased firm pricing power.
[11] Also see Sbordone (2010), which models how greater trade competition reduces the sensitivity of inflation to real marginal costs of production, so that an increase in traded goods reduces the slope of the Phillips curve.
[12] Wei and Xie (2018) also focus on the role of increased global value chains and how "longer" supply chains are driving an increased wedge between CPI and PPI baskets.
[13] Karabarbounis and Neiman (2013) provide evidence on the decline in the labor share since the 1980s.

affecting wage growth and worker bargaining power (such as the increased role of flexible hour jobs in the "sharing economy" and greater employer concentration in some industries[14]), these multifaceted changes in the global economy could further weaken the link between domestic slack and inflation.

This range of channels through which globalization could be affecting firm pricing decisions suggests that a more complete treatment of global factors and changes in the world economy could improve our understanding of inflation dynamics. Simply controlling for domestic slack and import prices does not seem to be a "sufficient statistic" to capture these multifaceted ways in which the global economy affects price setting. For example, the price of foreign goods and ability to shift production through supply chains may affect pricing even if not incorporated in import prices, as foreign prices may act as a counterweight on domestic pricing decisions even if goods are not imported. Measures of existing slack in the domestic economy may not capture the expected evolution of slack in other major economies, expectations that could affect firm price setting and therefore inflation. The price of imported oil may fluctuate due to geopolitical events and provide little information about the changes in global demand or other input costs relevant for firm pricing decisions.

Several papers have drawn attention to the increased role of globalization and global factors in inflation dynamics, using one of two very different approaches.[15] One approach avoids taking a view on exactly how globalization is affecting inflation, and instead estimates a global common factor or principal component for inflation in a set of countries. Prominent examples of this approach include: Cecchetti *et al.*, (2007), Hakkio (2009), Monacelli and Sala (2009), Ciccarelli and Mojon (2010), and Neely and Rapach (2011). These papers generally find a significant common global factor in inflation, but mixed evidence on whether the role of the global factor has increased over time. The major shortcoming of this approach, however, is that it does not identify what drives this common component in inflation across countries. For example, it could reflect a greater role common shocks (such as from more volatile or larger commodity price movements), a greater role of global slack on price setting, or more similar reaction functions in central banks. Each of these influences would have different implications for forecasting inflation and inflation models.

The other approach for more explicitly incorporating globalization in inflation dynamics is to add a variable to standard inflation models to capture a specific aspect of globalization. For example, Borio

[14] For evidence on the role of increased employer bargaining power on wage growth, see Benmelech, Bergman and Kim (2017) and Azar, Marinescu, Steinbaum and Taska (2017).
[15] Also see Jordan (2015), which discusses how globalization has affected inflation in Switzerland.

and Filardo (2007) suggests adding global slack to a Phillips curve model, and finds that global slack has had a greater effect on inflation over time—even supplementing the role of domestic slack in some economies.[16] Other papers, however, find that global slack does not significantly affect inflation in most economies.[17] Some papers, usually using industry data, have suggested a more explicit focus on supply chains (such as Auer *et al*., 2016, and Auer *et al*., 2017). Analyses of UK inflation have suggested incorporating controls for the exchange rate and commodity prices, which are significant in a Phillips curve framework (Forbes, 2015) as well as in a trend-cycle model (Forbes *et al*., 2017). Mikolajun and Lodge (2016) is the most comprehensive study of the role of globalization in inflation dynamics to date and its Phillips curve framework is similar to Section IV of this paper. Mikolajun and Lodge (2016), however, does not use other modelling approaches (such as the trend-cycle decomposition) and does not control for global producer price dispersion to capture the increased role of supply chains.[18]

Rather than focusing on one specific channel by which globalization could affect inflation dynamics, or one framework, this paper takes a more comprehensive approach. It borrows from three methodologies to assess the different effects of globalization on inflation dynamics: principal components, a Phillips curve model, and trend-cycle decomposition. It uses each framework to assess the role of global factors, as well as if that role has changed in the last decade. While this approach is intended to be broad, it is not inclusive and does not address a number of issues that could be influencing inflation dynamics—such as the increased commoditization of many goods (reducing firm pricing power), the challenges in measuring slack, and changes in the anchoring of inflation expectations. These topics are important, but have received prominent attention elsewhere. The analysis in this paper also focuses on the dynamics of CPI and core inflation, as comparable cross-country, time-series data on other inflation measures (such as wages) is more limited.

III. First Look: The Global Principal Component of inflation

As an initial look at the role of global factors on inflation dynamics around the world, this section estimates the shared global principal component in inflation. How important is this global component to movements in countries' inflation rates? Has the role of this global component changed over time?

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[16] International Monetary Fund (2016) finds similar evidence.
[17] See Ihrig *et al*. (2010), Eickmeier and Pijnenburg (2013) and Mikolajun and Lodge (2016). Bianchi and Civelli (2015) use a VAR to show that globalization increases the impact of global slack on inflation.
[18] Mikolajun and Lodge (2016) incorporates a "global inflation" variable, however, which may capture the effects of global producer price dispersion, although it may also capture the role of other variables, such as global slack.

I focus on five different measures of inflation: CPI inflation, core inflation (CPI inflation excluding food and energy prices), producer price inflation (PPI), service CPI inflation (services), and private sector hourly earnings inflation (wages). The original price indices for each series are from the OECD and IMF for as many countries as available from 1990 through 2017, with more information in Appendix A. Each inflation index is measured on a quarterly basis, annualized and seasonally adjusted.[19] There are (at most) 43 countries in the sample for each series, listed in Appendix B and divided into advanced economies and emerging markets based on IMF definitions. Data is more limited for some price series—especially for wage inflation and early in time—so parts of the analysis in the remainder of the paper will focus on restricted samples that are more consistent as needed for the relevant analysis.

Figure 1 reports the first and top five principal components for each inflation measure, for the full sample and then broken into advanced and emerging economies. To ensure that differences across inflation measures are not driven by sample changes, the second section of the table repeats the estimates for the smaller sample for which wage data is available. The estimates suggest that there is a noteworthy shared global component in CPI inflation. More specifically, 40% of the total variance in CPI inflation for all countries in the sample is explained by a single, common principal component. About 67% of the total variance in CPI inflation can be explained by just 5 common components. Less of the inflation variation in emerging markets can be explained by this common principal component—for which only 25% of the total variance in CPI inflation is explained by a single component (and the 76% explained by five components results from the small number of emerging markets in the sample).

The role of this shared principal component, however, varies across different inflation measures. This global component explains the greatest share of the variation in inflation for the PPI—for which 52% of the variance is explained by the first principal component. The global component is weakest for core and wage inflation—where the first principal component explains only about 21-23% of the variation in inflation. (This smaller role of the principal component for wages is also not explained by the different composition of the sample with data for wage inflation.) The greater role for a shared global component in CPI and PPI inflation may reflect a greater role for global factors, while the smaller role of this shared component in wages and core inflation may reflect a greater role for domestic factors.

[19] Seasonal adjustment is performed with the X-13ARIMA-SEATS program available at: https://www.census.gov/srd/www/x13as/. Data is also adjusted for well-known VAT increases that caused a one-quarter spike in inflation. The final inflation series is winsorized at the 0.1% level for each tail to remove several periods of extreme inflation (largely in emerging markets).

The statistics in Figure 1 report averages over the full sample from 1990 through 2017, but as discussed above, there have been significant changes in the global economy (as well as within countries) that could affect inflation dynamics. To test if the role of this shared global component in inflation has changed over time, Figure 2 graphs the first principal component for each inflation measure over 5-year windows since 1990. The graph only includes advanced economies in order to have a more stable sample (as most emerging markets only have data for the later years). The figure shows divergent trends in the shared principal component for different inflation series. The shared global component of CPI inflation has increased sharply over the sample period—more than doubling from 27% in the 1990-94 window to 57% in the 2015-2017 window. In contrast, the shared global component of core inflation has steadily fallen, from 43% at the start of the sample to 26% at the end. The shared component of service inflation has fallen even more sharply—but the data in the earlier window is more limited and may not indicate a widely shared trend. The global component of the PPI has been large and relatively stable over the full period—suggesting a tight link between producer prices in countries around the world from 1990 through today.

One challenge with this type of principal component analysis is that it does not provide any information on what is driving these different patterns across time and across inflation measures. For example, an increase in the fraction of the variation explained by a common component could be explained by very different changes in the global economy—such as larger common global shocks (*i.e.*, greater volatility in commodity prices), a greater sensitivity of countries to common global shocks (*i.e.*, due to greater exposure to global demand through trade), or tighter direct linkages between economies (*i.e.*, through greater reliance on global supply chains). An increase in the role of the first principal component, however, could also be explained by factors that are not typically included as "globalization", such as more central banks following inflation targeting and sharing more common reaction functions to inflation movements.

Nonetheless, even though principal component analysis cannot evaluate how changes in the global economy have affected inflation dynamics, the patterns from this analysis do suggest several empirical regularities that more formal analysis could hopefully help explain. Why has the common, global component of CPI inflation increased sharply since the 1990s? Why is the common global component significantly lower, and decreasing, for core inflation? What aspects of globalization could be driving these trends?

IV. The Role of Globalization: Phillips Curve Framework

A. *The Framework and Variables*

To better understand what is driving these different patterns, this section begins with the most commonly used (albeit also the most often criticized) framework for analyzing inflation dynamics: the Phillips curve. It focuses on a variant of the Phillips curve that incorporates not only domestic slack, but also standard extensions to the framework that have been widely incorporated over time, as well as a more comprehensive set of global variables (for the reasons discussed above). This hybrid baseline model incorporates the role of inflation expectations and forward-looking behavior from the New Keynesian Phillips curve, as well as a role for inertia and supply shocks from the "triangle" model developed in Gordon (2007).[20] More specifically, the baseline specification is:

$$\pi_{it} = \beta_1 \pi_{it}^{e} + \beta_2 \pi_{it}^{L} + \beta_3 GAP_{it}^{D} + \gamma_1 ER_{it} + \gamma_2 GAP_{t}^{F} + \gamma_3 Oil_{it}^{W} + \gamma_4 Comm_{it}^{W} + \gamma_5 PPIDis_{t}^{W} + \alpha_i + \epsilon_{it} \qquad (1)$$

for each country *i* in quarter *t.* Definitions for each variable are:

- π_{it} is the relevant measure of quarterly inflation (CPI or core), annualized and seasonally adjusted and described in more detail in the last section;
- π_{it}^{e} is inflation expectations, measured by the five-year ahead forecast for CPI inflation from the IMF's *World Economic Outlook;*
- π_{it}^{L} is lagged inflation, measured as the relevant inflation measure (CPI or core) over the previous four quarters (before quarter *t*);
- GAP_{it}^{D} is the domestic output gap, measured as a principal component of seven variables: the output gap, participation gap, and unemployment gap, and the percent deviation of hours worked, share of self-employed, share of involuntary part-time employed, and share of temporary employment from the relevant average over the sample period. (See discussion below for details.)

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[20] Although some papers choose to control for just inflation expectations, or just lagged inflation, or use lagged inflation as a proxy for inflation expectations, controlling for both measures is becoming more widely used, such as in Berganza *et al.* (2016), Blanchard *et al.* (2015), International Monetary Fund (2013), and Mikolajun and Lodge (2016). Albuquerque and Baumann (2017) derive a model showing the importance of controlling for lagged inflation and inflation expectations simultaneously if some firms are forward-looking and set prices to maximize profits, while others are backward-looking and set prices according to past values.

- ER_{it} is the percent change in the trade-weighted, real effective exchange rate index based on consumer prices (from the IMF) relative to two years earlier[21];
- GAP_t^F is the foreign output gap, measured as the output gap for all OECD economies and reported by the OECD;
- Oil_{it}^W is quarterly inflation (annualized) in an index of world oil prices (from Datastream) relative to the relevant measure of quarterly price inflation (either CPI or core) and lagged one quarter;
- $Comm_{it}^W$ is quarterly inflation (annualized) in an index of world commodity prices, excluding fuel (from Datastream) relative to the relevant measure of quarterly price inflation (either CPI or core) and lagged one quarter;
- $PPIDis_t^W$ is a measure of world producer price dispersion, measured as the change in the quarterly variance in PPI prices relative to four quarters earlier for all countries in the sample for which data is available (listed in Appendix B).[22]

Appendix A provides more detailed definitions and sources for each of these variables, and sensitivity tests in Section IV. D. examines the robustness to using different measures for key variables. The first three control variables (with coefficients denoted with a *β)* will be referred to as the "domestic" variables, and the last five, (with coefficients denoted with a *γ*) as the "global" variables. Although the real exchange rate captures both domestic and global influences, it is usually not explicitly included in Phillips curve regressions (only implicitly when a control for import prices in foreign currency is added), and therefore better fits with the "global" variables that are not traditionally part of this framework.

Most of these variables are straightforward and/or measured using the standard conventions in this literature. The one exception is the measure of the "output gap" or "slack". Papers such as Albuquerque and Baumann (2017) and Hong *et al.* (2018) have convincingly demonstrated the importance of measuring slack more broadly than simply the deviation of unemployment from a hard-to-estimate NAIRU. This unemployment gap may not capture the "discouraged workers" who are no longer recorded as looking for work, or may not capture people who are working part-time, fewer hours, or self-employed, but would prefer to be working full-time and/or more hours at a company. Data on these other aspects of slack, however, are not widely available on a comparable basis across

[21] The percent change in the exchange rate is relative to two years earlier (instead of one year for other variables) in order to allow for the longer lags by which exchange rate movements pass-through to prices.

[22] Measured relative to four quarters earlier to avoid any seasonal issues. This measure draws from the results in Auer, Levchenko and Sauré (2016) and Wei and Xie (2018), which show how global supply chains have affected PPI indices and increased the synchronization of producer prices across countries.

countries. Therefore, I follow the approach suggested by Albuquerque and Baumann (2017) for the United States and estimate a principal component of labor market slack, building on the set of cross-country variables suggested in Hong *et al.* (2018). More specifically, I calculate the principal component using seven measures of slack. The first three are from the OECD: the output gap, unemployment gap, and participation gap. I also include a calculated percent "gap" from the "normal" level (with "normal" defined as the relevant mean for each country over the sample period) for four measures: hours worked per person employed, the share of involuntary part-time workers, the share of temporary workers, and the share of self-employed workers (with the last three as a share of total employed).[23] Many of these variables are not available for all countries in the sample, in which case I calculate the principal component using as many as are available for each country.

B. Fixed Coefficient Estimates

Columns 1 and 2 of Figure 3 report estimates of the Phillips curve model in equation (1) for both CPI and core inflation, respectively, using random-effects with standard errors clustered by country over the full sample period from 1990-2017. All of the coefficients have the expected sign and almost all are significant at the 5% level. (The only exception is the dispersion in PPI prices for core inflation.) This suggests that in a cross-section of countries, the basic concepts of the Phillips curve framework appear to be intact.[24] More specifically, higher inflation expectations, higher lagged inflation, and a more positive domestic output gap, are all correlated with higher inflation. The significance of the global variables, however, also suggests that augmenting the standard Phillips curve framework with more comprehensive controls for global factors is appropriate. More specifically, a larger exchange rate depreciation, a more positive world output gap, and higher oil and commodity (ex. fuel) prices are all significantly correlated with higher CPI and core inflation. A greater dispersion in global producer prices is also correlated with significantly higher CPI inflation.

The magnitudes of the coefficients from these pooled regressions also provide a sense of which variables have a more meaningful impact on inflation. For example, the 0.670 coefficient on inflation expectations implies that a 1 percentage point increase in five-year ahead inflation expectations (*i.e.*,

[23] The data on hours is from the OECD. The other measures (involuntary workers, temporary workers, and self-employed) were all kindly shared by Hong *et al.* (2018). Many of these measures are only available on an annual basis and are therefore interpolated to quarterly to calculate the principal component measuring slack.

