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Inflation and the Steeplechase Between Economic Activity Variables

Jaromír Baxa, Miroslav Plašil, and Bořek Vašíček*

Abstract

A sharp increase in unemployment accompanied by a relatively muted response of inflation during the Great Recession cast further doubts on the validity of the Phillips curve. With the aid of dynamic model averaging (Raftery et al., 2010), this paper aims to highlight that the existence of a systemic relation between real activity and inflation is blurred due to (i) the failure to capture inflationary pressures by means of a single measure of economic activity, and (ii) the existence of a non-linear response of inflation to the driving variable. Based on data for the U.S. and other G7 countries, our results show that the relation between economic activity and inflation is quite sturdy when one allows for more complex assessment of the former. We find that inflation responds to different measures of economic activity across time and space, and no measure of economic activity clearly dominates. The output gap is often outperformed by unemployment-related variables such as the short-term unemployment rate, the unemployment expansion gap, and the unemployment recession gap. Finally, our results confirm a weakening of the inflation–activity relationship (i.e., a flattening of the Phillips curve) in the last decades, which might be attributed to structural changes in the economy and monetary policy, that is robust both across activity measures and across countries.

Abstrakt

Prudký nárůst nezaměstnanosti doprovázený relativně slabou odezvou na straně inflace v průběhu globální recese vedl k dalším pochybám o platnosti Phillipsovy křivky. Cílem této práce je s využitím metody dynamického průměrování modelů (Raftery et al., 2010) poukázat na skutečnost, že existence systematického vztahu mezi mírou reálné ekonomické aktivity a inflací je zastřena vzhledem k (i) obtížnému zachycení inflačních tlaků prostřednictvím jediné veličiny popisující ekonomickou aktivitu a (ii) existenci nelineární odezvy inflace na signály z reálné ekonomiky. Naše výsledky pro USA a další země skupiny G7 naznačují, že vztah mezi ekonomickou aktivitou a inflací je poměrně těsný, pokud jsou tlaky vycházející z reálné ekonomiky posuzovány komplexněji. Inflace reaguje v průběhu času a v různých zemích na různé ukazatele ekonomické aktivity a žádný z nich není jednoznačně dominantní. Mezera výstupu často popisuje inflační dynamiku hůře než ukazatele ekonomické aktivity založené na nezaměstnanosti, jako je krátkodobá nezaměstnanost, „unemployment expansion gap“ nebo „unemployment recession gap“. Práce dále potvrzuje slábnoucí vztah mezi ekonomickou aktivitou a inflací (tj. zplošťování Phillipsovy křivky) v posledních dekádách z důvodu strukturálních změn v ekonomice a měnové politice. Tento výsledek je robustní pro různé ukazatele ekonomické aktivity i pro různé země.

JEL Codes: G01, G15, G21, G24.

Keywords: Dynamic model averaging, inflation dynamics, Phillips curve, real economic activity.

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Nontechnical Summary

There is an ongoing controversy about the relationship between price inflation and domestic economic activity. Although the concept of the Phillips curve as a stable link between inflation and cyclical conditions is deeply rooted in macroeconomics, the empirical evidence for it is ambiguous. The empirical research on the inflation–real activity nexus has faced a number of uncertainties, namely (i) uncertainty about the appropriate variable for tracking real economy activity, (ii) uncertainty about whether the relationship between economic activity and inflation is linear or state-dependent, (iii) uncertainty about whether the relationship between the two variables changes permanently over time due to structural changes in the economy and monetary policy, and finally (iv) uncertainty about the appropriate measure of inflation that can be reasonably linked to economic activity.

This paper aims to address the first three uncertainties in a consistent manner, focusing on the United States and the other G7 countries. For all countries, we investigate the explanatory potential of a number of variables that traditionally represent economic activity in the literature on the Phillips curve or the New Keynesian Phillips curve: the output gap, real unit labor costs, growth of the employment rate, and the short-term unemployment rate. Additionally, following the recent contribution by Stock and Watson (2010), we also include the unemployment recession gap, which measures the difference between the current unemployment rate and the minimum observed over the past three years. The unemployment recession gap in fact stresses the role of periods with increasing unemployment. To account also for periods of a decreasing unemployment rate, we add its counterpart, the unemployment expansion gap. Finally, variables representing external shocks, such as oil prices and the nominal effective exchange rate, take part in our steeplechase.

