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Global Factors and Trend Inflation *[†]

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Abstract

We develop a model to empirically study the influence of global factors in driving trend inflation and the inflation gap. We apply our model to five established inflation targeters and a group of heterogeneous Asian economies. Our results suggest that while global factors can have a sizeable influence on the inflation gap, they play only a marginal role in driving trend inflation. Much of the influence of global factors in the inflation gap may be reflecting commodity price shocks. We also find global factors have a greater influence on inflation, and especially trend inflation, for the group of Asian economies relative to the established inflation targeters. A possible interpretation is that inflation targeting may have reduced the influence of global factors on inflation, and especially so on trend inflation.

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1 Introduction

... are central banks still masters of their domestic monetary destinies? Or have they become slaves to global factors? – Carney (2015)

Figure 1 presents year-on-year inflation in a number of industrialized countries to provide a flavor of global co-movement in inflation. Casual observation suggests inflation co-moves globally: a feature of the data that has been extensively statistically verified (e.g., see Ciccarelli and Mojon, 2010; Mumtaz and Surico, 2012). The stylized fact that inflation co-moves globally has led to interest in quantifying the role of global determinants of inflation (e.g., see Borio and Filardo, 2007; Neely and Rapach, 2011; Bianchi and Civelli, 2015; Auer, Levchenko, and Sauré, 2017) and examining the implications for monetary policy (Carney, 2015).

Our paper contributes to the debate on the role of global factors in driving inflation. Specifically, the main contribution of our paper is to develop a unified framework to study the role of foreign shocks in driving the permanent and transitory components of inflation, which we interpret as trend inflation and the inflation gap respectively. To answer whether global factors have monetary policy implications, we view distinguishing between trend inflation and the inflation gap as key. For example, Draghi (2015b) states "central banks typically choose to 'look through' such global forces until their effect on inflation fades out or until prices reverse". We interpret this statement as typical central banking doctrine that one should "look through" transitory or one-off changes in prices. Correspondingly, the degree of importance one should attach to the foreign determinants of domestic inflation from a policy perspective depends on how much foreign shocks feed into the trend, or the permanent component of, inflation. If the influence of foreign shocks are shown to be one-off or transitory, then the standard doctrine would be to "look through" or not respond to them. Our paper tackles this issue head-on by developing a model which quantifies the role of foreign shocks in the determination of trend inflation and the inflation gap.

We first apply our model to five advanced inflation targeting economies (Australia, Canada, New Zealand, Norway, and Sweden) to establish a benchmark, before applying the model to a more heterogeneous group of Asian economies. We highlight three main findings. First, a key result of our empirical exercise is that while they can have a sizeable influence on the inflation gap, foreign shocks play a smaller role in driving trend inflation. This result is consistent with the idea that inflation in the long-run appears to be a monetary phenomenon largely determined by domestic monetary policy, despite foreign shocks driving its short to medium run fluctuations. Second, we find that commodity price shocks account for a large share of the identified role of foreign shocks in driving inflation gap. Third, we uncover patterns which suggest inflation targeting may have led to foreign shocks having a smaller role in the dynamics of inflation. We make this conclusion by comparing the share of foreign shocks driving trend inflation and the inflation gap in our benchmark group of advanced and established inflation targeters relative to a group of Asian economies with varied monetary policy frameworks. We also find that extending the sample period to a non-inflation targeting period for the five inflation targeters results in a larger share of foreign shocks driving both their trend inflation and inflation gap.

Our empirical model can, at a broad level, be viewed as a Factor-Augmented Vector Autoregression (FAVAR). Using the FAVAR model, we construct trend inflation and the inflation gap consistent with the Beveridge and Nelson (1981)(BN) decomposition. By utilizing the BN decomposition, we adopt a similar concept of trend inflation and the inflation gap which is consistent with the wider trend inflation literature (see, e.g. Stock and Watson, 2007). Taking guidance from the well-established Structural Vector Autoregression (SVAR) literature, the small open economy structure we adopt provides a straightforward identification of foreign and domestic shocks. Our empirical strategy then consists of decomposing trend inflation and the inflation gap into the identified foreign and domestic shocks, thus providing an account of the role of foreign and domestic shocks in driving both trend inflation and the inflation gap.

While Unobserved Components (UC) models have featured prominently in trend inflation literature (e.g., see Stock and Watson, 2007; Mertens, 2016; Chan, Clark, and Koop, 2017), we make a deliberate deviation from the UC literature in one important dimension; by allowing for multivariate information through the FAVAR framework. Our choice allows us to draw on the SVAR literature to identify foreign shocks, and thus tease out causality within our framework. Even so, we stress that the concept of trend inflation is identical to the UC framework, providing a natural link to this body of work. Our work is also related to the literature on the foreign determinants of inflation. In particular, much of the work on the globalization of inflation has looked at the influence of foreign vis-a-vis domestic slack in driving inflation (e.g. Borio and Filardo, 2007; Ihrig, Kamin, Lindner, and Marquez, 2010). Indeed, we concur, similar to others (e.g. Milani, 2010; Eickmeier and Pijnenburg, 2013), that a regression against a foreign slack measure, such as a foreign output gap, is not sufficiently rich to tell apart the effect of domestic shocks from that of foreign shocks. If an economy is sufficiently open, then foreign shocks drive *both* the foreign and domestic slack, which means one cannot tell the influence of foreign shocks without a formal identification exercise, which is why we view our identification exercise as crucial. In this regard, we take a much broader perspective relative to the extant work of foreign determinants of inflation, which largely focus their attention to only a measure of foreign slack.

The rest of the paper is organized as follows. In Section 2, we provide a description and justification of our empirical methodology. In Section 3, we present trend inflation estimates for Australia, Canada, New Zealand, Norway, and Sweden. We also use our decomposition to understand the role of foreign shocks in driving trend inflation and the inflation gap. Section 4 extends the analysis to a heterogeneous group of ten Asian economies and offers a more in-depth look into the role of inflation targeting. We then offer some concluding remarks.