[24] The between-R^2s are generally much higher than the within--R^2s, although both are high for this type of cross-country regression, indicating that the model has a higher degree of explanatory power when capturing differences across countries than within countries. For example, for CPI inflation, the within-R^2 is 0.43 and the between-R^2 is 0.98.

from 2% to 3%) is correlated with an increase in CPI annual inflation of 0.67 percentage points. An improvement in the domestic output gap of 1 percentage point[25], however, would only increase CPI inflation by 0.09 percentage points. The impact of a 1 percentage point improvement in the global output gap is only slightly smaller (at 0.07). A 10% depreciation of the real exchange rate over the last two years corresponds to an increase in CPI inflation of 0.2 percentage points on average. The coefficient for oil and commodity prices is larger for CPI inflation than core inflation (as expected).

These estimates, however, are pooled across a diverse set of countries, and the relationship between these different variables and inflation varies across economies. For example, some countries may be more exposed to global demand, and therefore more affected by changes in the global output gap, while other economies may be much larger or more closed and less affected by exchange rate movements. The general significance of the coefficients may mask strong effects in some countries, combined with a poor fit for the Phillips curve framework and/or global variables in the majority of the sample. To test this, columns 1 and 2 at the top of Appendix C report results when the Phillips curve model from Figure 3 is repeated individually for each country. The table summarizes the percent of countries for which the relevant variable (from equation 1) is significant at the 10% level with the expected sign (positive for all variables except the real exchange rate). These results suggest that the Phillips curve framework has more moderate success in explaining inflation in individual countries. Inflation expectations are positively correlated with inflation in about half the sample, and lagged inflation is the variable most often significant (for 59% and 84% of the countries for CPI and core inflation, respectively), suggesting a high degree of persistence in the inflation process (which will be explored in the next section). The domestic output gap is only positive and significant in 38% of the countries for both inflation measures. Moving to the global variables, the real exchange rate is significant in about one-third of the countries for CPI inflation, the world output gap and commodity prices in 28%, and oil prices in 22% of the sample. Patterns are similar, although the global variables are less often significant for the regressions with core inflation, particularly for oil prices, commodity prices, and global PPI dispersion, which are significant about half as often for core as CPI inflation.

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[25] The magnitude is not straightforward to assess as the output gap is calculated as a principal component with different weights on different measures of slack for different countries. A simple interpretation is for a country that only has information for the output gap and unemployment gap (difference between the NAIRU and unemployment rate) in the calculation of the principal component. In this case, the 1 percentage point would correspond to a one percentage point change in both the output gap and unemployment gap. If only one of these variables is available, it would only correspond to the same change in that one variable. All variables are expressed such that an increase is a reduction in slack.

Also noteworthy is that for most individual countries, one to three of the relevant variables in equation (1) are significant with the expected sign—but rarely are all variables significant. For example, consider the estimates for CPI inflation for two different European nations: Germany and Iceland. For Germany, inflation expectations, lagged inflation and the world output gap are positively and significantly correlated with CPI inflation, but the coefficients on domestic slack and the other variables are not significant (all at the 10% level). In contrast, for Iceland domestic slack, world oil prices, and the exchange rate are all significantly correlated with CPI inflation (with the expected signs), with no significant role for global slack nor the other variables. The results for the pooled regressions mask these significant differences in the inflation process for different countries. This could also explain why different studies have found opposing results on the roles for key variables (such as for global slack); the composition of countries in the sample can significantly affect results. Also noteworthy are the statistics in the last row of Appendix C, which show that at least one of the global variables is significant in about half the sample for regressions predicting CPI inflation, and 34% for core. This confirms that the global factors can play an important role in explaining inflation dynamics in individual countries, although not for all.

C. Changes in Coefficients over Time

The role of different variables in the Phillips curve framework could vary not only across countries, but also over time.[26] This could occur due to the changes in the global economy discussed in Section II, as well as due to many other factors—such as changes in domestic labor markets or the credibility of central banks. In order to adjust for this potential instability in the coefficients, I restimate the Phillips curve model from equation (1), except instead of holding coefficients fixed over the full sample, estimate rolling regressions over eight-year windows (with the regression window rolled forward one quarter at a time so that the number of observations remains constant across specifications).[27] These rolling estimates confirm the findings of past work; in many cases the coefficients on variables in the Phillips curve relationship change over time. This is true in the pooled sample that includes all the countries for which data is available, and even more dramatically in some (but not all) the individual country results.

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[26] For evidence on changes in coefficients on specific variables over time, see Albuquerque and Baumann (2017), Berganza *et al.* (2016), Blanchard, Cerutti and Summers (2015), IMF (2016), and Mikolajun and Lodge (2016).
[27] I focus on time-varying coefficients in rolling regressions, rather than using Kalman-filter based models with time-varying coefficients or specifically modelling any nonlinearity, due to the evidence in Albuquerque and Baumann (2017) that this yields the lowest RMSE.

For example, Figure 4 shows the coefficient estimates for the global variables and domestic slack from the rolling regressions predicting CPI inflation (part a) and core inflation (part b). The blue, solid lines are the mean coefficients, and the dashed red lines show the estimates at the 25th and 75th percentile of the distribution. Some of the coefficient estimates move sharply over the last 20 years. For example, focusing on the estimates for CPI inflation, the coefficient on the exchange rate is negative at the start and end of the sample, as expected, but positive around the global financial crisis—indicating weaker pass-through from exchange rate movements to inflation over this period (which could occur if exchange rate depreciations were driven largely by demand shocks).[28] The coefficient on global commodity prices shows a fairly steady upward trend—and has a scale four times larger than for oil prices, suggesting a larger role for commodity price movements on inflation, especially in the later decade. The coefficient on world PPI dispersion is large during the early 2000's, falls during and after the crisis, and has recently increased—suggesting that the impact of producer price pressures has shifted meaningfully over the last 20 years.

Patterns for the domestic and world output gaps are particularly noteworthy. The coefficient on the world output gap is negative for some of the earlier years in the sample, and then gradually increases so that it is consistently larger and more positive in the years after the global financial crisis (albeit falling back briefly in the second half of 2016). In contrast, the coefficient on the domestic output gap is positive in the period just before the global financial crisis (as expected in standard Phillips curve models), before falling sharply around the crisis and remaining negative from 2010 through most of the period since, albeit picking up to become positive again in 2017.

The graphs for core inflation (panel b) also show some variation in the coefficient estimates over time, but the y-axis on many of these graphs is smaller—and often half that of the corresponding graph for CPI inflation—suggesting more muted changes in these coefficients. The coefficient on commodity prices no longer increases steadily over time (as for CPI inflation), but the coefficient on oil prices does increase. Most noteworthy are the coefficients on the two output gap variables. The coefficient on the world output gap is consistently positive after the crisis, and higher than most of the earlier period (except in 2003). In contrast, the coefficient on the domestic output gap falls during the crisis and has remained close to zero since 2010. This is consistent with the graphs for CPI inflation suggesting a

[28] See Forbes, Hjortsoe and Nenova (2015 and 2017).

stronger relationship between the world output gap and inflation, and weaker relationship between the domestic output gap and inflation, in roughly the last ten years.

Given the instability in these various parameter estimates, it is useful to more formally test if these coefficient changes imply a more important role for global variables (and less important role for domestic slack) in inflation dynamics over time. As a baseline, columns 3 and 4 of Figure 3 test if the coefficients have changed significantly in the last decade relative to the earlier part of the sample by adding an interaction term between each of the eight variables and a dummy equal to one for the years 2007 through 2017.[29] These results for the pooled sample indicate that the role of several variables has changed significantly in the last decade. More specifically, focusing first on the results for CPI inflation in column 3, the global output gap and world commodity prices are insignificant for the earlier period, but positive and significant for the last decade (supporting the results in the rolling coefficient graphs). The impact of world PPI dispersion is significant in the first part of the sample, and not only falls by a significant amount in the last decade, but becomes negative (also consistent with the patterns seen in the rolling graphs). A χ^2 test (reported at the bottom of the table) rejects the hypothesis that the coefficients on the five global variables are the same in the pre-crisis window relative to the last decade.

In contrast to these results for CPI inflation, the relationship between the global variables and core inflation has changed less over the last decade. The real exchange rate and oil prices continue to be significantly correlated with core inflation over the full sample period, but variables such as global slack and world commodity prices are no longer significant for the earlier part of the period, nor has their role significantly increased in the last decade (as with CPI inflation). The χ^2 test cannot reject the hypothesis that the coefficients on the five global variables are the same in the pre-crisis window relative to the last decade for core inflation. Domestic slack, however, is significantly less correlated with core inflation in the last decade (as is lagged inflation), while inflation expectations are significantly more correlated. These pooled results suggest that although global variables have had a significantly greater impact on CPI inflation over the last decade, they may not have had a larger role in explaining core inflation dynamics—unless they have contributed to the reduced influence of domestic slack.

As discussed above, however, these pooled results can aggregate very different relationships across countries. Therefore, columns (3) and (4) of Appendix C summarize results when the same global

[29] I focus on the window 2007q1 through the most recent quarter available for each country (which is in 2016 or 2017 for most of the sample). These periods are chosen so that the later period corresponds to that in the trend-cycle analysis in the next section.

Phillips curve model from columns (3) and (4) of Figure 3 is estimated for each country separately, with additional rows at the bottom summarizing whether coefficients have changed significantly in the most recent decade in either direction. The results again indicate the diversity of relationships across countries, but a few patterns are noteworthy. In the earlier period, few of the global variables are significant—except the real exchange rate, which is significant for 35% of the countries for CPI inflation (comparable to estimates for the domestic output gap and inflation expectations). Perhaps more interesting is which coefficients have changed significantly over the last decade. The global coefficient that is most often significantly different in the last decade is for the world output gap—which has a significantly larger positive coefficient in 19% (23%) of the countries for CPI (core) inflation. In contrast, the coefficient on the domestic output gap is significantly negative in a similar share of countries (13%-26%). The test results near the bottom of the table suggest that the impact of the global variables on CPI (core) inflation is significantly different in the last decade in 32% (26%) of the countries. This does not suggest, however, that the global variables are not widely significant; instead, the last row indicates that at least one of the global variables is significant in just over half of the individual country regressions (for both inflation measures). Therefore, global factors can be important—although exactly which ones are significant varies widely across countries.

To better assess if including these global variables in simple Phillips curve models and allowing their impact to vary over time can meaningfully improve our understanding of inflation dynamics, Figure 5 performs a final set of tests. It returns to the rolling regression estimates of equation (1), but now estimates two variants of the model: with the full set of domestic and global variables (as in Figure 4), and then with just the domestic variables ($\pi_{it}^{e}, \pi_{it}^{L}, GAP_{it}^{D}$). Figure 5a graphs the average of the absolute value of the deviation of actual inflation from predicted inflation (using these rolling coefficients) in each quarter. The graphs for CPI and core inflation show the superior performance of the model including both the global and domestic variables (in red) to that with just the domestic variables (in black). Moreover, the graphs also show less difference in the two models' predictions in the earlier part of the sample, but a more notable improvement for the model incorporating the global variables from 2013-2017 for both inflation measures.

Figure 5b attempts to quantify this improvement in the model's performance when the global variables are included, especially in recent years. It reports the absolute value of the deviation of predicted relative to actual inflation for the same two models, as well as the same deviation for a third model that includes the domestic variables plus changes in oil prices (the most common addition to

Phillips curve models). Over the full period, the average deviation of actual CPI inflation from predicted inflation is 0.77 for the model with just domestic variables, 0.73 for the model with domestic variables plus oil prices, and 0.50 for the model that includes the full set of global (and domestic) variables. For core inflation, the same deviation for the model with just the domestic variables (with or without oil prices) is almost twice as large (at 0.42) as that when the global variables are included (0.24). Also noteworthy is the breakdown at the bottom of Figure 6b for the same calculations over different periods. Including the global variables only leads to a moderate reduction in the errors in the first decade of the sample (of roughly 1/3), and a more meaningful reduction from 2012 through 2017 (of over one-half) for both CPI and core inflation. The improved performance of the model including the global variables is not driven by the period of the global financial crisis in 2008-2009, and the global variables add substantially more explanatory power to the model for core inflation in the early 2000's—around the time that China entered the WTO and many of the changes in the global economy discussed in Section II accelerated. Although these comparisons are not formal tests of the different channels by which globalization may have affected the inflation process, they do show that global variables have become more important to understanding inflation dynamics over time.

D. Sensitivity Analysis

The baseline results throughout this section required making a number of choices about specification, variable definitions, and timing conventions. Therefore, as a final analysis based on the Phillips curve framework, this section summarizes a series of sensitivity tests—focusing on the pooled results testing if the relationship between key variables and inflation has changed over time (in Figure 3, columns 3 and 4). More specifically, this section discusses four sets of sensitivity tests: (1) different variable definitions; (2) different time periods and treatment of crisis periods; (3) different country samples; and (4) different specifications. A selection of the results, including any that vary meaningfully from the baseline (repeated in column 1), is reported in Figure 6.

First, I use several different variable definitions. Several papers have highlighted the challenges in measuring the output gap (or slack),[30] so instead of using a principal component which captures broader measures of slack (such as in hours worked and participation), I instead use the standard measures of the output gap (column 2) or unemployment gap. Then I estimate the model using one control for commodity prices (an all-commodity index), instead of controlling separately for oil prices as

[30] See Albuquerque and Baumann (2017), Hong *et al.* (2018), and discussion in Section IV.A.

well as commodity (excluding fuel) prices. Next, I estimate a model that interacts the world output gap with exports/GDP for each country. In most of these cases, the key results are unchanged. The only exception is when the output gap is measured using the unemployment gap, in which case the coefficient on the domestic output gap becomes insignificant, supporting previous work that the unemployment gap is a less accurate measure of overall slack.

Second, since the analysis in this paper has highlighted how the relationship between inflation and different variables can change over time, I estimate several extensions to explore how the results change over different periods, paying particular attention to the role of the global financial crisis and euro crisis. I begin by estimating the pooled regression for only the last decade (column 3), thereby excluding the pre-crisis years. Then I use the full sample period, but exclude the period of the global financial crisis and euro crisis (2008-2014), so that the "post" period is only the three years from 2015-2017 (column 4). Next, I add dummy variables for the crisis years, and then I include the global financial crisis in the earlier period, and define the "post" period as 2013-2017 (column 5). Although most of the results highlighted above persist, a number of variables become significant under these different timing conventions—especially the coefficients testing if the relationship between several global variables and inflation have changed over time. For example, when the regressions just focus on the most recent periods (such as entirely dropping the pre-crisis window, only including the last five years as the "post" period, or dropping the global and euro crises so that only the last three years are the "post" period), then the world output gap is positively and significantly correlated with CPI inflation (albeit usually not with core inflation) in the "post" period. Producer price dispersion also plays a stronger role in the most recent years (and a weaker role during the crisis)—as also found in the rolling regressions. The impact of oil and commodity prices also varies based on the exact years included and period definitions—with greater effects during the windows of larger commodity prices swings. Taken as a whole, this series of extensions supports the results in the rolling regressions—that the impact of different variables on inflation can vary meaningfully over time.

Third, I test for the impact of different country selection. Given the larger movements in inflation (and several other variables) in emerging markets, I exclude emerging markets from the sample (column 6). The key results are unchanged. Next, to better focus on advanced economies with their own currencies and independent central banks, I repeat the analysis except only include advanced economies that have their own currencies (thereby excluding all countries currently in the euro area). This excludes a large fraction of the sample. The results (column 7) now suggest a significant weakening in the relationship between the domestic output gap and both CPI and core inflation in the later period, as well as a significant positive relationship between the world output gap and both inflation measures in the later period. This is consistent with a significant weakening in this key “Phillips curve” relationship over the last decade for advanced economies outside the euro area, which may be partially replaced by a stronger relationship between inflation and the global output gap.