All these variables are fed through a procedure called dynamic model averaging (Raftery et al., 2010), which marries the flexibility of the time-varying parameter framework with a model-uncertainty treatment conceptually close to Bayesian model averaging. In particular, we assume the existence of a single "true" model in each period, which can switch over time. In effect, we can select variables with dominant effects on inflation in each period and even allow for time-varying strength of the relationship between these variables and inflation.

Our results show that inflation does respond to economic activity, but the explanatory potential of different measures of economic slack varies across time and space and no measure of economic activity clearly dominates in all countries or over the whole sample. The output gap is often outperformed by unemployment-related variables such as the short-term unemployment rate, the unemployment expansion gap, and the unemployment recession gap. Overall, we found that the relation between economic activity and inflation is quite sturdy when one allows for more complex assessment of the former. This implies that macroeconomic models working with some version of the Phillips curve should take such complexity into account.

Additionally, our results point to the importance of including foreign factors, although their relevance also varies over time. In particular, there are long periods when (exogenous) foreign factors are significant inflation drivers. Nevertheless, it should be noted that when used in isolation foreign factors outperform measures of domestic activity only in few rare cases. Thus they have only additional rather than leading explanatory power for fitting and predicting the inflation gap.

Finally, we document a weakening of the inflation–activity relationship (i.e., a flattening of the Phillips curve) in the recent decades that is robust both across activity measures and across countries. Although there is still no consensus whether these developments shall be attributed to structural changes in the economy or rather to monetary policy, the fact that inflation has become the only target variable of most central banks supports the hypothesis that monetary policy contributed to some degree to the weakening of the trade-off. Besides, this flattening is conditional on inflation expectations remaining anchored in most countries. There is no guarantee that a flat Phillips curve would persist if inflation expectations were to break away from (more or less explicit) inflation targets.

1. Introduction

There is an ongoing controversy about the relationship between price inflation and domestic economic activity. While the concept of the Phillips curve is deeply rooted in macroeconomics and most (Keynesian-style) macroeconomic models begin with its very existence, the empirical evidence on the impact of domestic slack on inflation is (if anything) very ambiguous.[1] One possible explanation for this ambiguity is that it is not easy to extract the appropriate inflation-driving signal from the available data on real economic activity. In reality, there are several potential "economic" variables tracking domestic economic activity, for example output versus employment measures. Besides, the number of real economy measures expands substantially when statistical methods start working to extract the appropriate signal that might be linked to inflation.

The link between economic activity and price inflation regained importance as the global financial crisis caused a significant decline in economic activity elsewhere, while the decline in inflation was much less general. Although the very recent downward pressures on inflation seem to suggest otherwise, there is a general impression that during the recent Great Recession inflation fell by less than one might expect. This has been attributed variously to long-term inflation expectations being firmly anchored at pre-defined inflation targets (e.g. IMF, 2013), a flatter Phillips curve, implying a weakening of the trade-off between inflation and unemployment (Matheson and Stavrev, 2013), and to an increase in structural unemployment and a related decline in potential output, implying that the output gaps are not as negative as they might appear and therefore that the downward pressures on inflation from the real economy are not that strong (e.g. Kocherlakota, 2010).

While the empirical literature has long strived to uncover the nature of the inflation–real activity trade-off, the results are very dispersed and often ambiguous. The empirical research on the inflation–real activity nexus has faced various uncertainties, namely (i) uncertainty about the appropriate variable for tracking economic activity (or, in fact, the appropriate measure of price inflation that can be related to domestic economic activity), (ii) uncertainty about whether the relationship between economic activity and inflation is linear or state-dependent, and (iii) uncertainty about whether the relationship between the two variables is subject to permanent changes due to structural changes in the economy and monetary policy.[2]

The first issue has commonly been addressed by using various measures of domestic economic activity. Traditional measures such as the unemployment gap and the output gap have been coupled with new model-based measures such as real marginal cost. The most popular proxy of the latter is the labor income share (Galí and Gertler, 1999). In general, it has proved difficult to find a measure that performs well and is superior to others across time and space. The identification is further complicated for small open economies, where inflation levels are affected to an important degree by external factors. As in the case of domestic slack, there is no full agreement on which external factors

[1] There seems to be a certain historical parallel between the breakdown of the Phillips curve and the breakdown of money-demand function. An intuitive narrative is that both relations broke down once the variables in question (i.e. monetary base in the former case and inflation in the latter) became the objective variable of monetary policy.