2 Empirical Specification

We first estimate trend inflation and the inflation gap for five advanced inflation targeting economies, before extending our analysis to 10 Asian economies. Our benchmark five advanced economies are Australia, Canada, New Zealand, Norway, and Sweden. Our choice of these five economies as a benchmark, besides their institutional similarities and being regarded as small open economies, is also driven by data considerations. These five economies have at least 25 years of reasonably good and consistent data. This period largely coincides with low inflation, and often an inflation targeting regime, which means the issue of dealing with any possible structural breaks is less relevant. It is natural therefore to first establish some observations about five similar economies with relatively good data, before we extend the analysis to a wider group of Asian economies, where data availability is of greater concern. We subsequently decompose the estimated trend inflation and inflation gap into components driven by foreign and domestic shocks for each country. The second part of our empirical exercise enables us to understand the role of foreign shocks on both trend inflation and the inflation gap. In the subsections that follow, we first introduce our trend-cycle decomposition. We then present our empirical model and briefly discuss our estimation strategy. We also detail our identification procedure to infer the role of foreign shocks.

2.1 Permanent-Transitory Decomposition

This subsection outlines the concepts of trend and gap which we use in this paper. We work with the Beveridge and Nelson (1981) (BN) decomposition to perform a trendcycle decomposition on inflation. The BN decomposition has proven a useful approach to separate trend from cycle in a wide variety of settings (e.g. Evans and Reichlin, 1994; Morley and Piger, 2012; Kamber, Morley, and Wong, 2017). Moreover, the equating of trend inflation as the BN permanent component of inflation is now quite widespread within the empirical literature (e.g. Stock and Watson, 2007; Cogley, Primiceri, and Sargent, 2010). Our work follows in this tradition.

Let π_t represent the inflation rate and assume π_t evolves as a driftless random walk, which is consistent with the current practice of modeling trend inflation (e.g. Stock and Watson, 2007). We denote trend inflation as the BN permanent component of inflation, τ_t , as the long-horizon forecast of the level of inflation given the information at time t and a suitably specified time series model to form this expectation,

$$\tau_t = \lim_{j \to \infty} \mathbb{E}_t \pi_{t+j}.$$
 (1)

The transitory component, $\tilde{\pi}_t$, is the inflation gap, where $\tilde{\pi}_t = \pi_t - \tau_t$. Let $\{\mathbf{y}_t\}$ be a vector of variables with $\Delta \pi_t$, the first difference of inflation, its k^{th} element. We can write the law of motion of the state equation in $\{\mathbf{y}_t\}$ as a first order autoregressive process,

$$\mathbf{y}_{\mathbf{t}} = \mathbf{B}\mathbf{y}_{\mathbf{t}-1} + \mathbf{H}\boldsymbol{\nu}_{\mathbf{t}} \tag{2}$$

where **B** is a companion matrix, ν_t is a vector of serially uncorrelated forecast errors with covariance matrix, Σ_{ν} , and **H** is a matrix which maps the forecast errors to the companion form. Defining $\mathbf{e}_{\mathbf{k}}$ as a selector row vector with 1 as its k^{th} element and zero otherwise, the trend inflation and the inflation gap consistent with the BN decomposition can be written as (see, e.g. Morley, 2002)

$$\tau_t = \pi_t + \mathbf{e}_k \mathbf{B} (\mathbf{I} - \mathbf{B})^{-1} \mathbf{y}_t \tag{3}$$

$$\tilde{\pi}_t = -\mathbf{e}_k \mathbf{B} (\mathbf{I} - \mathbf{B})^{-1} \mathbf{y}_t.$$
(4)

Equations (3) and (4) make it clear that if we have an empirical model cast into a form like Equation (2), we can decompose inflation into its trend and gap components which is consistent with the BN decomposition. We work with what can broadly be described as a Factor-Augmented VAR (FAVAR). Our model choice can readily be cast into the form suggested by Equation (2) and allows us to model specific features of interest to our research question.

While our modeling choice deviates from Unobserved Components (UC) models of trend inflation (e.g. Stock and Watson, 2007; Mertens, 2016), our concept of trend is identical. This stems from the facts that (univariate) UC models possess an ARIMA reduced form (see Watson, 1986; Cochrane, 1994) and that the (filtered) trend from a UC model is equivalent to the BN permanent component (see Morley, Nelson, and Zivot, 2003). By appealing to the BN decomposition, it is clear that our estimate of trend is conceptually identical to that of UC models.¹ We now turn our attention to specifying our empirical model.

¹Moreover, a univariate UC model, like Stock and Watson (2007), may admit moving average dynamics through omitted multivariate information. In the online appendix, we show that the multivariate approach we adopt may be mitigating some of these moving average dynamics and that our modeling approach is conceptually akin to estimating an alternative representation of the univariate UC models.

2.2 FAVAR Model

Our model is close to a standard FAVAR model (e.g., Bernanke, Boivin, and Eliasz, 2005) with slight deviations to allow for some specific features of interest. The FAVAR approach allows us to collect a range of economic data such as industrial production, unemployment, output and employment. We extract factors to account for all such relevant information without being constrained to collect the same data series across all countries, as these may sometimes be unavailable. This is helpful with regards to our modeling approach as our first order of interest is to model inflation. While we allow information such as real domestic economic activity to affect inflation, we are only interested to the extent we can include this as relevant information, rather than the actual series itself. The FAVAR approach thus allows us to account for the real economic environment as factors, without the constraint of specifying similar time series across all countries.

Before getting into specifics, it may be helpful to first provide a broad overview of our model. Our model can be thought of two large blocks, a foreign and domestic block. The two large blocks can also be further sub-divided into two smaller sub-blocks. The two subblocks of the foreign block are made up of commodity prices and factors extracted from taking principal components of a large international dataset. The commodity price subblock is modeled using the real U.S. dollar price of energy, agricultural commodities, and metals and minerals from the World Bank's dataset, and are the same three commodity price series Fernández, Schmitt-Grohé, and Uribe (2017) use to model foreign shocks in their paper. The domestic block is similarly made up of two sub-blocks. The first subblock is made up of factors extracted from principal components of a dataset of domestic variables. The second sub-block includes the first difference of two inflation rates, CPI inflation, which we refer henceforth as headline inflation, and a core inflation measure, often taken to be CPI excluding food and energy. The foreign block is modelled as block exogenous to the domestic block to achieve identification of foreign shocks. This is an identifying restriction which has roots in the traditional small open economy SVAR literature which models the small open economy as too small to affect the foreign economy (e.g. Zha, 1999; Justiniano and Preston, 2010; Fernández, Schmitt-Grohé, and Uribe, 2017). Headline and core inflation are modeled as co-integrated, and thus by construction, share the same permanent component, which is trend inflation in our empirical exercise. The inflation gap is derived from the difference between headline and trend inflation. We model the entire system as a VAR process, with the block exogeneity and error correction term between the two inflation rates being our main deviations from a typical FAVAR model.