As a final set of sensitivity tests, I use different specifications and combinations of the key variables. For example, I just add a control for one global variable at a time to the standard domestic variables, or only include smaller subsets of these global variables (instead of all five simultaneously). The key results are generally unchanged, although if only one of the world output gap or world commodity prices is included (but not the other), this variable is more often significant—possibly indicating that these two variables are capturing a similar phenomenon (as a more negative world output gap often translates into lower commodity prices). I have also experimented with different lag structures, and timing conventions for the variables calculated as changes (such as measuring the percent change in the real exchange rate relative to one year ago instead of two years ago). These modifications can affect the coefficient estimates for the variables which have been modified (such as reducing the significance of the exchange rate variable when assessed over shorter windows), but does not change the other key results.

This series of sensitivity test highlights the challenges in modelling inflation dynamics – the role of different variables can change significantly over time. With that important caveat, there are several patterns that emerge in these pooled cross-country results. The standard Phillips curve variables—of domestic slack and inflation expectations—still play a significant role in explaining inflation dynamics, although the role of domestic slack seems to have decreased over the last decade, especially for advanced economies outside the euro area. Global variables also play a meaningful role, and their role seems to have increased significantly over the last decade, especially for CPI inflation. More specifically, the world output gap and/or world commodity prices have had a stronger relationship with CPI inflation recently. There is also evidence that producer pricing competition (and supply chains) had a greater impact on inflation before the global financial crisis, and over the last three years, but less so around the periods of the global and euro crises. The tests statistics at the bottom of Figure 6 show that the global variables are jointly significant in all of the regressions predicting CPI and core inflation, and have changed significantly over the last decade for all of the specifications for CPI inflation, but have not changed significantly for most of the specifications for core inflation.

E. Phillips Curve Analysis: Summary

To summarize, this section has found that the Phillips curve framework suggesting a positive effect of the domestic output gap and inflation expectations on inflation still "works", but is missing something: controls for global factors and changes in the global economy. Global variables incorporated in the standard Phillips curve framework are usually significantly correlated with inflation in pooled regressions, as well as in over half the countries when analyzed individually. Including these global variables and allowing key parameters to change over time significantly improves the ability of simple models to explain inflation dynamics. Changes in the global economy have had the greatest impact on the dynamics of CPI inflation over the last decade—largely due to a greater role of global slack and global commodity prices. The role of the global factors has changed less in specifications predicting core inflation, but these factors are still usually jointly significant and their inclusion can still meaningfully reduce errors in models predicting both CPI and core inflation. There is also some evidence that domestic slack has had less impact on inflation in the last decade, especially for core inflation and advanced economies outside the euro zone. Exactly which global and domestic factors are important, and how their role has changed over time, however, varies meaningfully across individual countries.

V. The Role of Globalization: Trend-Cycle Framework

Although frameworks based on the Phillips curve are useful for understanding key relationships affecting inflation, the instability in the parameters of these relationships—as shown using several different approaches above—limit their ability to explain inflation dynamics in real time and to forecast inflation. Other frameworks can be a useful compliment. One such framework is a "trend-cycle" approach, which separates inflation into a slow-moving, persistent trend and a more temporary cyclical component. This section uses this approach to calculate the trend and cyclical components of CPI and core inflation in each country, and then evaluates if the standard Phillips curve variables and global factors used in the last section are correlated with these two components of inflation. The section ends by assessing if the key global drivers of cyclical and trend inflation have changed over time.

A. The Trend-Cycle Model

Although the majority of work analyzing and forecasting inflation has focused on structural relationships grounded in the Phillips curve framework, Stock and Watson (2007) provides an alternative, data-driven and more atheoretical approach. It proposes focusing on the time-series dynamics of price levels to isolate a low frequency and slow-moving component of inflation (the `trend') from deviations around this trend (what I will call the 'cycle'). Stock and Watson (2007) develops this framework in an unobserved component stochastic volatility (UCSV) model, which inspired a series of papers using and building on this approach. Most of these papers have focused on understanding inflation dynamics in the U.S. (such as Clark and Doh, 2011, Stock and Watson, 2010, Chan, Koop and Potter, 2013, Chan, Clark and Koop, 2015, and Cecchetti *et al.*, 2017),[31] while Cecchetti *et al.* (2007) applies the UCSV model to the G-7 countries, and Forbes *et al*. (2017) builds on these models to analyze inflation dynamics in the U.K.

This section takes the trend-cycle model developed in Forbes *et al.* (2017) and applies it to the larger sample of developed and emerging markets used throughout this paper.[32] This model is grounded in the UCSV model developed by Stock and Watson (2007), but also allows deviations in trend inflation to follow an autoregressive process.[33] This more complicated formulation can make it more difficult to achieve convergence in the estimates of trend inflation, but better captures the inflation dynamics in this paper's more diverse sample of countries (as compared to the US example for which the original UCSV model was developed). More specifically, and following Forbes *et al.* (2017), assume that inflation π_t (either CPI or core) can be expressed as:

$$\pi_t - \tau_t = \varphi(\pi_{t-1} - \tau_{t-1}) + \eta_t, \text{ where } \eta_t = \sigma_{\eta t}\zeta_{\eta t} \quad (2)$$

$$\tau_t = \tau_{t-1} + \varepsilon_t, \text{ where } \varepsilon_t = \sigma_{\varepsilon t}\zeta_{\varepsilon t}, \text{ and} \quad (3)$$

$$\zeta_{\eta t}, \zeta_{\varepsilon t} \sim N(0,1). \quad (4)$$

In other words, inflation can be expressed as a combination of a slow-moving trend (τ_t), and deviations around this trend (η_t). The trend follows a unit root process, while inflation deviations around this trend follow an AR(1) process, such that shocks to inflation around its trend have a modest degree of

[31] Also see Hasenzagl *et al.* (2017) which estimates a model for the US that includes a slow-moving trend, a cycle connecting nominal and real variables, and oil prices.
[32] See Forbes *et al.* (2017) for a comparison of estimates based on different modelling assumptions for the UK, including results for recursive estimates, a UCSV model which does not allow for the additional AR(1) term in inflation deviations from trend, and an autoregressive-unobserved-components model (or ARUC, which assumes that the stochastic volatilities remain constant).
[33] Chan, Koop and Potter (2013) and Cecchetti *et al.* (2017) also allow deviations in trend inflation to follow an autoregressive process, but do not simultaneously allow for stochastic volatility in the innovations to the inflation process. This approach makes sense for US inflation dynamics—the focus in these papers—but does not well describe the characteristics of the inflation data in other countries (as shown in Forbes *et al.*, 2017 for the UK).

persistence. The innovations ($\zeta_{\eta t}$ and $\zeta_{\varepsilon t}$) are both assumed to be independent, normally distributed, and serially uncorrelated.

The evolution of the variances of the shocks to the trend and cyclical component are:

$$\ln(\sigma_{\eta t}) = \ln(\sigma_{\eta t-1}) + \upsilon_{\eta t} \, , \tag{5}$$

$$\ln(\sigma_{\varepsilon t}) = \ln(\sigma_{\varepsilon t-1}) + \upsilon_{\varepsilon t}, \tag{6}$$

$$\upsilon_{\eta t} \sim N(0, \gamma_1) \text{ , and} \tag{7}$$

$$\upsilon_{\varepsilon t} \sim N(0, \gamma_2), \tag{8}$$

with $v_{\eta t}$ and $v_{\varepsilon t}$ both also assumed to be independent, normally distributed and serially uncorrelated. Forbes *et al.* (2017) refer to this framework as the "ARSV" model, as it can be roughly characterized as a combination of the UCSV model (from Stock and Watson, 2007) and the auto-regressive (ARUC) model developed in Chan, Koop and Potter (2013). It captures both the autoregressive process as well as the stochastic volatility observed in the inflation data, while making minimal other assumptions.

Next, this framework can be used to estimate trend inflation (τ_t) for CPI and core inflation for each of the countries in the sample, using the quarterly, annualized, seasonally-adjusted inflation data from 1990 through 2017 discussed in Section II and Appendix A.[34] The first 12 observations for each country were used to calibrate the prior information, resulting in estimates of trend inflation from 1993 through 2017 for most advanced economies (but limited coverage of emerging markets). The resulting estimates of trend inflation are then subtracted from CPI and core inflation to back out the "cyclical" component of inflation for each country in each quarter—what I will refer to as the "cycle".

Figure 7 reports key statistics from these calculations of cyclical and trend inflation for the advanced economies.[35] To get a sense of the precision of the estimates, columns 1 and 2 report the average distance from the 15th to the 85th percentiles of the estimated trends. The average distance is 0.95 for CPI inflation, and 0.71 for core inflation over the full sample period, suggesting that there is some imprecision in the estimates. Columns 3 through 6 report the median variances in the trend and cyclical components; the variances of the trends are substantially lower than for the cyclical

[34] Estimates are the (pointwise) median of 1000 draws. If the algorithm did not converge within five hours, the estimation was terminated.

[35] Most emerging markets do not have sufficient data to calculate trend inflation for the longer time periods for this table, and for the few which do, all have periods of very high inflation (usually around financial crises that correspond to sharp devaluations) which can skew some estimates.

components, consistent with our interpretation of the trend as a slow-moving and more stable component. Columns 7 and 8 report the percent of the variation in inflation for each country explained by the trend.[36] Over the full sample period, the trend explains 31% of the variation in CPI inflation and 55% in core inflation. This suggests that most of the volatility in CPI inflation in advanced economies is driven by short-term cyclical movements (albeit the volatility in the trend still plays a meaningful role), while volatility in core inflation is driven by roughly equal contributions from the cyclical and trend components. Also noteworthy are changes over the two halves of the sample, with the variance in the trend falling from the earlier period to the last decade, while the variance in the cyclical component of CPI inflation (but not core), increases in the later period. This would be consistent with greater volatility in commodity prices over the last decade, which would be expected to have a greater impact on CPI than core inflation, and on the cyclical component of inflation instead of the trend.

Appendix D reports the key statistics from Figure 7, except now by individual country instead of the sample medians. The range in the percent of the variation in inflation explained by movements in the estimated trend is noteworthy (columns 7 and 8). For some countries that have experienced periods of sharply higher inflation (often linked to currency crises), a large share of this deviation is identified as an increase in trend inflation. Focusing on economies that have not experienced these types of crisis-related periods of high inflation, the trend explains a large share of the variation in inflation for many countries—such as explaining over 40% of the variation in core inflation in France, Italy, Israel, Japan, Spain, Sweden, Switzerland, UK, and US (amongst others). In other advanced economies, however, the trend explains a much lower share of the variation in core inflation, such as explaining less than 10% in Australia, Canada, New Zealand and Norway. Moreover, for some countries in which the trend explains a large share of the variation in core inflation, it is less powerful in explaining CPI inflation—such as for France and the US, where the explanatory power of the trend is about four times larger for core than CPI inflation.

In order to better understand these differences across countries, Figure 8 graphs a sample of these estimates—with the countries selected to show typical results for different regions, as well as the diversity in country experiences, while still keeping the number of figures manageable. The black line shows reported inflation, with the share identified as trend in blue and as the "cycle" in red. The first six graphs (Panel a) focus on European countries. The graphs in the top row capture the typical patterns for

[36] Calculated as: $\frac{\sum_{t=1}^{T} (\tau_t - \bar{\pi}_t)^2}{\sum_{t=1}^{T} (\pi_t - \bar{\pi}_t)^2}$.

CPI inflation for most of the euro area; much of the variation is driven by cyclical movements—with particularly large cyclical drags on inflation during the period of the global financial crisis and euro area debt crisis (2012-2014). CPI inflation, however, generally tracks the slower moving trend, which has steadily declined in most euro area countries—especially in periphery countries. This underlying trend inflation has started to pick up in most euro area countries, but remains well below 2% at the end of 2017. At the bottom of Panel a are results for core inflation for European countries that are not in the euro area, and which show a range of experiences. Trend core inflation is higher and has been relatively stable around 2% in Norway, but fallen sharply in Sweden and especially Switzerland—where trend inflation is estimated to be close to zero at the end of 2017.

Panel b of Figure 8 shows similar graphs for advanced economies outside of Europe (with graphs for CPI inflation again in the top row and core inflation at the bottom). Much of the variation in inflation for countries such as Australia, Canada and New Zealand is driven by the cyclical component—possibly reflecting the greater role of commodities in these economies. Japan—like Switzerland—currently has trend inflation near zero—although it has begun to pick up recently (with trend CPI inflation estimated at 0.40 and trend core at 0.25 at the end of 2017). The US and UK show a more balanced role for the trend and cyclical components in driving inflation volatility—with cyclical factors driving the short-term ups and downs in inflation around the slower moving trend. Trend inflation in the US and UK also fluctuates over time—particularly in the UK—and at the end of 2017 is somewhat above 2% in the UK (at 2.7% for trend CPI and 2.3% for core) and just about at 2% in the US (at 1.9% for trend CPI and core). It is worth noting that this decomposition suggests that the weakness in US core inflation in 2017, which generated substantial attention and seemed to be inconsistent with standard Phillips curve models, is identified as being entirely cyclical and not a decline in underlying trend inflation.

These graphs decomposing inflation into a trend and cyclical component show some different patterns over time in many countries and raise a number of questions. What drives movements in the trend and cyclical components of inflation? Why has trend inflation moved away from the inflation target in many advanced economies? Could changes in the global economy be driving these changes over time?

B. Fixed Coefficient Estimates: Inflation and the Trend

This section analyzes the factors correlated with the cyclical and trend components of CPI and core inflation over the full sample period. The approach taken is atheoretical—to basically run "horse races" to see which variables explain the dynamics of the different inflation measures. This is useful to understand key patterns in the data, but subject to the caveat that it may not capture underlying structural economic relationship that are more complex and not easily tested in the simple regressions shown below. In order to facilitate a comparison with the earlier sections of this paper, the same variables are used as in the Phillips curve analysis in Section IV.

To begin, in order to assess the role of the slow-moving trend in driving inflation rates, as well as the ability of other variables to explain the cyclical component of inflation (*i.e.*, the deviations of inflation from the trend), I estimate the following random-effects model for the full sample of countries from 1993 through 2017:

$$\pi_{it} = \alpha_i + \beta\tilde{\tau}_{it} + \sum_{k=1}^{7} \boldsymbol{\gamma_k X_{kit}} + e_{it}. \tag{9}$$

The π_{it} is CPI or core inflation for country *i* in quarter *t* (seasonally-adjusted and annualized), $\tilde{\tau}_{it}$ is the slow moving trend for country *i* in quarter *t* estimated in Section V.A., and the $\boldsymbol{X_{it}}$ are *k* additional variables that could help explain the cyclical movements in inflation around this trend.[37] For the baseline analysis, the *k* variables for X_{it} are the seven variables that correspond to those used for the Phillips-curve analysis in Section IV: two domestic variables that are central to most frameworks for analyzing inflation (the output gap and inflation expectations) and five "global" variables (the country's real exchange rate, the world output gap, world oil prices, world commodity prices, and world PPI dispersion).[38] Each variable in $\boldsymbol{X_{kit}}$ is defined as in the last section, with details in Appendix A. The domestic output gap continues to be measured as a principal component in order to incorporate a broader concept of slack than captured in the unemployment gap.