[2] There is an ongoing discussion about the identification strategy for inflation expectations in the context of the New Keynesian Phillips curve. Since our goal is to study the link between economic activity and inflation in a broader context, we leave aside the discussion on this lively topic and we refer the reader to the most current and extensive review of the identification problem in Mavroeidis et al. (2013).

are relevant (Batini et al., 2005; Mihailov et al., 2011). Recent (mainly empirical) literature deals with the global dimension of inflation, studying directly the extent to which global developments are able (by affecting the domestic supply and demand conditions, for example) to explain domestic inflation developments (e.g. Ciccarelli and Mojon, 2010; Eickmeier and Pijnenburg, 2013; Mumtaz and Surico, 2012).

The second issue has been dealt with using empirical models allowing for potential nonlinearities. The idea that the trade-off between inflation and economic activity can be nonlinear, for example due to downward price and wage stickiness, has been tossed around for some time (Ball et al., 1988) and seems to be supported by empirical studies based on micro data (see, for example, Klenow and Malin, 2011, for a recent review). Yet, at the macroeconomic level the empirical evidence is rather mixed (Aguilar and Martins, 2005; Laxton et al., 1999; Dolado et al., 2005). The nonlinearity hypothesis has also been discussed during the recent turmoil. Among others, Stock and Watson (2010) argue that inflation in the U.S. has been affected by domestic real activity mainly during recessions. However, Meier (2010) provides more ambiguous evidence for OECD countries, in particular pointing to difficulties in identifying such a relationship in an environment with very low inflation.

The third issue is partially reflected in studies focused on structural changes in the inflation process across time (Cogley et al., 2010; Cogley and Sbordone, 2008; Kang et al., 2009; Zhang and Kim, 2008). Popular explanations of the permanent decrease in comovement between inflation and domestic economic activity – often referred to as a flattening of the Phillips curve – include globalization (Borio and Filardo, 2007; Razin and Binyamini, 2007) and good monetary policy (Roberts, 2006; Ball and Mazumder, 2011), but there is no full consensus yet (Kuttner and Robinson, 2011).

This paper aims to address the above-mentioned uncertainties in a consistent manner as follows. First, our model for inflation follows Stock and Watson (2010), i.e., we focus on the deviation of inflation from a stochastic trend (derived from an unobserved component model with stochastic volatility – the UC-SV model of Stock and Watson, 2007), which can be interpreted as long-term expected inflation. Therefore, we assume that real economic activity can affect the short-term component of inflation whereas its long-term level is given by other factors such as the credibility of monetary policy, which in turn determines the level of inflation expectations, and also supply shocks with persistent effects (e.g. significant changes in commodity prices).

Second, we address the fact that one can choose between various measures of domestic economic activity rather than sticking to a single one. Besides traditional measures (the output gap, unit labor costs, employment) we employ measures that potentially allow for a nonlinear relationship between inflation and economic activity by their very construction without any need to resort explicitly to a nonlinear estimation framework. In particular, we follow the idea of Stock and Watson (2010) that inflation can be affected asymmetrically along the business cycle (it falls in a recession). Besides their "unemployment recession gap" we construct its expansion-type counterpart, the "unemployment expansion gap," where both these measures stress the importance of local extremes (as opposed to global ones). We also control for potential foreign inflation determinants, in particular oil prices and the nominal exchange rate. Third, we allow for potential permanent change in the inflation process and its determinants across time. We use dynamic model averaging, or DMA (Raftery et al., 2010), which marries the flexibility of the time-varying parameter framework (e.g. Harvey, 1989) with a model-uncertainty treatment similar to Bayesian model averaging, or BMA (Hoeting at al., 1999). In particular, we assume the existence of a single model to drive inflation (defined in terms of various different measures of real economic activity), which can switch in each period.[3]

Our paper is specifically related to studies that try to uncover comovement between inflation and domestic economic activity in diverse empirical settings. Most of this empirical work is related to the U.S. (Stock and Watson, 2010; Ball and Mazumder, 2011; Koop and Korobilis, 2012). The studies for other countries usually deal with the somewhat wider issue of Phillips curve stability and nonlinearity (e.g. Aguilar and Martins, 2005; Dolado et al. 2005; Musso et al., 2007) rather than dealing specifically with the complexity of the inflation–real activity trade-off. Notable exceptions include Andrle et al. (2013), who study the aggregated euro area using the frequency rather than the time domain, Bankovskis et al. (2011), who use a suite of models such as TV VAR and DSGE aimed at both the aggregated euro area and selected individual EU countries, and Morley et al. (2011), who test the importance of trend inflation and the real activity gap for explaining the inflation variation in G7 countries. Both studies find a positive relationship between inflation and economic activity, although the importance of this relationship varies (in the frequency/time domain).