Model Specifics

Factors In the model, the domestic and foreign block each features a sub-block which uses factors extracted from international and domestic datasets. The international dataset includes economic indicators such as real GDP, industrial production, capacity utilization, output per person etc., for the U.S., U.K., Germany, France and Japan. To construct domestic factors, for each of the five advanced inflation targeting economies, we construct a dataset comprising, as much as possible, the same set of variables (see Data Appendix for the full list of variables). Data from China is not included in our international dataset as we do not have enough data covering all our sample. This can be potentially problematic given China's growing role in the global economy. However, because we are using factors from five major economies to form an indicator of the global economic environment, the use of factors across five major economies should provide a reasonable guard against misspecifying the state of the global economic environment despite the omission of China. Moreover, we also include variables such as the Baltic Dry Index, which is sometimes taken as an indicator of global economic activity, in the international dataset when we construct factors. Lastly, commodity prices are in the foreign block. To the extent that commodity prices are driven by the state of the global economy means that the role of China is accounted for, albeit in an implicit fashion. All of these features should somewhat, if not fully, mitigate the omission of Chinese data from the construction of the foreign block.²

Selection of Number of Factors To close the specification of our empirical model, we need to determine the number of retained foreign and domestic factors, η^* and η . Our objective with the modeling of factors is to model all relevant information. This is especially important in our context as informational deficiency may render the identified foreign shocks as non-fundamental (e.g., see Fernández-Villaverde, Rubio-Ramrez, Sargent, and Watson, 2007). We therefore use an informational sufficiency test based on the extracted factors as proposed by Forni and Gambetti (2014) to guide the specification of our FAVAR. We start with a baseline specification using the commodity price block, the first difference of headline and core inflation and a one principal component each from the international and domestic dataset. We first specify the domestic block by sequentially adding principal components from the domestic dataset for the equations in the domestic block until the included factor no longer Granger causes any of the included variables at a 5% level of significance. This specifies η . Following which, we then specify the number of retained factors from the international dataset, η^* , by similarly sequentially adding principal components from the foreign block until the included factor no longer Granger

²We do not to include the exchange rate in our baseline model to keep a clean separation between foreign and domestic blocks. Being a relative price, it is not clear whether the exchange rate should be in the domestic or foreign block, especially within the context of the block exogeniety identification. Our results, however, are robust to whether we consider the exchange rate in either of the foreign or domestic block.

causes any of the other variables at a 5% level of significance.³ We allow the number of domestic and foreign factors to differ between countries, but still maintain the domestic and foreign factor dichotomy in our empirical framework, a feature we can exploit to study the effect of foreign shocks.

Co-integration of Headline and Core Inflation The co-integration between headline and core inflation is not strictly necessary for constructing trend inflation and the inflation gap using the BN decomposition. However, given both core inflation and headline inflation should conceptually share the same trend, using some form of error correction mechanism between them should help us better identify the trend component. This is because core inflation is often regarded as removing the transitory component of inflation. Note that our approach does not systematically regard core inflation as trend inflation. If there are fluctuations in core inflation which the model interprets as transitory, the model will parse out these fluctuations when constructing trend inflation.

Estimation Given that a number of the specifications we estimate contain four or five retained factors and that we work with relatively short data samples for some countries, the possibility of overfitting becomes non-trivial. We opt for Bayesian estimation, using the natural conjugate Normal-Inverse Wishart prior in conjunction with the Minnesota Prior, so as to utilize standard methods to apply shrinkage to mitigate possible overfitting. We relegate detail on the specific prior and estimation step to the online appendix. We estimate the FAVAR with four lags, as typical for quarterly data. While we leave estimation details in the online appendix, we highlight that we exclude the constant in the headline and core inflation equations, thus imposing a trend inflation estimate that follows a random walk without drift, and so consistent with the wider trend inflation literature (e.g. Stock and Watson, 2007). Post-estimation, we take the posterior mode (which is analogous to the posterior mean in our class of models), cast it in the form implied by Equation (2) and use Equation (3) and (4) to apply the BN decomposition to get an estimate of trend inflation and the inflation gap. We also detail in the online appendix how to cast the model post-estimation into a form implied by (2).

The sample starts in 1992Q1 and ends in 2016Q4 to coincide with a common sample consisting of observations in an inflation targeting regime with low and stable inflation for all five countries. While starting estimation from the 1980s (the date of the earliest available data) does not materially alter our main conclusions regarding the role of foreign shocks in the inflation gap and trend inflation, the sensitivity of the time series estimate of trend inflation suggests one needs to seriously address structural breaks in order to

³Note that we retain block exogeniety structure throughout our procedure of testing for Granger causality, which is why we test for Granger Causality from the principal components from the domestic dataset to only variables in the domestic block, but test for Granger causality from the principal components from the international dataset to all the variables in the model.

consider data from the 1980s. It is certainly worthwhile to address the breaks if one was interested in estimating a trend inflation model for a specific country. Our objective is, however, to draw conclusions by estimating the model on a wide variety of countries, we choose to restrict the sample rather than deal with each country on an individual basis.