The results from estimating equation (9) are reported in columns 1 and 2 of Figure 9 for CPI and core inflation, respectively. The coefficients on the trend are highly significant and equal to 0.59-0.64, showing an important role for the trend in explaining overall inflation dynamics (which is not surprising given that the trend is a function of the inflation data). All of the other variables have the expected sign, and all except one (on the exchange rate) are significant in the regressions for CPI inflation. This includes most of the global variables, with a more positive world output gap, higher world oil prices, higher world commodity prices, and greater producer price dispersion all significantly correlated with higher cyclical inflation. For the regressions on core inflation, however, most of the global variables are not significant

[37] Estimated with random effects and error terms are adjusted for heteroscedasticity and clustered by country.
[38] The only variable from the Phillips curve model in equation (1) that is not included is lagged inflation, due to the high collinearity with the trend included in equation (9).

at the 5% level (except for PPI dispersion), supporting a greater role for the global variables in the cyclical movements of CPI inflation than for core inflation. For both measures of inflation, the domestic output gap and inflation expectations are significantly correlated with inflation (as found in the Phillips curve regressions)—and despite the addition of controls for the slow-moving trend.

These pooled regressions capture average relationships across the full sample of countries, but as seen in the graphs decomposing the trend and cyclical components of inflation (Figure 8), there are meaningful differences in these inflation dynamics across countries. Therefore, Appendix E repeats the analysis in Figure 10, except summarizes the results from estimating the model separately for each country.[39] Columns 1 and 2 report the percent of the regressions on CPI and core inflation for which the corresponding variable is significant (at the 10% level) and has the expected sign. The top, left cell indicates that the coefficient on trend inflation is positive and significant in 96% of the regressions for CPI inflation and 100% for core.

The summary of results in columns 1 and 2 show several noteworthy patterns. First, the trend is almost always positive and significant—usually at the 1% level, as well as at the 10% level used as the threshold for the table. Second, the other control variables are occasionally significant—with some of the global variables significant as often as the standard domestic variables. For example, in the regressions explaining CPI inflation, the variables most often significant (all in 21% of the countries) are: the domestic output gap, world output gap, inflation expectations, and the exchange rate. Third, the general insignificance of many of the explanatory variables agrees with other studies that use a trend-cycle decomposition and generally find that after controlling for the trend, most other variables play a small role in explaining the cyclical movements, especially in core inflation.[40] Finally, and perhaps most noteworthy, is the last row of the table which reports that in 46% of the individual country regressions for CPI inflation, and 37% for core inflation, at least one of the global variables is significant with the expected sign. This suggests that the global variables can play a role in explaining the cyclical variation in inflation rates in some countries—even after controlling for the slow-moving trend.

This series of results also suggests that in order to understand inflation dynamics, it is important to understand the slow-moving trend—especially for core inflation where the global variables play a less important role. Therefore, I next repeat the same series of regressions, except now focus on

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[39] Throughout this paper, all error terms are adjusted for heteroscedasticity and serial correlation.
[40] For example, see Cecchetti *et al.* (2017) and Forbes *et al.* (2017).

understanding changes in the trends for CPI and core inflation. More specifically, I follow Cecchetti *et al.* (2017) and Forbes *et al.* (2017) and estimate:

$$\Delta\tilde{\tau}_{it} = \alpha_i + \sum_{k=1}^{7} \boldsymbol{\gamma_k} \Delta \boldsymbol{X_{kit_t}} + e_{it} \,, \tag{10}$$

where all variables are defined above, except now expressed in first differences.[41] As explained in Cecchetti *et al.*, (2017) it is necessary to estimate the equation in first differences due to the assumption that the trend is a random walk (equation 3), so that the level of inflation is non-stationary.[42]

The results from these panel regressions of the trend for CPI and core inflation are reported in columns 1 and 2 of Figure 10, and a summary of the key results when the regressions are estimated separately for each country are in columns 1 and 2 of Appendix F. Both figures show noteworthy differences relative to the comparable regressions for the cyclical component of CPI and core inflation. The variables central to most inflation models—the domestic output gap and inflation expectations—are not significant in regressions for trend CPI inflation, but are significant for regressions explaining trend core inflation. The only variable that is significantly correlated with both measures of trend inflation is the exchange rate (which was the one variable not significant for the cyclical movements in CPI and core inflation), suggesting a more persistent impact of exchange rate movements on inflation rates (at least for some countries). The individual country results suggest that these pooled estimates continue to mask important differences across countries. Individual global variables can play a significant role—especially for trend CPI inflation—but are less often significant in the regressions predicting trend core inflation (a similar difference as found for the regressions predicting the cyclical components of CPI and core inflation). The final line of the table, however, suggests that the global variables—as a whole—are more often important—even if different global factors tend to be significant for different countries. In 79% of the individual country regressions predicting trend CPI inflation, and 59% for trend core, at least one of the global variables is significant with the expected sign.

As seen in the analysis in the last section based on a Phillips curve framework, however, the relationship between these different global and domestic factors and inflation can change over time.

[41] The change in the trend is relative to the previous quarter. The change in the other variables is relative to one year ago for the base case in order to allow for lagged effects on trend inflation. The sensitivity analysis shows that using different lag structures or timing does not affect the key results. The current approach reduces concern about seasonality, and also allows country-specific regressions, which have more limited degrees of freedom.

[42] This also assumes that inflation expectations are nonstationary and have the same time-series properties as inflation. Forbes *et al.* (2017) also shows the impact of using levels instead of changes for some variables.

C. Changes over Time: Inflation and the Trend

Have the drivers of the cyclical and trend components of inflation changed over time? To test this, I repeat the analysis from the last section, except now test if key coefficients have changed over the last half of the sample (2007-2017) relative to the first half of the sample (1996-2006). The later window corresponds to the later window in the Phillips curve estimates in Section IV.C, although the earlier window is shorter due to the extra years needed to calculate the trends. I continue to test for significant changes over time by including a dummy variable for the last decade interacted with each of the explanatory variables.

The results for CPI and core inflation for the pooled sample of countries are shown in columns 3 and 4 of Figure 9, with the corresponding results for individual countries shown in columns 3 and 4 of Appendix E. The bottom half of the table indicates that there have been significant changes in the relationship between three of the variables and inflation in the last decade. More specifically, increases in commodity prices and the world output gap have had a relatively greater correlation with the cyclical component of CPI and core inflation, respectively, over the last ten years. The dispersion in world producer prices has had a significantly smaller correlation with the cyclical component of CPI inflation. These are the same three variables that were estimated to have a significant change in their relationship with CPI inflation in the last decade in the Phillips curve results in Figure 3, column 3 (with all the changes also in the same direction). The bottom of the table shows that a χ^2 test rejects the hypothesis that the coefficients on the five global variables are the same in the earlier window as in the last decade for both inflation measures. The estimates for the individual country results (in Appendix E) again show the diversity of experiences across countries—with no variables other than the trends significant in over one-third of the regressions. The χ^2 tests (reported at the bottom) reject the hypothesis that the coefficients on the five global variables are the same in the earlier window relative to the last decade for CPI inflation in only 14%-26% of the countries. The global variables are still important, however, with at least one of the global variables significant in 61%-67% of the individual country regressions.

Finally, columns 3 and 4 of Figure 10 and Appendix F repeat the same analysis, except now focus on correlations with changes in the trends. In the pooled results, there is some evidence that world oil prices had a greater impact on both measures of trend inflation in the later period, while the real exchange rate and dispersion of world producer prices may have had less impact, but some of these coefficients are only significant at the 10% level and not robust across the sensitivity tests (reported below).[43] The χ^2 tests at the bottom of the table further suggest that the coefficients on the global variables do not change significantly in the later decade. The individual country regressions continue to highlight the differences across economies; the comparable χ^2 tests at the bottom of the table suggest that there is a significant change in the relationship between the global variables and trend CPI inflation in half the countries in the later period (and 41% of the countries for trend core inflation), and that at least one of the global variables is significant in 68%-74% of the countries. Exactly which global variables are significant or change significantly in the last decade, however, varies. The variable that is most often significant for both measures of trend inflation is that on the domestic output gap—especially for core inflation—suggesting that this basic Phillips curve relationship is still important in understanding patterns in trend inflation, even with a fuller set of control variables.

D. Sensitivity Analysis: Inflation and the Trend

This series of tests examining the relationship between the cyclical and trend components of inflation and different variables has required making a number of choices about variable definitions, specification, and timing conventions. Therefore, as a final analysis, this section performs the same series of sensitivity tests as for the Phillips curve regressions in Section IV.D—focusing on the pooled results which allow the coefficients to change over the last decade (in Figures 9 and 10, columns 3 and 4). Key results are reported in Figure 11a for regressions of the cyclical component of CPI and core inflation (with controls for the trend) and Figure 11b for regressions of the trends.

First, I use several different variable definitions: the unemployment gap or output gap (column 2) instead of the principal component to measure the domestic output gap; an all-commodity index to capture changes in oil prices and non-fuel commodity prices instead of controlling for them separately; and interact the world output gap with each country's ratio of exports to GDP to better capture exposure to global demand. In most cases, the key results are unchanged. The main exception is when the domestic output gap is measured using simply they OECD output gap measure, in which case the coefficient on the domestic output becomes negative and significant, and that on the world output gap becomes positive and significant over the last decade for regressions for CPI and core inflation (similar to as found in the comparable Phillips curve sensitivity tests).

[43] Since the coefficient on the exchange rate for the full period is negative, the positive coefficient for the interaction term in the later part of the period indicates less impact of changes in the exchange rate on inflation.

Second, I focus on how the results change over different periods and if the global financial crisis or euro crisis are affecting key results. I perform several tests: estimate pooled regression for only the last decade (column 3); use the full sample period, but exclude the global financial crisis and euro crisis from 2008-2014 (column 4); add dummy variables for the crisis years; and include the global financial crisis in the earlier period so that the "post" period is 2013-2017 (column 5). Although most of the key results highlighted above persist, a number of additional variables become significant—especially the coefficients indicating if the relationship between the global variables and inflation have changed over time. For example, in regressions allowing relationships over the last few years to change (columns 3-5), the world output gap is more often positively and significantly correlated with inflation (both the cyclical and trend components) and producer pricing dispersion appears to play a stronger role—changes similar to those found in the comparable Phillips curve sensitivity tests. The impact of oil and commodity prices also varies based on the exact years included in each sample. This series of results supports the graphs of the rolling Phillips curve regressions in Section IV.C showing that the impact of different variables on inflation varies over time.

Third, I test for the impact of country selection: excluding emerging markets (column 6) and only including advanced economies that have their own currencies (column 7). In both of these extensions, the coefficients on inflation expectations and the domestic output gap lose significance in regressions for CPI and core inflation. The coefficient on the domestic output gap is significantly smaller in regressions for trend CPI and core inflation in the last decade when the sample only includes the advanced economies with their own currencies (as also found for the comparable sensitivity tests based on the Phillips curve framework). This suggests that the key relationship between domestic slack and inflation may be less potent in advanced economies, especially those outside the euro zone and when explaining trend inflation over the last decade.

As a final set of sensitivity tests, I use different specifications and combinations of the key variables, such as only including one global variable at a time, or a smaller subsets of these global variables, or different lag structures and timing conventions for the percent changes. The key results are generally unchanged.

E. Trend-Cycle Analysis: Summary

Decomposing inflation into a cyclical component and slow moving trend, and then analyzing which variables are correlated with movements in these components of inflation, yields a number of conclusions—conclusions that are very similar to those obtained using the Phillips curve framework in the last section. The trend-cycle analysis highlights two challenges in modelling inflation dynamics: that the role of different variables can change significantly over time, and that different variables play different roles in different countries. Nonetheless, several general patterns emerge and are shared by many countries. The standard Phillips curve variables (domestic slack and inflation expectations) still play a significant role in explaining inflation, especially the trend of core inflation, although there is some evidence that the role of domestic slack may have weakened over the last few years, especially for the advanced economies outside of Europe.

Global variables have also played a significant and meaningful role, and their role has changed over time. More specifically, there is some evidence that the world output gap and/or world commodity prices have had a stronger positive relationship with the cyclical component of inflation in the last decade, especially in the last few years. There is also evidence that producer price competition (and supply chains) had a greater impact on inflation before the global financial crisis, and over the last three years, but less so around the time of the global and euro crises. The global variables are jointly significant in all of the regressions predicting CPI and core inflation, and in all of the tests, there have been significant changes in the relationship between these variables and CPI inflation over the last decade (and in about ¾ of the comparable tests for core inflation). The global variables are also important in understanding trend CPI and core inflation, and estimated to be jointly significant in about ¾ of the corresponding regressions, but there is less evidence that their role has changed significantly over time. Overall, it is not surprising that the role of the global variables has changed more for the cyclical components of inflation than the trends. This result is similar to those in the Phillips curve regressions, where the global variables have become more important over the last decade in explaining movements in CPI than core inflation.

VI. Summary and Conclusions

The global economy has changed in many ways over the last twenty years—including through increased trade flows, a greater role for emerging markets in driving global growth and commodity price fluctuations, and the increased use of supply chains to shift segments of production to cheaper locations. These forms of globalization could also affect inflation dynamics in different ways—such as by linking firm pricing decisions more closely to changes in global demand and supply, changing how exchange rate movements affect inflation, and causing greater volatility in oil and other commodity markets (volatility that can have nonlinear effects on prices). Many of these changes, and especially any which generate a greater role for global factors in inflation dynamics, could simultaneously weaken the role of domestic factors in inflation models, potentially even explaining the recent fragility in the "Phillips curve" relationship between domestic slack and inflation in many advanced economies.

This paper uses three different approaches (principal components, a Phillips curve framework, and a trend-cycle decomposition) to evaluate the role of global factors in understanding inflation dynamics and if their role has changed over time. Although some results vary across countries and across inflation measures, the three approaches all yield the same general conclusion: global variables should no longer be ancillary to models of inflation dynamics. Simply adding a single control for oil prices or import prices to standard Phillips curve models is not sufficient. Global factors can significantly affect inflation, and including more comprehensive controls for global factors can meaningfully improve the ability of simple models to predict inflation. The impact of global factors has also changed significantly over time—especially for CPI inflation and the cyclical component of inflation. For example, in both the Phillips curve and trend-cycle frameworks, changes in the world output gap and commodity prices have had a greater impact on CPI inflation and the cyclical component of inflation over the last decade. Inflation models should not only more carefully control for changes in the global economy, but also allow coefficients in the models to be dynamic and evolve over time.

This does not mean, however, that the traditional domestic factors driving inflation are no longer relevant; instead, domestic slack and inflation expectations continue to play a significant role in explaining different measures of inflation, especially core and trend inflation. There is some evidence, however, that the relationship between domestic slack and core inflation may have weakened over the last decade—especially in advanced economies outside the euro area. The importance of different domestic and global variables also varies significantly across countries, as well as across time within individual countries.

The results in this paper also raise a number of new questions. Why does the role of the different global factors vary across countries? Why have different global factors—such as producer price dispersion and commodity prices—had such different effects on the inflation process at different points in time? Are the changes in the relationships between the global factors and different measures of inflation that have occurred over the last few years long-lasting—or do they simply reflect the characteristics of the global economy over the last few years?

Although this paper does not answer these questions, it does show that as the global economy has evolved, it is time that our inflation models also evolve. This does not imply that the Phillips curve framework is "dead" and that new models need to be developed from scratch. Instead, just as the global economy has grown and better integrated nations that were at the periphery of the global trading system, our basic inflation models should also grow and more explicitly integrate global factors that have largely remained at the periphery of standard inflation models.