Our paper is close in spirit to Stock and Watson (2010) in terms of our use of the inflation gap (derived by the UC-SV model) and our quest for a measure of domestic economic activity which can be linked to the former. Besides considering a wider sample of countries, we extend Stock and Watson (2010) to include the DMA technique, which allows us to (i) deal with the uncertainty related to the real economy measure, and (ii) model the relationship between inflation and a given variable on real economic activity in a time-varying manner. We are not the first to use DMA for the analysis of inflation dynamics. In particular, Koop and Korobilis (2012) used DMA to analyze its forecasting potential vis-à-vis other methods and found it to be a promising avenue for inflation forecasting. Koop and Onorante (2011) employed DMA to investigate the relative importance of forward-looking and backward-looking expectations in the New Keynesian Phillips curve. Though these authors use a similar methodology, their research questions are different from ours. In addition, our approach differs in the universe of admissible models. While the former authors generally consider a wide range of models arising from an arbitrary combination of variables, we restrict the model universe to quite a small set of models, all of which, however, have a clear structural and economic interpretation.

Finally, in broad terms, our research can also be linked to studies trying to identify changes in inflation dynamics across time, such as Baxa et al. (2012), Cogley and Sbordone (2008), Cogley et al. (2010), Kang et al. (2009), and Zhang and Kim (2008). While this literature on the whole agrees on the changing nature of inflation dynamics (Pivetta and Reis, 2007, being an exception to this), and in particular on a decline in inflation persistence, the specific issue of the inflation–activity nexus has not been well researched yet.

Our results can be summarized as follows. First and foremost, we find a positive and statistically significant relationship between inflation and domestic economic activity. However, inflation responds to (or at least commoves with) different measures of economic activity conditionally on

[3] Our primary focus on model selection (i.e. we employ dynamic model selection or DMS) rather than on model averaging is related to the fact that DMA is commonly used to identify the most relevant variables across different models, while our task is to assess what measure of the meta-variable "economic activity" can be linked to inflation in each period.

time and space, and no measure of economic activity clearly dominates for the entire sample. Second, while the traditional output gap generally performs rather poorly, the recently proposed unemployment recession gap (Stock and Watson, 2010) did not prove to be as promising as claimed. In general, this measure does not convincingly outperform the others in terms of its impact on the inflation gap), nor is its short-term relationship found to be stable. Third, the relationship between (any measure of) economic activity and inflation exhibits a highly nonlinear pattern over time, with the observable weakening of the relationship (i.e., the flattening of the Phillips curve) being robust both across activity measures and across countries. Fourth, foreign factors are found to be relevant for all countries, although their relevance varies across time. Finally, our results seem to clarify why the empirical evidence on the use of an individual measure of domestic economic activity comes to rather ambiguous or even negative conclusions about the inflation–activity nexus. Proper selection of the variable representing economic activity seems to be a promising way to go.

The paper is organized as follows. In section 2, we discuss the relationship between inflation and economic activity from the point of view of an appropriate measure of both. Section 3 presents our empirical framework. Section 4 presents the empirical evidence, with more country-specific narratives detailed in the appendix. The final section concludes.

2. Inflation and Economic Activity

We noted that the empirical relationship between inflation and domestic economic activity can be obscured by numerous uncertainties. One of the most prominent ambiguities is related to the choice of real domestic activity measure. In what follows we discuss several economic activity variables that will be subsequently placed in an empirical horse race.[4] It should be stressed that our aim is not to construct the best measure of economic activity, but rather to choose between measures that are commonly used.[5] In general, they are based on either output or employment. The prominent example of the former is the output gap as an encompassing measure of capacity utilization in the economy. The very idea that the productive capacity of the economy can be identified is rather controversial, especially in the case of open economies, where production factors are mobile (Bermingham et al., 2013). In addition, the statistical derivation of the unobservable potential output is subject to statistical uncertainty and none of the methods for deriving it can be seen as superior (Billmeier, 2009; Orphanides and van Norden, 2002). Therefore, we resort to the common HP filter, which for most countries in the sample is very close to the production-function based estimation published by the OECD. It should be noted that as a two-sided filter the HP filter is in a different position than the other variables employed, where past information is used. However, given that our focus is not on forecasting but rather on the relationship between inflation and economic activity, and the output gap derived from the HP filter is the most popular measure of the former, we consider its use to be reasonable.[6]

[4] Details on the data used can be found in the Appendix I.