2.3 Decomposing the Role of Foreign Shocks

In order to identify the role of foreign shocks, a final step post-estimation is to orthogonalize the reduced form residuals, ν_t . Let ϵ_t^* and $\bar{\epsilon}_t$ represent the block of foreign and domestic shocks, which are the structural shocks of the model. The structural shocks are constructed to be uncorrelated across and to each other, so as to be able to ascribe a causal interpretation of foreign and domestic shocks. We now define a matrix, **A**, which maps the reduced form shocks to the structural shocks where,

$$\begin{aligned}
\mathbf{A}\boldsymbol{\epsilon}_{t} &= \boldsymbol{\nu}_{t} \\
\begin{pmatrix} \boldsymbol{A}_{11} & \boldsymbol{0} \\ \boldsymbol{A}_{21} & \boldsymbol{A}_{22} \end{pmatrix} \begin{pmatrix} \boldsymbol{\epsilon}_{t}^{*} \\ \bar{\boldsymbol{\epsilon}}_{t} \end{pmatrix} &= \begin{pmatrix} \boldsymbol{\nu}_{t}^{*} \\ \bar{\boldsymbol{\nu}}_{t} \end{pmatrix}.
\end{aligned} (5)$$

The triangular structure of \mathbf{A} reflects an extension of the block exogeneity identification restriction. Note that because we do not attempt to separately identify individual foreign and domestic shocks, our identification procedure is sufficient to aggregate all the foreign and domestic shocks in our model.⁴ Further disaggregation of foreign and domestic shocks will require stronger identification assumptions, which may be less tenable than the looser restriction we currently present. While we present stronger identification restrictions later in the paper to attempt to gain finer interpretation of the foreign shocks, we keep the foreign and domestic shocks dichotomy unless we explicitly state so.

To decompose trend inflation and the inflation gap into foreign and domestic shocks, Morley and Wong (2017) show that the BN permanent and transitory component can be written as a function of the history of forecast errors. This can be shown by recursively substituting Equation (2) into Equations (3) and (4) respectively and substituting $\mathbf{A}\epsilon_{\mathbf{t}} = \nu_{\mathbf{t}}$. After some algebraic manipulation we obtain,

⁴To see this, suppose we had an orthonormal matrix Q where $\begin{pmatrix} Q_{11} & 0 \\ 0 & Q_{22} \end{pmatrix}$ with Q_{11} and Q_{22} are similarly orthonormal. Then it is easy to see that even if we postmultiply **A** by Q, $\Sigma_{\nu} = \mathbf{A}\mathbf{Q}\mathbf{Q}'\mathbf{A}'$ is satisfied and this retains the relative shares of the aggregate foreign and domestic shocks unaltered but merely changes the individual and domestic foreign shocks.

$$\Delta \tau_t = \mathbf{e}_{\mathbf{k}} (\mathbf{I} - \mathbf{B})^{-1} \mathbf{H} \mathbf{A} \boldsymbol{\epsilon}_t \tag{6}$$

$$\tilde{\pi}_t = -\mathbf{e}_k \left\{ \sum_{i=0}^{t-1} B^{i+1} (\mathbf{I} - \mathbf{B})^{-1} \mathbf{H} \mathbf{A} \boldsymbol{\epsilon}_{t-i} \right\} - \mathbf{e}_k B^{t+1} (\mathbf{I} - \mathbf{B})^{-1} \mathbf{e}_k' \Delta \pi_0.$$
(7)

The final term in Equation (7) contains an initial condition, $\Delta \pi_0$, but the influence of the initial condition is expected to vanish towards zero given term, $\mathbf{B^{t+1}}$. Equations (6) and (7) show that the change of trend inflation and the inflation gap are just linear functions of the history of foreign and domestic shocks, which provides the basis for our subsequent analysis.

Comparing our Modeling Approach

Before we move on to discussing the results, it is worth contrasting our modeling choices relative to the wider literature. While there will nevertheless be pros and cons regarding any modeling choice, we wish to emphasize that many of our modeling choices are designed to best explore our focus on the importance of foreign shocks on the dynamics of inflation gap and trend inflation.

A Broader View of Foreign Shocks Our work builds on previous contributions on the globalization of inflation. In much of this work, which is notably inspired by Borio and Filardo (2007), the approach of studying the influence of globalization on inflation is to estimate Phillips Curves augmented by a foreign output gap. Another way of viewing this approach is that global slack, through foreign output gap, is an appropriate proxy for the influence of foreign shocks. A common approach for constructing a foreign slack measure is to extract the cyclical component from a weighted sum of aggregate global output using the HP filter. In our modeling approach, we take a broader view of the foreign determinants of inflation by identifying foreign shocks. To the extent that the existing work uses the foreign output gap as a proxy for foreign shocks, it is more likely that our approach, using a broader dataset, will better identify foreign shocks than a filtered component of weighted output.⁵ Moreover, foreign shocks can drive both the domestic and foreign output gap and solely observing the foreign output gap without a formal identification exercise is insufficient to tell apart the role of foreign shocks or global determinants of inflation, a point which Eickmeier and Pijnenburg (2013) and Bianchi and Civelli (2015) attempt to address in their work. As argued by Ihrig, Kamin, Lindner, and Marquez (2010), the use of a foreign slack may represent an overly narrow

⁵Moreover, it is also well known that the HP filter produces spurious cycle, a point well covered in the rest of the literature that we do not wish to over emphasize (see, e.g. Cogley and Nason, 1995; Phillips and Jin, 2015; Hamilton, 2017).

concept of the role of the globalization of inflation. If one wishes to take a broader view that inflation could be driven by a multitude of foreign shocks, such as commodity price shocks or shocks to the foreign resource utilization that may not be adequately reflected in aggregate output, our approach is likely to be more accurate in determining the effects of foreign shocks.

Contrast with Multivariate UC Models Our work has links to more recent development of multivariate UC models, which follow the highly influential work of Stock and Watson (2007) (e.g. Kim, Manopimoke, and Nelson, 2014; Chan, Clark, and Koop, 2017; Chan, Koop, and Potter, 2016; Stock and Watson, 2016; Mertens, 2016). As we had previously mentioned, our approach can be interpreted similarly to a UC model given the equivalence between the BN trend and the UC (filtered) trend. What distinguishes our modeling approach is that we decompose the trend and cycle into the underlying shocks as in Morley and Wong (2017) and therefore we can ascribe a causal role for foreign and domestic shocks within our modeling framework. One could view our approach as modelling foreign shocks, with trend inflation and the inflation gap in a single step, as opposed to a two step approach of estimating regressions on a trend and gap extracted from a UC model (see, e.g. Forbes, Kirkham, and Theodoridis, 2017). In this respect, our approach provides a more consistent unifying framework to study the issue of how foreign shocks drive trend inflation. At the same time, our reading of the existing multivariate UC work also suggests that while observables such as unemployment (Chan, Koop, and Potter, 2016) or the output gap (Kim, Manopimoke, and Nelson, 2014) may directly enter the law of motion of the inflation gap, designing testable restrictions to ascribe causality on trend inflation is challenging as trend inflation often remains a driftless random walk, driven by its own shock. A strength of our approach is that we can ascribe a causal role of foreign shocks on trend inflation and the inflation gap by building on well-developed tools such as factor models and SVAR identification.