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Figure 1

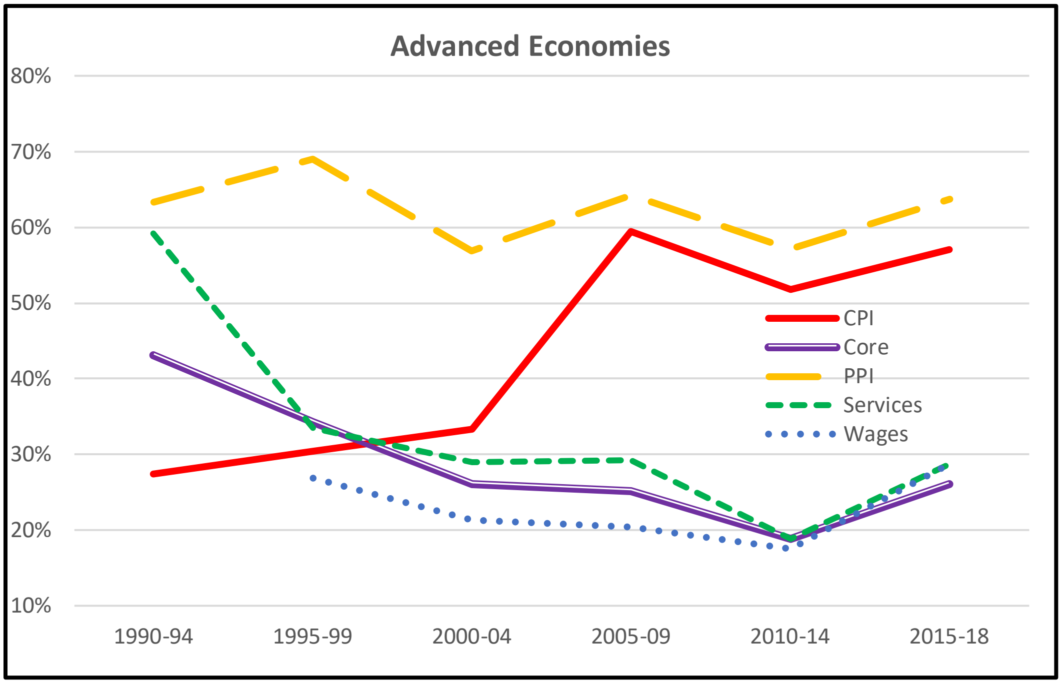
Global Principal Component in Different Inflation Series

	Fraction of Variance Accounted for:				
	CPI	Core	PPI	CPI Services	Wages
Full sample:					
1st PC	40.25%	20.93%	51.58%	31.35%	22.51%
1st 5 PCs	66.75%	51.09%	76.01%	57.13%	54.06%
# countries	***43***	***38***	***35***	***27***	***20***
Sample of countries with wage data:					
1st PC	44.83%	26.02%	56.32%	35.35%	22.51%
1st 5 PCs	74.03%	60.57%	83.76%	70.06%	54.06%
# countries	***20***	***20***	***19***	***15***	***20***
Advanced economies:					
1st PC	41.14%	25.07%	60.48%	32.94%	22.73%
1st 5 PCs	69.09%	53.22%	81.53%	60.08%	55.32%
# countries	***31***	***31***	***29***	***24***	***18***
Emerging markets					
1st PC	25.39%	23.21%	39.19%	.	.
1st 5 PCs	75.53%	85.38%	95.74%	.	.
# countries	***12***	***7***	***6***	***.***	***.***

Notes: *Fraction of variance accounted for by either one or five principal components (PC) for each of five inflation measures. CPI is headline consumer price inflation. Core inflation is CPI less food and energy. PPI is producer price inflation. CPI services is the CPI for services, and Wages is private sector, household hourly wages. All inflation measures are relative to the previous quarter, annualized and seasonally adjusted. See Appendix A for more details on data. Advanced economies and emerging markets are defined according to the IMF.*

Figure 2

Percent of Variance of Inflation Measures Explained by 1st Principal Component Over Time



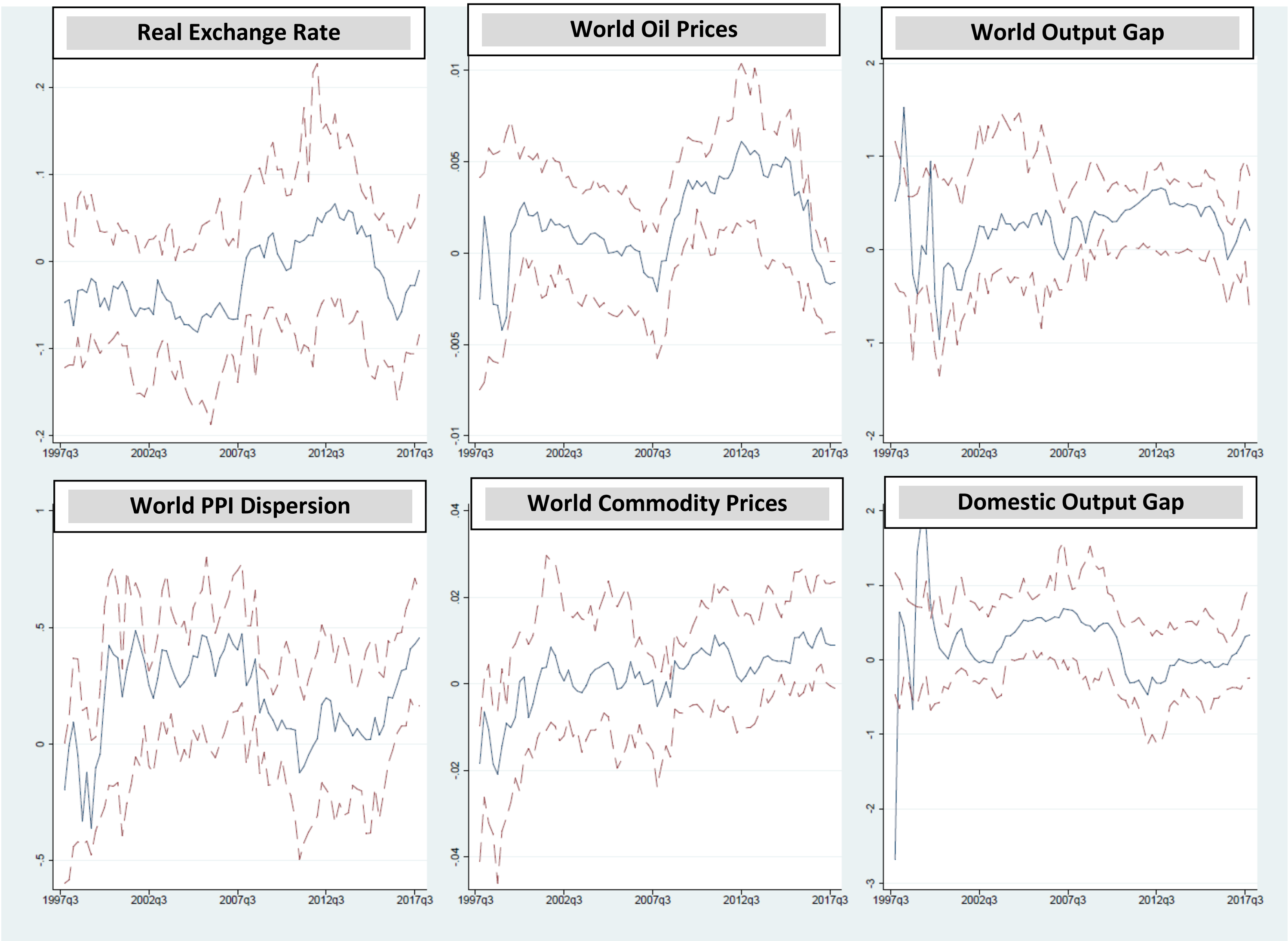
Notes: *Percent of variance for each measure of inflation explained by first principal component over 5-year windows starting in 19990-94. See notes to Figure 1 for definitions of different inflation measures.*

Figure 3: Phillips Curve Estimates—Pooled Country Sample

	CPI Inflation (1)	Core Inflation (2)	CPI Inflation (3)	Core Inflation (4)
Inflation	0.670***	0.462***	0.592***	0.416***
Expectations	(0.073)	(0.052)	(0.089)	(0.058)
Lagged	0.646***	0.704***	0.682***	0.750***
Inflation	(0.034)	(0.024)	(0.055)	(0.033)
Domestic	0.094***	0.084***	0.115***	0.116***
Output Gap	(0.017)	(0.012)	(0.028)	(0.022)
Real Exchange	-0.020***	-0.013***	-0.025***	-0.018***
Rate	(0.006)	(0.004)	(0.008)	(0.005)
World Output	0.072***	0.043***	0.027	0.037
Gap	(0.023)	(0.012)	(0.045)	(0.036)
World Oil	0.002***	0.001**	0.002***	0.001**
Prices	(0.001)	(0.000)	(0.001)	(0.000)
World Commodity	0.010***	0.003**	0.002	0.002
Prices	(0.002)	(0.001)	(0.003)	(0.002)
World PPI	0.114***	0.019	0.301***	0.012
Dispersion	(0.034)	(0.028)	(0.074)	(0.048)
*Post * Inflation*			0.188**	0.165***
Expectations			(0.090)	(0.056)
*Post * Lagged*			-0.116	-0.154***
Inflation			(0.083)	(0.058)
*Post * Domestic*			-0.052	-0.078**
Output Gap			(0.044)	(0.035)
*Post *Real*			0.008	0.008
Exchange Rate			(0.014)	(0.009)
*Post * World*			0.122**	0.044
Output Gap			(0.057)	(0.049)
*Post * World Oil*			0.000	0.000
Prices			(0.001)	(0.001)
*Post * World*			0.014***	0.001
Commodity Prices			(0.004)	(0.003)
*Post * World*			-0.322***	0.008
PPI Dispersion			(0.094)	(0.066)
Constant	-0.636***	-0.389***	-0.582***	-0.416***
	(0.165)	(0.083)	(0.146)	(0.092)
Adj. R2	***0.55***	***0.63***	***0.56***	***0.63***
# observations	***3002***	***3038***	***3002***	***3038***
χ2 *test for change in 5 global variables 2007-17*			**22.97*** **	**2.56**

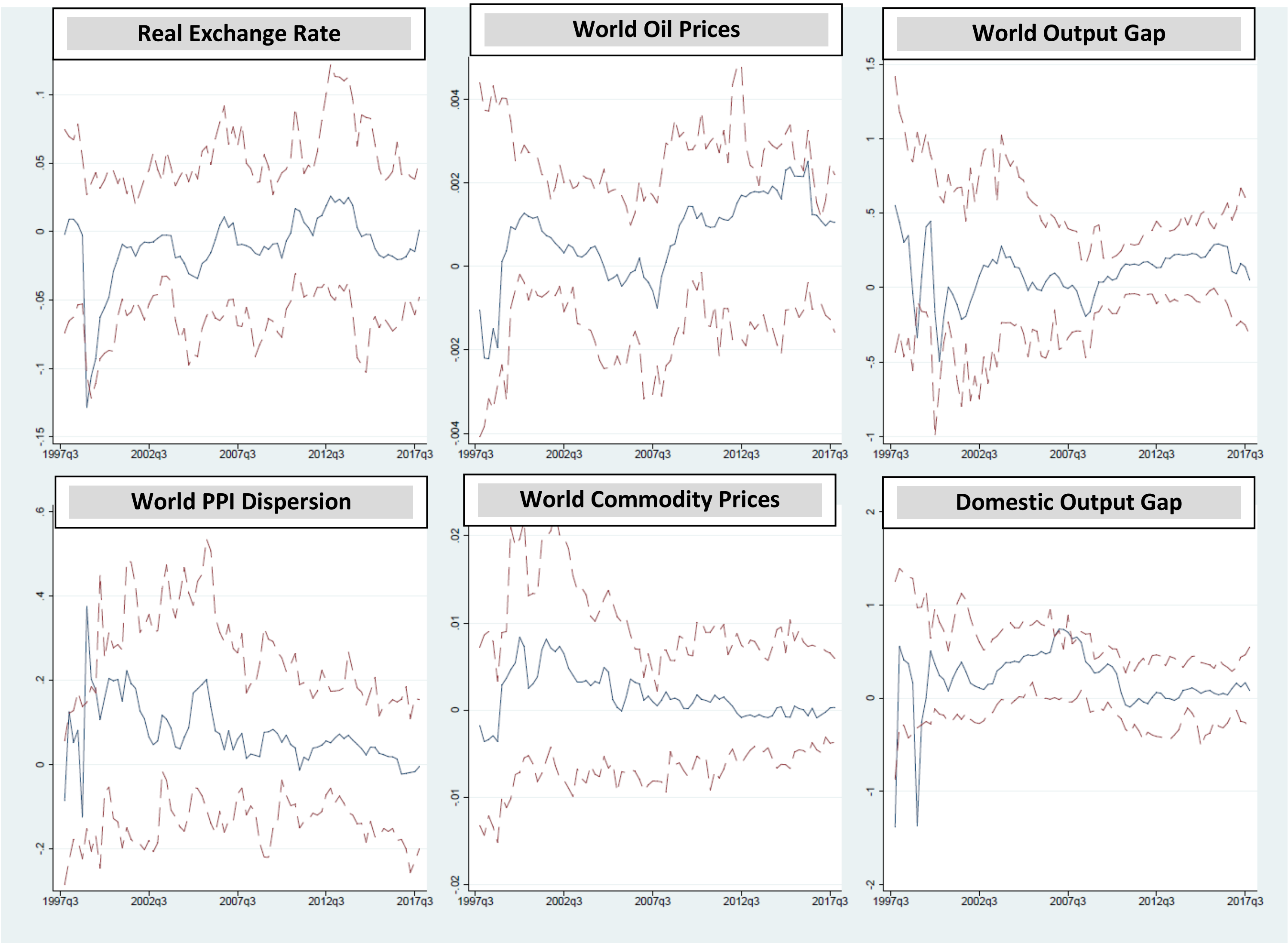
Notes: *Phillips curve regression of equation (1) for quarterly CPI and core inflation from 1990-2017. "Post" is a dummy variable equal to 1 for the years 2007-2017. See Appendix A for data definitions. Estimated using random effects with robust standard errors clustered by country. *** is significant at the 1% level, ** at the 5% level and * at the 10% level.*

Figure 4a: Rolling Regressions based on Phillips Curve Framework—CPI Inflation



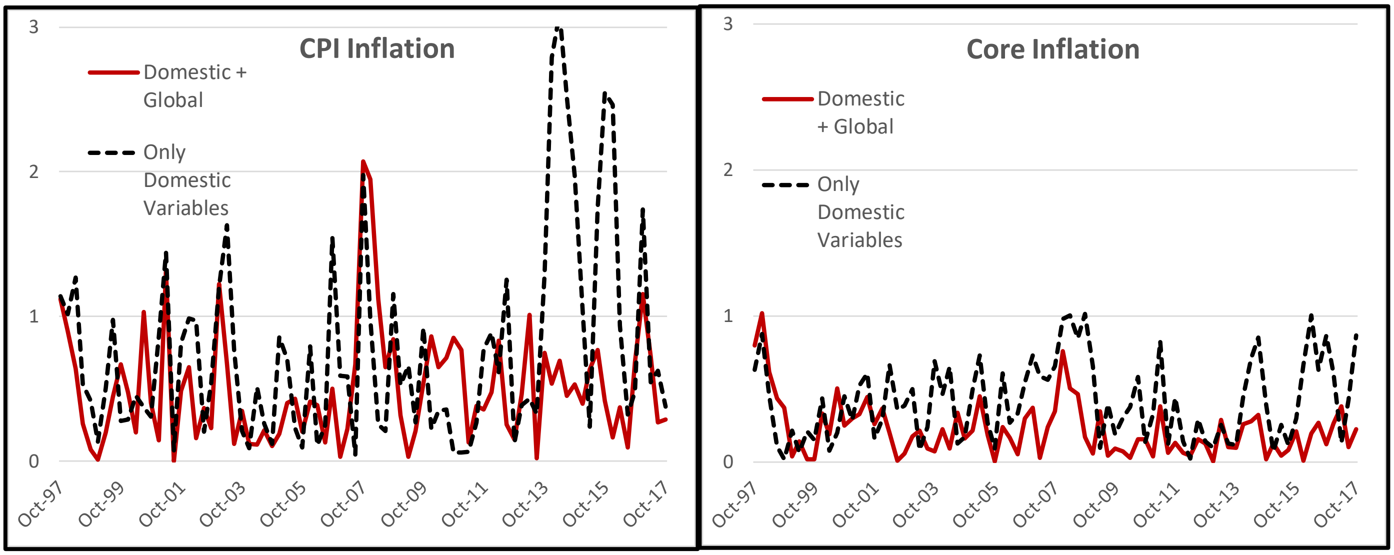
Notes: *Rolling regressions for Phillips curve in equation (1) for quarterly CPI inflation from 1990-2017 using eight-year windows. Solid blue line is the mean coefficient estimate for all countries for which data is available, and the dashed red lines are the 25th and 75th values of the distribution. See Appendix A for data definitions.*

Figure 4b: Rolling Regressions based on Phillips Curve Framework—Core Inflation



Notes: *Rolling regressions for Phillips curve in equation (1) for quarterly core CPI inflation from 1990-2017 using eight-year windows. Solid blue line is the mean coefficient estimate for all countries for which data is available, and the dashed red lines are the 25th and 75th values of the distribution. See Appendix A for data definitions.*

Figure 5a: Gap between Actual and Predicted Inflation, with and without Global Variables



Notes: Absolute value of the difference between actual inflation and predicted inflation each quarter when equation (1) is estimated with 8-year rolling regressions and different control variables. "Only Domestic Variables" is when the model only includes controls for inflation expectations, lagged inflation, and the domestic output gap. "Domestic + Global" is the full set of variables listed in equation (1).