3 Benchmark Results

3.1 Trend Inflation Estimates

Figure 2 presents estimates of trend inflation with quarter on quarter annualized inflation rates. While some of the trend inflation estimates appear to be more volatile than what one would extract from methods such as applying a bandpass or HP filter, we find our estimates for all countries stay largely close to their inflation target.⁶ That said, any comparison relative to an inflation target, or inflation target band, is only suggestive

 $^{^{6}\}mathrm{We}$ present estimates with their inflation target bands in the online appendix to avoid cluttering up our figure.

because the target is often couched in language that does not necessarily correspond to the concept of an infinite horizon forecast.⁷ Given that we are studying a sample of what many regard as successful inflation targeters, however, one's *a priori* expectation is that trend inflation estimates should not deviate too much from these targets. That our trend inflation estimates are close to official inflation targets provides some confidence about their plausibility.

The trend inflation estimates unsurprisingly mirror the inflation experiences of the five countries. It is misleading, however, to interpret the trend inflation estimates as "drawing a line through inflation" and not providing any value-added beyond looking at headline inflation. To the extent that one interpretation of trend inflation is the implicit inflation target (see Cogley and Sbordone, 2008; Cogley, Primiceri, and Sargent, 2010), allowing for possible persistence in the inflation gap would seem like a desirable modeling feature. Despite using quarter-on-quarter, as opposed to year-on-year, inflation, which by construction is noisier, there are certainly periods where headline inflation has persistently deviated from trend inflation. This can most obviously be seen from Sweden, and to some extent, New Zealand, at the end of the sample. Consistent with the wider literature (e.g. Cogley, Primiceri, and Sargent, 2010; Kim, Manopimoke, and Nelson, 2014), our results support the finding that accounting for multivariate information is helpful in allowing for large and persistent deviations of headline inflation from its trend.

3.2 How important are foreign shocks?

This section presents the central point of the paper: while foreign shocks explain a sizeable portion of inflation gap, they only play a limited role in the evolution of trend inflation. To do so we quantify the relative importance of foreign shocks by computing the share of domestic and foreign shocks in the variance decomposition of trend inflation and the inflation gap.

Let N^* and M be the number of foreign variables and the total number of variables in the FAVAR system, respectively. The first difference of headline inflation is in the k^{th} position in the system, with $k > N^*$.⁸ To calculate a variance decomposition, we use Equations (6) and (7) to obtain (see also Morley and Wong, 2017)

⁷For example, Australia has an inflation target of "2-3 percent over the business cycle" while the Reserve Bank of New Zealand is charged to "keep inflation within a range of 1 to 3 percent on average over the medium term".

⁸Recall $N^* = \eta^* + 3$ as the foreign block contains η^* retained principal components from the international dataset and three commodity prices. $M = \eta + 2 + N^*$ as the domestic block contains η retained principal components from the domestic dataset, headline and core inflation.

$$\Psi_F^{\tau} = \frac{\sum_{j=1}^{N^*} \left\{ \mathbf{e}_{\mathbf{k}} (\mathbf{I} - \mathbf{B})^{-1} \mathbf{H} \mathbf{A} \mathbf{e}'_{\mathbf{j}} \right\}^2}{\mathbf{e}_{\mathbf{k}} (\mathbf{I} - \mathbf{B})^{-1} \mathbf{H} \boldsymbol{\Sigma}_{\boldsymbol{\nu}} \mathbf{H}' (\mathbf{I} - \mathbf{B})^{-1'} \mathbf{e}_{\mathbf{k}}'}$$
(8)

$$\Psi_{F}^{\tilde{\pi}} = \frac{\sum_{j=1}^{N^{*}} \left[\mathbf{e}_{\mathbf{k}} \sum_{\mathbf{i}=\mathbf{0}}^{\infty} \left\{ \boldsymbol{B}^{i+1} (\mathbf{I} - \mathbf{B})^{-1} \mathbf{H} \mathbf{A} \mathbf{e}_{\mathbf{j}}^{\prime} \right\} \right]^{2}}{\mathbf{e}_{\mathbf{k}} \left\{ \sum_{\mathbf{i}=\mathbf{0}}^{\infty} \left[\boldsymbol{B}^{i+1} (\mathbf{I} - \mathbf{B})^{-1} \mathbf{H} \boldsymbol{\Sigma}_{\nu} \mathbf{H}^{\prime} \left\{ \boldsymbol{B}^{i+1} (\mathbf{I} - \mathbf{B})^{-1} \right\}^{\prime} \right] \right\} \mathbf{e}_{\mathbf{k}}^{\prime}}, \qquad (9)$$

where Ψ_F^{τ} and $\Psi_F^{\tilde{\pi}}$ are the shares of foreign shocks in the variance decomposition of trend inflation and the inflation gap, respectively.

Figure 3 presents the relative share of foreign shocks in the variance decomposition of inflation gap and trend inflation for each country in our sample. We find that foreign shocks have a larger impact on the cycle relative to the trend. For all countries except Norway, the share of foreign shocks in the variance decomposition of inflation gap lies between 20-30 %. The corresponding share for trend inflation is much lower, often less than 10%. For Norway, although the level of the shares of foreign shocks are low for both components, the share of foreign shocks in the variance decomposition of trend inflation is still about twice the corresponding share in inflation gap. One possibility for foreign shocks to have a limited impact on trend inflation dynamics is that, in an inflation targeting framework, monetary authorities might work to mitigate the influence of foreign shocks on trend inflation as there is less room to persistently accommodate foreign shocks. This is an issue that we seek to examine more closely when we consider a larger sample of heterogeneous Asian economies in the next section.

Given our broad tentative conclusion that foreign shocks appear to explain a large share of the inflation gap, we next aim to better understand these identified foreign shocks. While block exogeneity of the foreign block is enough to identify the share due to the sum of all foreign shocks, individually identifying foreign shocks requires more stringent identifying restrictions in the foreign block of the model.

We thus distinguish between commodity price shocks and other foreign shocks. In order to identify commodity price shocks, we assume that the block of three commodity prices are pre-determined to the rest of the foreign block. This identifying assumptions about commodity prices are defensible to the extent that much of commodity supply is pre-determined from futures markets and thus producers take at least some time to adjust supply to price incentives. This additional identifying assumption has wider appeal, at least with regards to empirical work identifying oil or commodity price shocks (see, e.g. Bachmeier and Cha, 2011; Kilian and Lewis, 2011; Wong, 2015), and has been shown to be tenable within oil markets (see Kilian and Vega, 2011). We also note that the identification of the effects of foreign shocks as a whole is not affected by the particular identification assumptions on commodity block of the model as long as we keep the small open economy structure by imposing the block exogeneity of the foreign block.

Figure 4 presents a finer decomposition of foreign shocks on the inflation gap, distinguishing between commodity price shocks and other foreign shocks. It shows, to the extent that foreign shocks drive the inflation gap, commodity price shocks play a significant role as, almost all of the share of foreign shocks is due to commodity price shocks. Our results are broadly consistent with Kearns (2016), who finds that much of the correlated forecast errors of inflation globally can be explained by commodity prices, and specifically food and oil prices.

It is also worth contrasting our results with Fernández, Schmitt-Grohé, and Uribe (2017) who identify foreign shocks by only considering three real commodity prices and suggest that foreign shocks explain about one third of the business cycle fluctuations.⁹ While we have a narrowly defined focus on modeling inflation, the main difference between our foreign block and theirs is the presence of foreign factors extracted from the large FAVAR dataset in our case. We can interpret our finding that, at least for the modeling of inflation for these five advanced inflation targeting economies, Fernández, Schmitt-Grohé, and Uribe (2017)'s strategy of using the three commodity prices alone may be sufficient to account for most of the effects of foreign shocks.

3.3 Low Inflation post-2008

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Our results so far document the role of foreign shocks on inflation dynamics throughout the sample. In this subsection, we focus on the foreign and domestic driver of inflation since 2008, a period characterized with persistently low inflation outcomes.

A feature of our modeling strategy is that we can decompose the role of foreign and domestic shocks on trend inflation and the inflation gap between any two choice periods t and t + h through

$$\pi_{t+h} - \pi_t = [\tau_{t+h} + \tilde{\pi}_{t+h}] - [\tau_t + \tilde{\pi}_t]$$
(10)

$$= \tau_{t+h} - \tau_t + \tilde{\pi}_{t+h} - \tilde{\pi}_t \tag{11}$$

$$= \sum_{j=0}^{n} \Delta \tau_{t+j} + \tilde{\pi}_{t+h} - \tilde{\pi}_t \tag{12}$$

$$= \sum_{j=0}^{h} \Delta \tau_{t+j}(\epsilon^*) + \sum_{j=0}^{h} \Delta \tau_{t+j}(\bar{\epsilon})$$

change in trend due to foreign shocks change in trend due to domestic shocks $\underbrace{\tilde{\pi}_{t+h}(\epsilon^*) - \tilde{\pi}_t(\epsilon^*)}_{\tilde{\pi}_t(\epsilon^*)} + \underbrace{\tilde{\pi}_{t+h}(\bar{\epsilon}) - \tilde{\pi}_t(\bar{\epsilon})}_{\tilde{\pi}_t(\bar{\epsilon})}$ (13)

change in gap due to foreign shocks change in gap due to domestic shocks

⁹Fernández, Schmitt-Grohé, and Uribe (2017) have a much broader focus and consider the impact of foreign shocks on trade balance, terms of trade, GDP, consumption and investment.

The third line is due to the fact that we model trend inflation as a random walk without drift, and thus the change in trend inflation between t and t + h is just the entire sequence of changes in the permanent component. Denote $\Delta \tau_t(\epsilon^*)$ and $\tilde{\pi}_t(\epsilon^*)$ as the components of the change in trend inflation and the inflation gap driven by foreign shocks and $\Delta \tau_t(\bar{\epsilon})$ and $\tilde{\pi}_t(\bar{\epsilon})$ the components driven by domestic shocks. We obtain the fourth line by using Equations (6) and (7), where the trend and gap in any period can be fully and linearly decomposed into components driven by foreign and domestic shocks, respectively.¹⁰

The decomposition of the change in inflation between any two periods to four components can provide insights as to whether domestic or foreign shocks were dominant in the period of low inflation post-2008, and the extent to which these effects were permanent or transitory.

We focus our attention to sub-periods that represent periods of falling headline inflation with clear identifiable links to global developments. We choose the start dates of these sub-periods to be when inflation was observed to be somewhat stable. The first sub-period is 2008Q1-2009Q1 which corresponds to the collapse of inflation during the Great Recession. While the NBER dated the start of the U.S. recession in December 2007, inflation globally only collapsed and hit a trough in either 2008Q4 or (mostly) in 2009Q1. The second sub-period corresponds to the collapse in crude oil prices that took place over a period of 18 months starting from 2014Q3. The sharpest falls in oil prices occurred between 2014Q3 and 2015Q1, and the decline continued with the oil prices going slightly under \$30 in January 2016. The oil price collapse coincided with a period of persistently low inflation in many countries. It led to concerns over whether countries have fallen into a deflation trap or whether inflation expectations had become unanchored (e.g. Draghi, 2015a; The Economist, 2015), which make this episode a good test case for understanding the role of foreign shocks and whether their effects are permanent or transitory.