Figure 5b: Gap between Actual and Predicted Inflation, with Different Control Variables

	CPI Inflation			Core CPI Inflation		
	Domestic Variables	Domestic Variables & Oil	Global & Domestic Variables	Domestic Variables	Domestic Variables & Oil	Global & Domestic Variables
Full Period	***0.77***	***0.73***	***0.50***	***0.42***	***0.42***	***0.22***
Shorter Windows						
1997-06	0.62	0.69	0.42	0.36	0.39	0.26
2007-17	0.89	0.76	0.58	0.46	0.44	0.19
1997-02	0.65	0.73	0.47	0.34	0.35	0.32
2003-07	0.63	0.67	0.43	0.44	0.46	0.20
2008-09	0.62	0.82	0.71	0.65	0.66	0.30
2012-14	1.31	0.92	0.51	0.30	0.28	0.15
2015-17	1.09	0.74	0.50	0.49	0.45	0.17

Notes: Reports average of absolute value of the difference between actual inflation and predicted inflation each quarter when equation (1) is estimated with 8-year rolling regressions and different control variables. "Domestic variables" only includes controls for inflation expectations, lagged inflation, and the domestic output gap. "Domestic variables plus oil" also includes world oil prices. "Global and domestic variables" is the full set of variables. See Section IV. C for more details and Appendix A for variable definitions.

Figure 6: Phillips Curve Estimates—Sensitivity Analysis

	HEADLINE CPI							CORE CPI						
	Base	Output Gap (not PC)	Only 2008-17	Drop Crises (2008-14)	"Post" is 2013-17	Exclude EMs	Non-Euro AEs only	Base	Output Gap instead of PC	Only 2008-17	Drop Crises (2008-14)	"Post" is 2013-17	Exclude EMs	Non-Euro AEs only
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Inflation Expect.	0.592***	0.585***	0.711***	0.579***	0.656***	0.653***	0.786***	0.416***	0.413***	0.576***	0.414***	0.468***	0.438***	0.444***
Lagged Inflation	0.682***	0.679***	0.568***	0.684***	0.651***	0.537***	0.453***	0.750***	0.748***	0.570***	0.751***	0.712***	0.705***	0.619***
Domestic Out. Gap	0.115***	0.121***	0.065**	0.114***	0.097***	0.146***	0.163***	0.116***	0.123***	0.038	0.115***	0.094***	0.122***	0.140***
Exchange Rate	-0.025***	-0.027***	-0.028**	-0.025***	-0.021***	-0.021***	-0.018	-0.018***	-0.020***	-0.011	-0.018***	-0.013**	-0.018***	-0.015*
World Out. Gap	0.027	-0.035	0.105**	0.027	0.058**	0.019	-0.043	0.037	-0.026	0.087***	0.037	0.045***	0.021	-0.046
Oil Prices	0.002***	0.002***	0.001	0.002***	0.003***	0.002***	0.002**	0.001**	0.001**	0.001*	0.001**	0.001**	0.001*	0.000
Commodity Prices	0.002	0.002	0.019***	0.002	0.011***	0.000	-0.001	0.002	0.003	0.003	0.002	0.004***	0.002	0.001
PPI Dispersion	0.301***	0.304***	-0.037	0.302***	0.052	0.323***	0.297***	0.012	0.014	0.013	0.012	-0.012	0.015	-0.026
Interacted with Post period (2007-present)														
*Post*Inf. Exp.*	0.188**	0.167*		0.153	0.165**	0.033	-0.005	0.165***	0.153**		0.055	0.032	0.123**	0.056
*Post*Lagged Inf.*	-0.116	-0.129*		-0.093	-0.114**	0.038	0.115	-0.154***	-0.171**		-0.052	-0.112*	-0.097	0.037
*Post*Dom. OutGap*	-0.052	-0.053*		-0.090**	-0.030	-0.097*	-0.168***	-0.078**	-0.081***		-0.082**	-0.040	-0.093**	-0.180***
*Post*ER*	0.008	0.006		0.041**	0.003	0.004	0.010	0.008	0.008		0.004	-0.004	0.011	0.012
*Post*World OutGap*	0.122**	0.143**		0.377***	0.248***	0.139**	0.237***	0.044	0.082*		0.049	-0.045	0.057	0.171**
*Post*Oil*	0.000	0.000		0.003***	-0.003***	0.000	0.003	0.000	0.000		-0.001	0.000	0.000	0.001
*Post*Commodity*	0.014***	0.014***		-0.037***	-0.012***	0.017***	0.012**	0.001	0.000		-0.002	-0.007**	0.002	0.000
*Post*PPI Disp.*	-0.322***	-0.326***		0.209	0.413***	-0.370***	-0.243*	0.008	0.005		0.133	0.083	0.003	0.052
Constant	-0.582***	-0.509***	-0.532**	-0.554***	-0.623***	-0.394***	-0.614**	-0.416***	-0.358***	-0.351*	-0.410***	-0.435***	-0.375***	-0.318*
# obs	*3002*	*3002*	*1231*	*2143*	*3002*	*2712*	*1320*	*3038*	*3038*	*1240*	*2170*	*3038*	*2710*	*1316*
R2	*0.56*	*0.56*	*0.45*	*0.60*	*0.55*	*0.44*	*0.37*	*0.63*	*0.64*	*0.42*	*0.68*	*0.63*	*0.58*	*0.47*
χ^2 tests for:														
Δ global vars "post"	***23.0******	***27.5******		***51.1******	***113.5******	***47.1******	***44.4******	***2.6***	***4.4***		***9.3****	***8.1***	***4.5***	***9.1***
Global vars jointly	***154.3******	***165.5******	***163.1******	***178.3******	***197.3******	***157.5******	***372.5******	***40.0******	***36.3******	***37.6******	***32.8******	***29.4******	***36.5******	***111.6******

Notes: *Left side of table reports sensitivity tests for column (3) in Figure 3, and right side for column (4) in Figure 3. Column (1) on each side reports base case. Column (2) uses the OECD output gap instead of the principal component of a larger set of measures. Column (3) only includes the last decade (2008-17). Column (4) includes the full period starting in 1993, but excludes the global financial crisis and euro crisis periods (i.e., from 2008-2014). Column (5) only includes the last 5 years (2013-2017) as the "post" period. Column (6) excludes emerging markets and column (7) only includes advanced economies outside the euro area. Regressions of quarterly, annualized CPI or core inflation using random effects with robust standard errors clustered by country. See notes to Figure 3 for more details. The χ^2 test statistics reported at the bottom are: a test if the five global variables changed significantly in the "post" period (if the coefficients on their interactions are jointly significantly different than zero); and if the global variables in the both periods are significantly different than zero. The ***, **, * are significant at the 1%, 5% and 10% levels, respectively.*

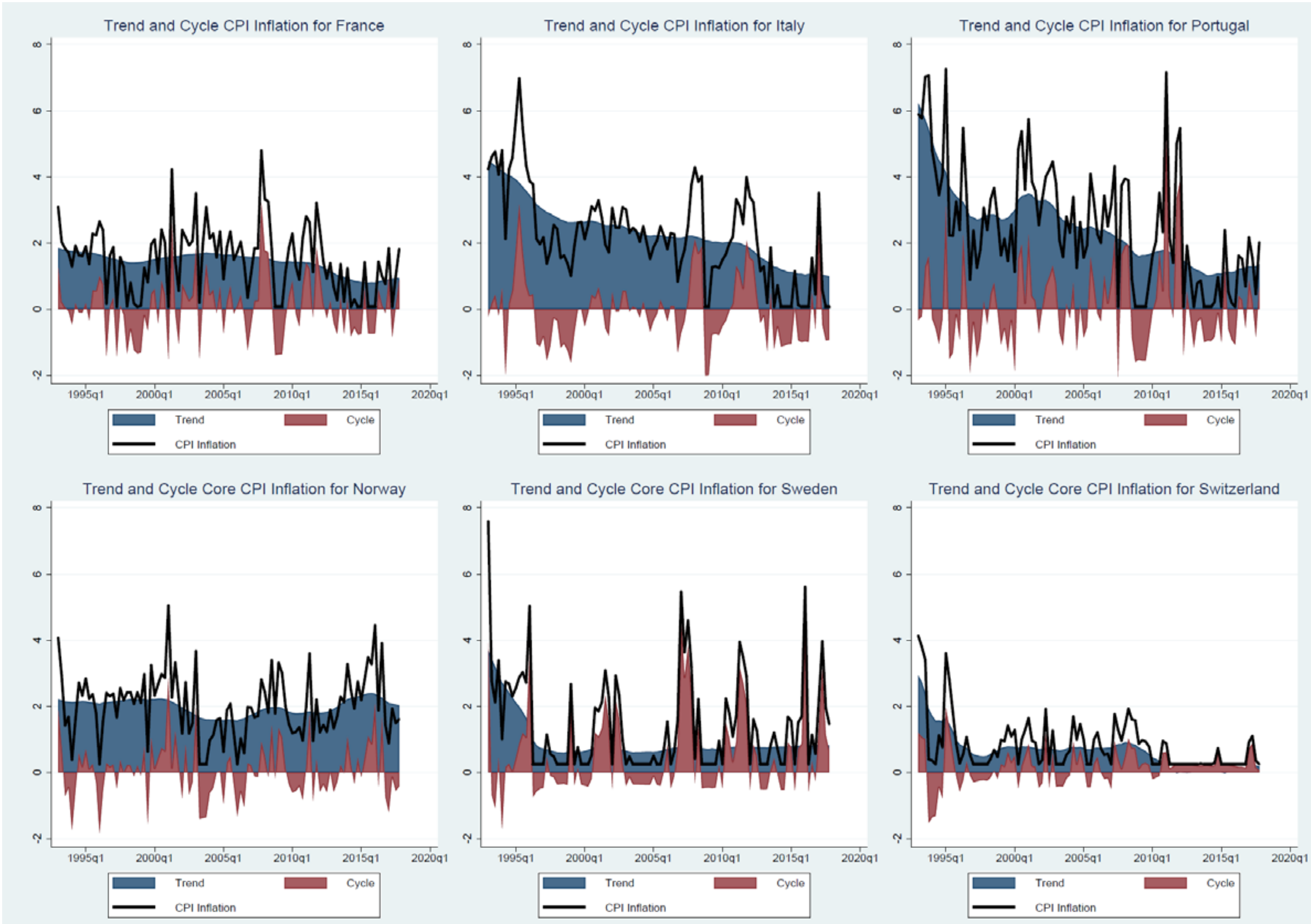
Figure 7

Median Values for Key Statistics for Trend-Cycle Estimates

	15%-85% Trend Range		Variance in "Trend"		Variance in "Cycle"		% of Variation Explained by Trend	
	CPI (1)	Core (2)	CPI (3)	Core (4)	CPI (5)	Core (6)	CPI (7)	Core (8)
1997-2017	0.954	0.708	0.382	0.311	1.504	0.710	31%	55%
1997-2006	0.910	0.787	0.268	0.325	1.297	0.836	21%	44%
2007-2017	1.051	0.663	0.172	0.109	1.589	0.600	37%	58%

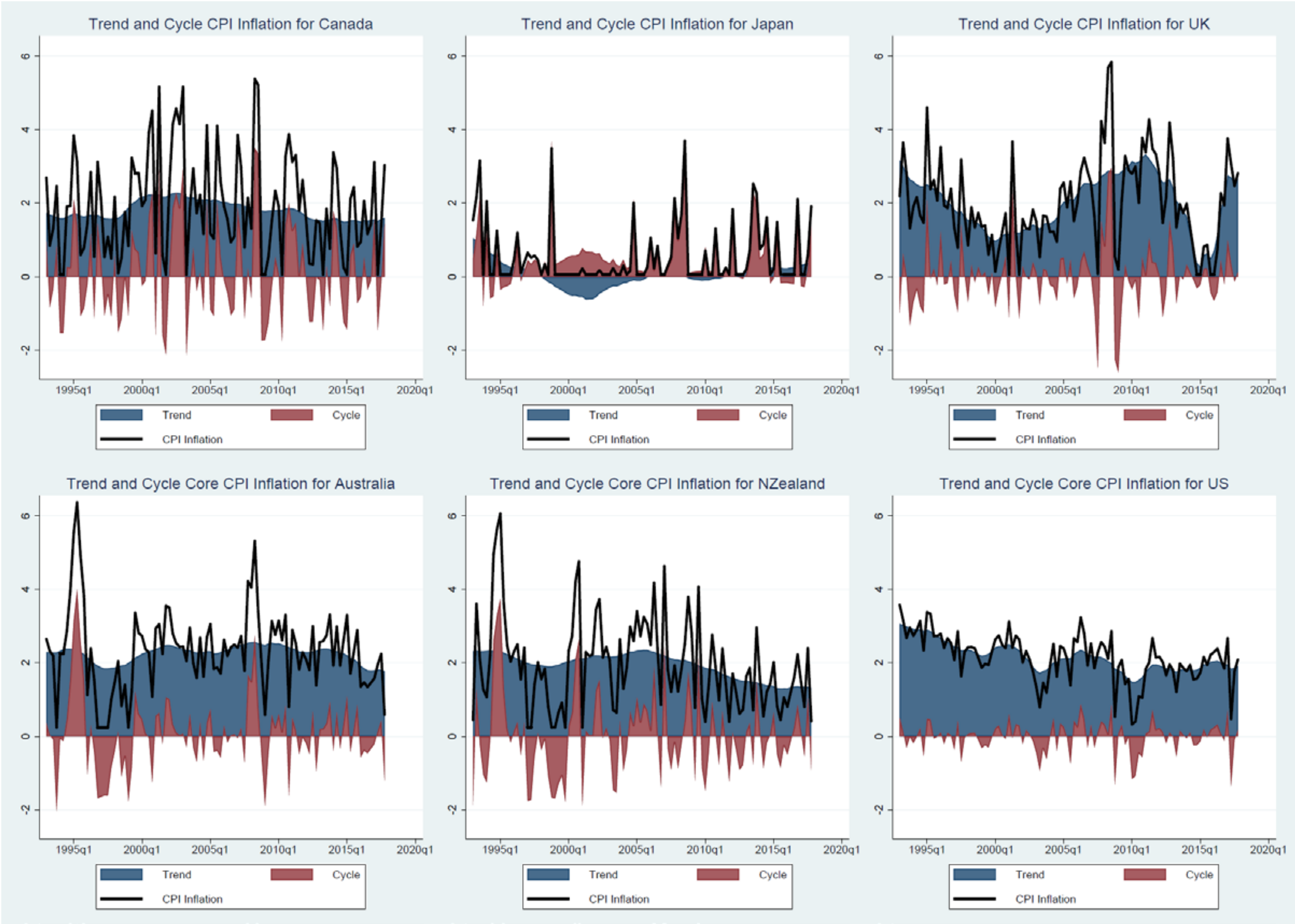
Notes: *Table reports key statistics for estimates of trend and cycle for CPI and core inflation for advanced economies using ARSV model developed in Forbes et al. (2017) and discussed in Section IV.A and equations (2)-(8). The column "15% to 85% Trend Range" reports the range between the 15th and 85th percentile estimates of the corresponding measure of the trend. See Appendix D for corresponding statistics for individual countries.*

Figure 8a: Trend-Cycle Estimates in Europe



Notes: *Black line is inflation (quarterly, annualized and seasonally adjusted). Estimates of trend (in blue) and cyclical component (in red) using ARSV model developed in Forbes et al. (2017) and discussed in Section IV.A and equations (2)-(8). Headline CPI inflation in top row and core inflation in bottom row.*

Figure 8b: Trend-Cycle Estimates Outside of Europe



Notes: *Black line is inflation (quarterly, annualized and seasonally adjusted). Estimates of trend (in blue) and cyclical component (in red) using ARSV model developed in Forbes et al. (2017) and discussed in Section IV.A and equations (2)-(8). Headline CPI inflation in top row and core inflation in bottom row.*

Figure 9: The Cycle and Trend in CPI and Core Inflation—Pooled Estimates

	CPI Inflation (1)	Core Inflation (2)	CPI Inflation (3)	Core Inflation (4)
Trend Inflation	0.635***	0.589***	0.588***	0.574***
	(0.117)	(0.129)	(0.129)	(0.141)
Inflation Expectations	0.565***	0.283***	0.642***	0.333**
	(0.203)	(0.109)	(0.234)	(0.139)
Domestic Output Gap	0.120***	0.119***	0.144***	0.138**
	(0.040)	(0.035)	(0.053)	(0.054)
Real Exchange Rate	-0.022	-0.009	-0.021	-0.010
	(0.015)	(0.011)	(0.015)	(0.010)
World Output Gap	0.067***	0.028	0.059	-0.042
	(0.020)	(0.020)	(0.054)	(0.052)
World Oil Prices	0.002***	0.000	0.001**	0.000
	(0.001)	(0.000)	(0.001)	(0.000)
World Commodity Prices	0.007***	0.000	0.000	0.000
	(0.002)	(0.001)	(0.003)	(0.002)
World PPI Dispersion	0.103***	0.048**	0.263***	0.109**
	(0.034)	(0.023)	(0.044)	(0.049)
*Post * Trend*			0.178	0.191
			(0.157)	(0.145)
*Post * Inflation Expectations*			-0.090	-0.074
			(0.186)	(0.221)
*Post * Domestic Output Gap*			-0.068	-0.059
			(0.056)	(0.056)
*Post *Real Exchange Rate*			-0.008	0.000
			(0.016)	(0.016)
*Post * World Output Gap*			0.054	0.122**
			(0.058)	(0.057)
*Post * World Oil Prices*			0.001	0.001
			(0.001)	(0.001)
*Post * World Commodity Prices*			0.008**	0.000
			(0.004)	(0.003)
*Post * World PPI Dispersion*			-0.233***	-0.099
			(0.075)	(0.072)
Adj. R2	***0.61***	***0.56***	***0.62***	***0.57***
# obs	***2725***	***2641***	***2725***	***2641***
χ2 te st for change in 5 global variables in 2007-17			***29.98****	***14.90***

Notes: *Regressions of quarterly (annualized and seasonally-adjusted) CPI or core inflation on the trend and other variables using random effects with robust standard errors clustered by country. See Appendix A for variable definitions. Sample period is 1993q1-2017q4. "Post" is a dummy variable equal to one in the period from 2007-17. A constant term is included but not reported. The χ^2 test statistic reported at the bottom is a test if the five global variables interacted with the post-period dummy are jointly significantly different than zero. The ***, **, * are significant at the 1%, 5% and 10% levels, respectively.*

Figure 10: The Trend in CPI and Core Inflation—Pooled Estimates

	Trend CPI (1)	Trend Core (2)	Trend CPI (3)	Trend Core (4)
Inflation	0.032	0.112***	0.105***	0.125***
Expectations	(0.050)	(0.031)	(0.029)	(0.037)
Domestic	0.015	0.033***	0.017	0.045***
Output Gap	(0.013)	(0.009)	(0.013)	(0.014)
Real Exchange	-0.007**	-0.002**	-0.013*	-0.005**
Rate	(0.003)	(0.001)	(0.007)	(0.002)
World Output	0.017	-0.003	-0.012	-0.006
Gap	(0.026)	(0.005)	(0.033)	(0.018)
World Oil	0.001**	0.000	0.000	0.000
Prices	(0.000)	(0.000)	(0.000)	(0.000)
World Commodity	0.001	0.001	0.001	0.001
Prices	(0.001)	(0.001)	(0.001)	(0.001)
World PPI	-0.026	0.013*	0.000	0.022
Dispersion	(0.018)	(0.008)	(0.019)	(0.017)
*Post * Inflation*			-0.407	-0.064
Expectations			(0.297)	(0.048)
*Post * Domestic*			0.013	-0.021
Output Gap			(0.024)	(0.015)
*Post *Real*			0.012*	0.006**
Exchange Rate			(0.007)	(0.003)
*Post * World*			0.018	0.000
Output Gap			(0.040)	(0.023)
*Post * World Oil*			0.001**	0.001*
Prices			(0.001)	(0.000)
*Post * World*			-0.002	0.000
Commodity Prices			(0.002)	(0.000)
*Post * World*			-0.073*	-0.030*
PPI Dispersion			(0.039)	(0.018)
Adj. R2	***0.01***	***0.02***	***0.03***	***0.02***
# obs	***2680***	***2574***	***2680***	***2574***
χ2 t est for change in 5 global variables in 2007-17			***9.11***	***5.00***

Notes: *Regressions of quarterly trend CPI or trend core inflation using random effects with robust standard errors clustered by country. See Appendix A for variable definitions. Sample period is 1993q1-2017q4. "Post" is a dummy variable equal to one in the period from 2007-17. A constant term is included but not reported. The trend and all explanatory variables expressed in differences. The χ^2 test statistic reported at the bottom is a test if the five global variables interacted with the post-period dummy are jointly significantly different than zero. The ***, **, * are significant at the 1%, 5% and 10% levels, respectively.*

Figure 11a: The Cycle and Trend in CPI and Core Inflation—Sensitivity Analysis

	HEADLINE CPI							CORE CPI						
	Base	Output Gap (not PC)	Only 2008-17	Drop Crises (2008-14)	"Post" is 2013-17	Exclude EMs	Non-Euro AEs only	Base	Output Gap instead of PC	Only 2008-17	Drop Crises (2008-14)	"Post" is 2013-17	Exclude EMs	Non-Euro AEs only
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Trend	0.588***	0.573***	0.807***	0.581***	0.616***	1.023***	1.008***	0.574***	0.555***	0.709***	0.578***	0.586***	0.923***	0.869***
Inflation Expect.	0.642***	0.680***	0.326*	0.707***	0.596***	0.038	-0.137	0.333**	0.362***	0.429	0.303**	0.332***	0.082	-0.026
Domestic Out. Gap	0.144***	0.162***	0.086***	0.149***	0.122**	0.035	0.073	0.138**	0.153***	0.068***	0.136**	0.128***	0.050*	0.057
Exchange Rate	-0.021	-0.027*	-0.037*	-0.022	-0.023	-0.025*	-0.030	-0.010	-0.014	-0.017	-0.009	-0.004	-0.008	-0.013
World Out. Gap	0.059	-0.036	0.162***	0.060	0.043**	0.003	-0.039	-0.042	-0.126**	0.111***	-0.041	0.018	0.027	0.025
Oil Prices	0.001**	0.001**	0.001*	0.001**	0.002***	0.001*	0.001*	0.000	0.000	0.001	0.000	0.000	0.000	0.000
Commodity Prices	0.000	0.000	0.012***	0.000	0.006***	0.001	-0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PPI Dispersion	0.263***	0.259***	0.025	0.259***	0.084**	0.264***	0.285***	0.109**	0.105**	0.003	0.111**	0.068*	0.071	0.064
Interacted with Post period (2007-present)														
*Post*Trend*	0.178	0.192		0.077	0.179	-0.282**	0.217	0.191	0.179		0.338*	0.250	-0.192	0.198
*Post*Inf. Exp.*	-0.090	-0.126		-0.119	-0.203	0.431***	-0.077	-0.074	-0.093		-0.242	-0.243	0.295	-0.040
*Post*Dom. OutGap*	-0.068	-0.145***		-0.129*	-0.051	0.054	0.085	-0.059	-0.104**		-0.066	-0.073	0.030	0.042
*Post*ER*	-0.008	-0.002		0.044**	0.005	-0.003	0.011	0.000	0.001		0.002	-0.023**	0.000	0.002
*Post*World OutGap*	0.054	0.172***		0.273***	0.143**	0.112**	0.093	0.122**	0.195***		0.117**	0.003	0.044	0.041
*Post*Oil*	0.001	0.001		0.003**	-0.003***	0.002	0.003	0.001	0.001		0.000	0.000	0.001	0.002
*Post*Commodity*	0.008**	0.008**		-0.026***	-0.004	0.008**	0.006	0.000	0.000		-0.005	-0.004	0.000	-0.001
*Post*PPI Disp.*	-0.233***	-0.229***		0.152	0.297***	-0.249***	-0.177	-0.099	-0.095		-0.072	-0.064	-0.071	-0.055
Constant	-0.357*	-0.360*	0.172	-0.493*	-0.238	-0.099	0.407	0.201	0.221*	-0.024	0.264	0.238	0.020	0.404*
# obs	*2725*	*2725*	*1143*	*1930*	*2725*	*2443*	*1189*	*2641*	*2641*	*1120*	*1857*	*2641*	*2409*	*1256*
R2	*0.62*	*0.63*	*0.53*	*0.66*	*0.62*	*0.54*	*0.47*	*0.57*	*0.58*	*0.45*	*0.61*	*0.57*	*0.57*	*0.48*
χ2 tests for:														
Δ global vars "post"	***30.0******	***35.5******		***23.0******	***69.3******	***65.7******	***49.0******	***14.9*****	***18.7******		***12.3*****	***5.1***	***6.1***	***5.2***
Global vars jointly	***173.5******	***128.1******	***133.8******	***143.1******	***142.6******	***185.7******	***1,245.2******	***32.8******	***34.9******	***20.9******	***21.6*****	***30.7******	***25.2******	***76.7******

Notes: *Left side of table reports sensitivity tests for column (3) in Figure 9, and right side for column (4) in Figure 9. Column (1) on each side reports base case. Column (2) uses the OECD output gap instead of the principal component of a larger set of measures. Column (3) only includes the last decade (2008-17). Column (4) includes the full period starting in 1993, but excludes the global financial crisis and euro crisis periods (i.e., from 2008-2014). Column (5) only includes the last 5 years (2013-2017) as the "post" period. Column (6) excludes emerging markets and column (7) only includes advanced economies outside the euro area. Regressions of quarterly, annualized CPI or core inflation using random effects with robust standard errors clustered by country. See notes to Figure 9 for more details. The χ^2 test statistics reported at the bottom are: a test if the five global variables changed significantly in the "post" period (if the coefficients on their interactions are jointly significantly different than zero); and if the global variables in the both periods are significantly different than zero. The ***, **, * are significant at the 1%, 5% and 10% levels, respectively.*

Figure 11b: The Trend in CPI and Core Inflation—Sensitivity Analysis

TREND CPI

	Base	Output Gap (not PC)	Only 2008-17	Drop Crises (2008-14)	"Post" is 2013-17	Exclude EMs	Non-Euro AEs only
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Inflation Ex	0.105***	0.103***	-0.347	0.086***	0.028	0.070***	0.045
Domestic C	0.017	0.033*	0.036*	0.014	0.014	0.020**	0.027***
Exchange R	-0.013*	-0.014**	-0.002	-0.013*	-0.008*	-0.003**	-0.002**
World Out.	-0.012	-0.041	0.006	-0.003	0.012	0.028**	0.011
Oil Prices	0.000	0.000	0.001**	0.000	0.001**	0.000	0.000
Commodity	0.001	0.001	0.001	0.001	0.001	0.001*	0.000**
PPI Dispers	0.000	0.000	-0.063**	-0.003	-0.036*	-0.009	-0.008
Interacted with Post period (2007-present)							
*Post*Inf. Ex*	-0.407	-0.588		-0.170**	0.013	-0.397	0.012
*Post*Dom.*	0.013	0.082		-0.019	0.007	0.010	-0.027***
*Post*ER*	0.012*	0.012		0.016*	0.006	0.003	0.001
*Post*World*	0.018	-0.058		0.215***	0.136***	-0.018	-0.003
*Post*Oil*	0.001**	0.001**		0.001	0.000	0.001**	0.000
*Post*Comm*	-0.002	-0.001		-0.002	0.001	-0.002	0.000
*Post*PPI Di*	-0.073*	-0.081*		-0.014	0.063**	-0.071*	0.006
Constant	-0.036***	-0.035***	-0.036***	-0.049**	-0.050***	-0.023***	-0.017***
# obs	*2680*	*2680*	*1142*	*1886*	*2680*	*2408*	*1173*
R2	*0.03*	*0.07*	*0.03*	*0.04*	*0.02*	*0.03*	*0.08*
χ2 tests for:							
Δ global va	***9.1***	***7.8***		***11.7*****	***12.4*****	***8.7***	***9.2***
Global vars	***25.0******	***20.5*****	***8.7***	***28.1******	***27.8******	***22.6*****	***2,602.8******

TREND CORE

	Base	Output Gap nstead of P	Only 2008-17	Drop Crises (2008-14)	"Post" is 2013-17	Exclude EMs	Non-Euro AEs only
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Inflation Ex	0.125***	0.112***	0.060**	0.110***	0.115***	0.088***	0.083***
Domestic C	0.045***	0.071***	0.023**	0.043***	0.038***	0.037***	0.024**
Exchange R	-0.005**	-0.006***	0.001	-0.005**	-0.002*	-0.003*	-0.001
World Out.	-0.006	-0.064**	-0.003	0.004	-0.007	0.009	0.004
Oil Prices	0.000	0.000	0.001	0.000	0.000	0.000	0.000
Commodity	0.001	0.001	0.000	0.001	0.001	0.001*	0.000**
PPI Dispers	0.022	0.022	-0.007	0.018	0.007	0.006	0.001
Interacted with Post period (2007-present)							
*Post*Inf. Ex*	-0.064	-0.113*		-0.116*	-0.102***	-0.022	-0.059***
*Post*Dom.*	-0.021	-0.034*		-0.012	-0.031**	-0.014	-0.016**
*Post*ER*	0.006**	0.006**		0.003	0.001	0.004	0.000
*Post*World*	0	0.031		0.057	0.066**	-0.017	-0.008
*Post*Oil*	0.001*	0.001*		0.000	0.000	0.001	0.000**
*Post*Comm*	0.000	0.000		-0.001	0.000	0.000	0.000
*Post*PPI Di*	-0.030*	-0.031*		0.011	0.032**	-0.012	-0.004
Constant	-0.031***	-0.031***	-0.012***	-0.046***	-0.033***	-0.026***	-0.019***
# obs	*2574*	*2605*	*1120*	*1821*	*2605*	*2378*	*1241*
R2	*0.02*	*0.04*	*0.01*	*0.05*	*0.02*	*0.02*	*0.08*
χ2 tests for:							
Δ global va	***5.0***	***5.6***		***19.7******	***15.2******	***4.0***	***11.9*****
Global vars	***24.4******	***35.1******	***7.6***	***51.6******	***45.7******	***23.0*****	***64.4******