Figure 5 presents the change in the level of quarter on quarter headline inflation, with a corresponding decomposition of the change in inflation into four components. That is, for each country, we compute the contribution of domestic and foreign shocks on the dynamics of trend inflation and the inflation gap, respectively. The top panel focuses on the first sub-period 2008Q1-2009Q1, during which all five countries experienced a sharp fall in inflation. While drawing general conclusions across a number of countries can be challenging, we find that in all countries a fall in inflation gap driven by foreign shocks is responsible for a large share of the fall in headline inflation.

The bottom panel presents the change in inflation for the latter period, 2014Q1-2016Q1. Unlike the first sub-period, inflation outcomes across all five open economies are quite heterogeneous. For example, while inflation in Australia, Canada, and New Zealand

¹⁰We define the matrices $\mathbf{S}^* = [\mathbf{e}'_1 \dots \mathbf{e}'_{N^*} \mathbf{0}_{\mathbf{M} \times \mathbf{N}}]$ and $\mathbf{S} = [\mathbf{0}_{\mathbf{M} \times \mathbf{N}^*} \mathbf{e}'_{N^*} \dots \mathbf{e}'_{\mathbf{M}}]$. We can obtain the components $\Delta \tau_t(\epsilon^*)$ and $\tilde{\pi}_t(\epsilon^*)$ by postmultiplying the matrix \mathbf{S}^* after the matrix \mathbf{A} in Equations (6) and (7) respectively. We correspondingly obtain the components $\Delta \tau_t(\bar{\epsilon})$ and $\tilde{\pi}_t(\bar{\epsilon})$ by postmultiplying the matrix \mathbf{S} after the matrix \mathbf{A} in Equations (6) ant (7) respectively.

fell, inflation in Norway, and Sweden actually *rose*. When we perform the decomposition, it also becomes less clear whether foreign shocks were the main driver of inflation dynamics. For example, in Sweden, our decomposition suggests trend inflation rising due to domestic shocks, and in Norway, domestic shocks had a large role with both trend inflation and the inflation gap. At the same time, it appears that, in all five countries, domestic shocks seem to have propped up trend inflation, which partially or fully offset foreign shocks driving down trend inflation.

Overall, our assessment from studying these two episodes of falling headline inflation, with clear identifiable foreign dimensions, suggests that both episodes were different in terms of the role foreign shocks played in shaping inflation dynamics. Our results suggest that the large fall in inflation during the Great Recession is caused by foreign shocks which have mostly transitory effects on inflation. During the second episode, it is less obvious that foreign shocks were the dominant cause of the observed low inflation. While we estimate foreign shocks to have exerted downward pressure on trend inflation in the post-2014 period, we find that this is somewhat offset by the effect of domestic shocks in the opposite direction. We can interpret this as being consistent with the intentions of domestic monetary authorities in the five inflation targeting regimes, which sought to offset the effect of downward pressure on trend inflations.

3.4 Summary

Our empirical approach has produced trend inflation and inflation gap estimates for Australia, Canada, New Zealand, Norway, and Sweden in a sample period largely coinciding with inflation targeting. We identified foreign shocks within our empirical approach and two key findings stand out. First, foreign shocks appear more important for the dynamics of inflation gap than that of trend inflation. Second, when we further disaggregate the foreign shocks, we find that much of the share of foreign shocks in the variance of inflation gap reflects commodity price shocks.

The next part of the paper seeks to contrast these findings against a group of countries with different monetary policy regimes and institutional features.

4 Extensions

4.1 Extending to a Group of Asian Economies

We now extend our analysis to a wider group of 10 Asian economies: China, Hong Kong, India, Indonesia, Japan, Korea, Malaysia, Philippines, Singapore and Thailand. This heterogeneous group includes advanced and emerging market economies, as well as a mix of different monetary policy and exchange rate regimes. At a base level, we investigate whether our findings extend to a group wider than the benchmark. We therefore estimate the same model for each of the 10 Asian economies.¹¹ Data limitations are a greater concern with this group of countries given long consistent data coverage may be lacking. In general, we collect as many economic time series as we can to extract factors, although some of these countries may have as few as four or five variables available to construct the domestic factors sub-block.¹²

We first ask if our conclusion that foreign shocks are more important for the inflation gap than trend inflation holds with this larger sample of countries. Figure 6 presents these results ¹³ and suggests that our main conclusions carry over to the sample of Asian economies. We also identify commodity price shocks as in the case of the sample of inflation targeting economies and compute their share in the variance decomposition of trend inflation. These results are presented in Figure 7. Our conclusion that foreign shocks reflect largely, but not entirely, commodity price shocks appears robust when considering this wider group of countries.

In sum, when we extend our analysis to a sample of Asian economies with more heterogeneous monetary and exchange rate policy arrangements, the two key conclusions change little. We find consistent evidence that foreign shocks matter more for the inflation gap than trend inflation, and that much of the larger share in the inflation gap may well reflect commodity price shocks.

4.2 Does Inflation Targeting Make a Difference?

A natural question is whether one could explain some of the cross sectional differences in the share of foreign shocks. Indeed, a natural comparison is to consider the group of established inflation targeters relative to the heterogeneous group of Asian economies. From Figures 3 and 6, we compare the average share of foreign shocks driving trend inflation and the inflation gap for the two groups. We present this in the left panel of Figure 8. There is a sharp contrast where the benchmark inflation targeting group has a much lower share of foreign shocks driving both their trend inflation and the inflation gap. Indeed, the share of foreign shocks driving trend inflation is significantly lower for the inflation targeting group suggesting that inflation targeting regimes are more successful in reducing the impact of foreign shocks on trend inflation.

Another specification we consider is to estimate trend inflation over a longer sample

¹¹Given that we have economies like China and Japan in the sample of Asian economies, it is more debatable that a block exogeniety restriction is appropriate. Therefore, one needs to exercise some caution in reconciling these results with the main benchmark analysis.

¹²In the case where Japan is the domestic economy, data from the other four major economies are used to construct the foreign block. Otherwise, Japan is within the foreign block for all the other countries, as in our benchmark analysis.

 $^{^{13}\}mathrm{We}$ relegate the plots of our trend inflation estimates for the 10 Asian economies to the online appendix.

period for the benchmark countries rather than keeping it to the largely inflation targeting period. While we had kept to starting our sample in the 1990s largely due to data quality and to avoid modeling possible structural breaks across a number of countries, we can interpret the share of foreign shocks in the entire sample as a weighted average of the largely inflation targeting period and the pre-inflation targeting period. The right panels of Figure 8 presents these results. In general, we find a greater share for foreign shocks driving trend inflation and the inflation gap with a sample encompassing pre-inflation targeting and the inflation targeting regime.