Notes: *Left side of table reports sensitivity tests for column (3) in Figure 10, and right side for column (4) in Figure 10. Column (1) on each side reports base case. Column (2) uses the OECD output gap instead of the principal component of a larger set of measures. Column (3) only includes the last decade (2008-17). Column (4) includes the full period starting in 1993, but excludes the global financial crisis and euro crisis periods (i.e., from 2008-2014). Column (5) only includes the last 5 years (2013-2017) as the "post" period. Column (6) excludes emerging markets and column (7) only includes advanced economies outside the euro area. Regressions of quarterly, annualized CPI or core inflation using random effects with robust standard errors clustered by country. See notes to Figure 10 for more details. The χ^2 test statistics reported at the bottom are: a test if the five global variables changed significantly in the "post" period (if the coefficients on their interactions are jointly significantly different than zero); and if the global variables in the both periods are significantly different than zero. The ***, **, * are significant at the 1%, 5% and 10% levels, respectively.*

APPENDIX A: Data Definitions and Statistics

Variable	Definition	Details	Source	Mean	St. Dev.
Price/inflation Data					
CPI	Consumer prices, all items	Calculated as quarterly percent changes, annualized, seasonally adjusted[1]	Index data from IMF	4.071	3.780
Commodity prices, exc. fuel	World commodity price index, excluding fuel	Calculated as quarterly percent changes, annualized, in base regressions measured as difference relative to CPI or core inflation	Index from Datastream, code: WDXWPCN.F	3.876	20.379
Core inflation	Consumer prices, all items except food and energy	Calculated as quarterly percent changes, annualized, seasonally adjusted[1]	Index data from OECD	2.806	2.239
Oil prices	World oil price index	Includes oil, Brent, crude and post prices. Calculated as quarterly percent changes, annualized, in base regressions measured as difference relative to CPI or core inflation	Index from Datastream, code: WDXWPOI.F	24.24 6	82.135
Producer Price Inflation	Producer prices, all commodities	Calculated as quarterly percent changes, annualized, seasonally adjusted[1]	Index data from IMF	3.325	4.995
Service inflation	Consumer prices for services less housing	Calculated as quarterly percent changes, annualized, seasonally adjusted[1]	Index data from OECD	3.525	2.616
Wage inflation	Hourly earnings in the private sector	Calculated as quarterly percent changes, annualized, seasonally adjusted	Index data from OECD	3.609	2.824
Labor Market/Output gap data					
Domestic Output gap	Principal component of 7 measures of domestic slack, with a negative value indicating more slack	Principal component of as many of following variables as available: OECD domestic output gap, unemployment gap, participation gap, hours gap, involuntary workers gap, self-employment gap and temporary workers gap, all defined below	Calculated	- 0.274	1.810
Hours gap	Difference between hours worked and "normal" hours	Calculated as % of "normal" hours worked (the sample average for each country)	Calculated based on OECD data	0.000	0.029
Involuntary part-time workers gap	Difference between "normal" involuntary workers and current involuntary workers	Calculated as % of "normal" involuntary workers (the sample average for each country); available annually and interpolated to quarterly	Calculated based on Hong *et al*. (2017) data	0.423	-1.678
OECD Domestic Output gap	Output gap as % of GDP	Available annually and interpolated to quarterly	OECD	- 0.656	2.944
Participation gap	Gap between actual participation rate and "normal" participation rate	Calculated as % of "normal" participation rate (the sample average for each country); available annually and interpolated to quarterly	Calculated based on OECD data	- 0.175	1.077

Self-employment gap	Difference between "normal" self-employment and current rate of self-employment	Calculated as % of "normal" self-employment (sample average for each country)	Calculated based on OECD data	0.000	0.128
Temporary workers gap	Difference between "normal" temporary workers and current temporary workers	Calculated as % of "normal" temporary workers (sample average for each country); available annually and interpolated to quarterly	Calculated based on Hong *et al*. (2017) data	0.000	0.228
Unemployment gap	Difference of NAIRU and unemployment rate	Available annually and interpolated to quarterly	OECD	-0.374	1.739
World Output Gap	Estimated output gap for the entire OECD	Calculated as a % of GDP for relevant economies	OECD	-0.649	1.525
Other Control Variables					
Exports to GDP	Exports of goods and services to GDP	Quarterly data summed over last 4 quarters (or annual data interpolated if not available)	IMF, IFS	1.227	4.331
Inflation Expectations	5-year ahead forecast for CPI inflation	Forecasts released in spring WEO are treated as Q1, and in fall WEO as Q3; Q2 and Q4 are interpolated between the nearest spring and fall forecasts	IMF, from historical WEO forecasts, at: https://www.imf.org/external/pubs/ft/weo/faq.htm	2.842	1.175
PPI Dispersion	Dispersion of producer prices	Variance in producer prices for all countries in sample in each quarter	Calculated based on IMF PPI	4.266	0.721
Real exchange rate index	Real effective exchange rate based on consumer prices	% change in real exchange rate, relative to 8 quarters earlier	IMF, IFS	0.840	6.600

Note: Adjustments for VAT increases: Australia in 2000q3, Japan in 1997q2 and 2014q2, New Zealand in 2010q4, and United Kingdom in 2010q1 and 2011q1.

Appendix B: Country Sample

Advanced Economies[1]		*Emerging Economies*[1]
Australia	Korea	Brazil
Austria	Latvia	Chile
Belgium	Lithuania	China
Canada	Luxembourg	Colombia
Czech Republic	Netherlands	Hungary
Denmark	New Zealand	India
Estonia	Norway	Indonesia
Finland	Portugal	Mexico
France	Slovak Republic	Poland
Germany	Slovenia	Russia
Greece	Spain	South Africa
Iceland	Sweden	Turkey
Ireland	Switzerland	
Israel	United Kingdom	
Italy	United States	
Japan		

Note: Division between advanced economies and emerging markets based on definitions in IMF, *World Economic Outlook,* 2017Q4.

Appendix C: Phillips Curve Estimates—Individual Country Results

	CPI Inflation (1)	Core Inflation (2)	CPI Inflation (3)	Core Inflation (4)
% significant with expected sign:				
Inflation Expectations	45%	53%	35%	52%
Lagged Inflation	59%	84%	39%	52%
Domestic Output Gap	38%	38%	39%	35%
Real Exchange Rate	34%	28%	35%	26%
World Output Gap	28%	25%	6%	16%
World Oil Prices	22%	13%	23%	10%
World Commodity Prices	28%	16%	6%	19%
World PPI Dispersion	13%	6%	16%	6%
% significant and either positive or negative:				
*Post * Inflation*		*positive*	10%	19%
Expectations		*negative*	6%	0%
*Post * Lagged*		*positive*	10%	3%
Inflation		*negative*	10%	39%
*Post * Domestic*		*positive*	3%	13%
Output Gap		*negative*	13%	26%
*Post *Real*		*positive*	13%	6%
Exchange Rate		*negative*	13%	10%
*Post * World*		*positive*	19%	23%
Output Gap		*negative*	3%	13%
*Post * World Oil*		*positive*	6%	6%
Prices		*negative*	6%	3%
*Post * World*		*positive*	10%	10%
Commodity Prices		*negative*	0%	13%
*Post * World*		*positive*	0%	3%
PPI Dispersion		*negative*	13%	6%
χ2 test for change in 5 global variables in 2007-17			***32%***	***26%***
% with at least 1 significant global variable	***48%***	***34%***	***55%***	***52%***

Notes: *Table reports the % of coefficients that are significant at the 10% level with the sign as noted for the Phillips curve regression in equation (1) for quarterly CPI and core inflation from 1990-2017, estimated individually for each country. The "expected sign" in the top half of the table on all coefficients is positive, except on the Real Exchange Rate. In the bottom half of the table, results are reported for either sign. Constant is included but not reported. See Appendix A for data definitions. Estimates are OLS with robust standard errors.*

Appendix D: Key Statistics for Trend-Cycle Estimates by Country

	15%-85% Trend Range		Variance in "Trend"		Variance in "Cycle"		% of Variation Explained by Trend	
	CPI (1)	Core (2)	CPI (3)	Core (4)	CPI (5)	Core (6)	CPI (7)	Core (8)
Australia	0.95	0.71	0.07	0.05	1.91	1.01	5%	6%
Austria	0.95	0.62	0.15	0.18	1.01	0.53	13%	23%
Belgium	1.11	0.35	0.59	0.05	1.08	0.47	29%	16%
Canada	0.87	0.41	0.06	0.00	1.71	0.71	8%	8%
Czech Republic	.	0.84	.	0.40	.	1.32	.	63%
Denmark	0.33	0.42	0.00	0.11	1.26	0.33	0%	23%
Estonia	3.34	1.01	12.09	2.68	8.61	0.43	98%	85%
Finland	1.05	1.02	0.28	0.14	1.09	0.79	22%	24%
France	0.55	0.42	0.09	0.21	0.82	0.19	12%	49%
Germany	0.75	.	0.08	.	0.77	.	20%	.
Greece	1.65	1.37	10.69	13.58	1.28	2.89	106%	211%
Iceland	1.89	1.27	0.90	0.14	7.64	4.51	16%	13%
Ireland	1.04	1.25	5.87	5.44	2.21	2.73	159%	152%
Israel	2.14	2.12	12.14	14.30	5.75	5.45	76%	174%
Italy	0.91	0.58	0.76	1.22	1.00	0.30	38%	75%
Japan	0.64	0.50	0.12	0.19	0.60	0.13	87%	361%
Korea	0.99	0.86	1.68	1.35	3.12	1.09	38%	55%
Latvia	3.40	2.34	63.54	2.88	25.87	1.50	347%	59%
Lithuania	.	2.21	.	0.74	.	2.64	.	39%
Luxembourg	0.62	0.39	0.07	0.03	1.40	0.67	7%	5%
Netherlands	0.80	0.61	0.36	0.24	0.75	0.60	31%	26%
New Zealand	0.82	0.66	0.12	0.12	1.91	1.30	6%	8%
Norway	0.68	0.58	0.02	0.05	2.66	0.72	2%	9%
Portugal	1.20	0.93	1.34	3.23	1.71	0.77	53%	90%
Slovenia	2.10	0.97	10.71	1.58	2.72	0.67	93%	76%
Spain	1.15	0.64	0.84	1.52	1.73	0.71	30%	75%
Sweden	1.32	0.98	0.40	0.42	1.32	1.67	49%	57%
Switzerland	0.80	0.67	0.31	0.31	0.72	0.30	65%	85%
United Kingdom	0.91	0.77	0.59	0.48	0.79	0.39	45%	58%
United States	0.90	0.46	0.14	0.14	1.60	0.17	11%	42%
Median	***0.95***	***0.71***	***0.38***	***0.31***	***1.50***	***0.71***	***31%***	***55%***
Mean	***1.21***	***0.89***	***4.43***	***1.79***	***2.97***	***1.21***	***52%***	***68%***
# Obs	***28***	***29***	***28***	***29***	***28***	***29***	***28***	***29***
Min	***0.33***	***0.35***	***0.00***	***0.00***	***0.60***	***0.13***	***0%***	***5%***
Max	***3.40***	***2.34***	***63.54***	***14.30***	***25.87***	***5.45***	***347%***	***361%***
Std. Deviation	***0.75***	***0.53***	***12.25***	***3.59***	***4.91***	***1.29***	***70%***	***76%***

Notes: *Table reports key statistics for estimates of trend and cycle estimates of CPI and core inflation using ARSV model developed in Forbes et al. (2017) and discussed in Section IV.A and equations (2)-(8). The column "15% to 85% Trend Range" reports the range between the 15th and 85th percentile estimates of the corresponding measure of the trend.*

Appendix E: The Cycle and Trend in CPI and Core Inflation—Individual Country Estimates

	CPI Inflation (1)	Core Inflation (2)	CPI Inflation (3)	Core Inflation (4)
% significant with expected sign:				
Trend Inflation	96%	100%	89%	93%
Inflation Expectations	21%	7%	11%	15%
Domestic Output Gap	21%	15%	18%	26%
Real Exchange Rate	21%	7%	14%	11%
World Output Gap	21%	11%	0%	22%
World Oil Prices	14%	11%	21%	11%
World Commodity Prices	11%	4%	0%	4%
World PPI Dispersion	14%	7%	7%	7%
% significant and either positive or negative:				
*Post * Trend*		*positive*	21%	26%
		negative	18%	11%
*Post * Inflation Expectations*		*positive*	21%	26%
		negative	14%	19%
*Post * Domestic Output Gap*		*positive*	7%	7%
		negative	11%	7%
*Post *Real Exchange Rate*		*positive*	11%	4%
		negative	4%	15%
*Post * World Output Gap*		*positive*	18%	7%
		negative	0%	15%
*Post * World Oil Prices*		*positive*	7%	7%
		negative	0%	7%
*Post * World Commodity Prices*		*positive*	7%	11%
		negative	0%	7%
*Post * World PPI Dispersion*		*positive*	0%	4%
		negative	4%	7%
χ2 te st for change in 5 global variables in 2007-17			***14%***	***26%***
% with at least 1 significant global variable	***46%***	***37%***	***61%***	***67%***

Notes: *Table reports the percent of coefficients on each variable that have the expected sign and are significant (at the 5% level) when the respective regression from Figure 9 is estimated for each country individually. All coefficients are expected to be positive, except for the real exchange rate (RER) which is expected to be negative. See notes to Table 9 for details on regression specification. A constant is included in each regression but not reported. Estimates are OLS with robust standard errors.*

Appendix F: The Trend in CPI and Core Inflation: Individual Country Estimates

	Trend CPI (1)	Trend Core (2)	Trend CPI (3)	Trend Core (4)
% significant with expected sign:				
Inflation Expectations	29%	33%	29%	37%
Domestic Output Gap	46%	44%	43%	56%
Real Exchange Rate	29%	19%	36%	19%
World Output Gap	18%	15%	32%	37%
World Oil Prices	43%	7%	7%	7%
World Commodity Prices	36%	19%	21%	15%
World PPI Dispersion	0%	4%	0%	11%
% significant and either positive or negative:				
*Post * Inflation*		*positive*	16%	13%
Expectations		*negative*	12%	13%
*Post * Domestic*		*positive*	14%	11%
Output Gap		*negative*	11%	26%
*Post *Real*		*positive*	21%	11%
Exchange Rate		*negative*	11%	11%
*Post * World*		*positive*	11%	19%
Output Gap		*negative*	21%	22%
*Post * World Oil*		*positive*	14%	7%
Prices		*negative*	4%	4%
*Post * World*		*positive*	0%	0%
Commodity Prices		*negative*	7%	15%
*Post * World*		*positive*	7%	19%
PPI Dispersion		*negative*	7%	7%
χ2 te st for change in 5 global variables in 2007-17			***50%***	***41%***
% with at least 1 significant global variable	***79%***	***59%***	***68%***	***74%***

Notes: *Table reports the percent of coefficients on each variable that have the expected sign and are significant (at the 5% level) when the respective regression from Figure 10 is estimated for each country individually. All coefficients are expected to be positive, except for the real exchange rate (RER) which is expected to be negative. See notes to Table 11 for details on regression specification. A constant is included in each regression but not reported. Estimates are OLS with robust standard errors.*