Comparing our benchmark results relative to a group of heterogeneous Asian economies and a longer sample period, we find evidence that inflation targeting does reduce the influence of foreign shocks on inflation, especially on trend inflation.¹⁴ Some caution is necessary in interpreting these results, however, as the comparison is relative to five inflation targeters, and we are only considering a very small sample. Nonetheless, the results appear sufficiently compelling to suggest a link between the impact of foreign shocks on inflation and inflation targeting. Moreover, as we mentioned, foreign shocks should only influence trend inflation if there is a systematic attempt by the domestic monetary authority to accommodate foreign shocks. Inflation targeting, as a monetary policy regime, is designed precisely to prevent such accommodation as the level of trend inflation could be considered as central banks' choice variable. In this regard, we would expect inflation targeting regimes to have a smaller role for foreign shocks, and this is indeed consistent with the additional analysis.

5 Conclusion and Discussion

In this paper, we develop an open economy model to estimate trend inflation, which allows us to quantify the role of foreign shocks in driving both trend inflation and the inflation gap. We focus most of the application to study five advanced inflation targeting economies, Australia, Canada, New Zealand, Norway, and Sweden.

We highlight three key findings. First, we find that foreign shocks appear to be more important for the inflation gap, relative to trend inflation. Second, commodity price shocks account for much of the reported shares of foreign shocks in the inflation gap. Our two conclusions are broadly supported when we expand the sample to a fairly heterogeneous sample of 10 Asia-Pacific economies, which feature of mix of emerging market and developed economies. Our third conclusion is that inflation targeting as a monetary policy regime might have reduced the influence of foreign shocks, especially on trend inflation. We reach this conclusion by observing that the share of foreign shocks

¹⁴One interpretation, consistent with Bjørnland, Thorsrud, and Zahiri (2017), is that inflation targeting central banks may not be responding to the global economy as they are "keeping a tight rein" on domestic inflation and domestic factors.

in our five established inflation targeters during the inflation targeting period is very small (less than 10% for the vast majority and often less than 5%) as compared to the group of Asian economies, which have more varied monetary policy regimes. We also find that extending the sample period to a non-inflation targeting period for the five inflation targeters reveals a larger share of foreign shocks driving both their trend inflation and inflation gap.

It is important to stress that the literature on the increased globalization of inflation argues that domestic inflation has become *more* sensitive to global slack over time, which is subtly different from our work, as we only measure the average share of foreign shocks in trend inflation and the inflation gap over the entire sample. However, we do propose an empirical setup which allows for a broader view of global determinants (i.e. foreign shocks) that tackles a first order policy issue of whether the influence of foreign shocks is transitory or permanent. This may provide a good starting point to model time variation in future work in order to investigate whether inflation has become increasingly globalized. However, we note that Bianchi and Civelli (2015) do explicitly model time variation in studying the effect of the increased globalization of inflation, albeit with a narrower focus on global slack, and find no evidence of time variation. We note that there could be other channels of transmission from globalization, such as greater contestability in the domestic market through innovations in the online markets or links through global value chains (see for example Auer, Levchenko, and Sauré, 2017; Auer, Borio, and Filardo, 2017). These are factors that our model does not explicitly account for. While we do not see this as an egregious omission given our emphasis on historical data, this may become an important dimension of the effects of globalization and may be worthwhile pursuing in future work.

The overall conclusion from our findings is that even if foreign shocks matter for inflation, inflation in the long run is ultimately a domestic phenomenon. That is, without any accommodation by domestic monetary policy, the effects foreign shocks on inflation are transitory, which supports the conventional wisdom that inflation in the long run remains a choice variable for domestic monetary authorities.

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Figure 2: Trend Inflation Estimates

Notes: Trend inflation and headline inflation in annualized percentage terms. The dotted line is quarter on quarter CPI inflation. The thick line are the trend inflation estimates.



Figure 3: Share of Foreign Shocks

Notes: Both the shares of foreign and domestic shocks sum up to 100.





Notes: Both the shares of the commodity price shocks and the other foreign sum up to the sum of the foreign shocks. The foreign and domestic shocks (in Figure 3) in turn sum up to 100.



Figure 5: Decomposing Change in Inflation

Notes: $\pi_{t+h} - \pi_t$ - Total Change in quarter on quarter headline inflation. $\sum_{j=0}^{h} \Delta \tau_{t+j}(\epsilon^*)$ - The change in trend inflation due to foreign shocks. $\sum_{j=0}^{h} \Delta \tau_{t+j}(\bar{\epsilon})$ - The change in trend inflation due to domestic shocks. $\hat{\pi}_{t+h}(\epsilon^*) - \hat{\pi}_t(\epsilon^*)$ - The change in the inflation gap due to foreign shocks. $\hat{\pi}_{t+h}(\bar{\epsilon}) - \hat{\pi}_t(\bar{\epsilon})$ - The change in the inflation gap due to domestic shocks. The four components sum up to the total change.



Figure 6: Share of Foreign Shocks

Notes: Both the shares of foreign and domestic shocks sum up to 100.





Notes: Both the shares of the commodity price shocks and the other foreign sum up to the sum of the foreign shocks. The foreign and domestic shocks (in Figure 6) in turn sum up to 100.



Figure 8: Share of Foreign Shocks in Inflation Dynamics in Different Countries

Notes: Asian countries include China, Hong Kong, India, Indonesia, Japan, Korea, Malaysia, Philippines, Singapore and Thailand. Inflation targeting countries are Australia, Canada, New Zealand, Norway and Sweden. Results for benchmark sample are for the five inflation targeting countries with data samples beginning in the 1990s. The shares for the benchmark sample are identical to those presented in Figure 3. Full sample refers to results for the inflation targeting countries with data samples beginning in: Australia 1990Q1, Canada 1984Q3, New Zealand 1986Q2, Norway 1981Q2 and Sweden 1987Q2.

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