[5] In other words, we do not try to find the best existing horse, but instead try to select between the horses that normally run in the steeplechase. For example, we use the common measure of the output gap derived from the HP filter rather than using alternative methods for its construction.

[6] In addition, since our primary motivation is to find the structural relationship between inflation and economic activity as opposed to conducting a pure forecasting exercise, we do not use vintage data.

In terms of the employment-based measures there are more alternatives. The traditional Phillips curve is based on the unemployment rate, in particular its deviation from the NAIRU. Therefore, actual unemployment above its equilibrium level implies downward pressures on wages, whereas below-equilibrium unemployment implies upward pressures. Consequently, the NAIRU can be seen as the counterpart of potential output, and also shares with it all the problems related to the estimation of an unobserved variable. However, it has been suggested (see also Blanchard and Wolfers, 2000) that the long-term (structurally as opposed to cyclically) unemployed are not able to compete for existing jobs and therefore do not exert wage pressure. Therefore, it might be preferable to track unemployment slack only in terms of cyclical unemployment. However, it is empirically difficult to distinguish between the two (structural unemployment corresponds to the NAIRU, which is unobserved and is commonly estimated only at lower, i.e., annual, frequency), so as a proxy we use the short-term unemployment component, assuming that long-term employment corresponds to structural unemployment (cf. Stock, 2011).

An alternative employment-based measure that is a determinant of disposable income is (the change of) total employment. Indeed, different levels of unemployment rates can be consistent with different levels of employment, depending on labor market flows from temporary inactivity to the work force and vice versa. Total employment also affects the aggregate income of the economy and therefore also determines effective demand, which is in turn a key driver of inflation impulses (from the demand side).

Stock and Watson (2010) recently proposed an employment-based measure that explicitly takes into account the idea that there might be a nonlinear relationship between inflation and economic activity. They construct an "unemployment recession gap" as the difference between the current (quarterly) unemployment rate and the minimum value in the last (in their case eleven) quarters (including the current one). The idea behind this one-sided gap is to pay attention to economic downturns, or in other words to track whether unemployment is higher than in recent years (in this case the gap is positive with the value of current unemployment and zero otherwise). The unemployment recession gap is in fact a concept related to deviations from the NAIRU based on the idea that the NAIRU follows the trend in the unemployment rate and that stable levels of unemployment are less likely to cause inflationary pressures in the economy. Hence, the concept of the unemployment recession gap is more simple, albeit more intuitive. In addition, we extend the idea that local rather than global extremes are what might matter by constructing the inverse measure – the "unemployment expansion gap" – as the difference between the current unemployment rate and the maximum value of observed unemployment over the last few quarters (including the current one), which is a measure of higher unemployment than usual. Adding the unemployment expansion gap to the set of regressors allows us to take into account the possible nonlinear behavior of inflation associated with either economic downturns or economic upturns.

Finally, a specific employment-based measure compatible with the micro-funded model of the New Keynesian Phillips curve is marginal cost, which is proxied by real unit labor costs (Galí and Gertler, 1999; Galí et al., 2001). While this measure was proposed as a viable alternative to the empirical pitfalls of traditional measures such as the output gap, the empirical evidence on its performance as an inflation driver is rather ambiguous. Consequently, this measure had to be further refined (Mazumder, 2010) in order to deal with its intrinsic countercyclicality (Rudd and Whelan, 2007). Still, real unit labor costs can be a relevant inflation driver as they contain information about changes in productivity and other changes in the economy relevant to the price-setting behavior of firms.

Although our focus is on domestic economic activity, in line with numerous papers documenting the importance of external inflation factors in explaining domestic inflation dynamics (Batini et al., 2005; Mihailov et al., 2011), we also include variables representing external inflationary pressures in our study. External cost-push factors related to commodity prices and exchange rates might even affect relatively large countries, as was evident not only in the Great Inflation of the 1970s, but also in the rising inflation rates around the world at the onset of the Great Recession due to the peak in oil prices.[7] Consequently, we use two additional variables for tracking this: the nominal effective exchange rate and oil prices.[8]

3. Model and Estimation Strategy

To analyze the relationship between inflation and real economy variables we follow and further enrich the methodology of Stock and Watson (2010). We consider a simple multivariate model in which a measure of economic activity, x_t, is used to explain the forecast error as represented by the difference between the rate of inflation at time *t+h*, π_{t+h}, and the inflation trend, τ_t. The model can be expressed in the following form:

$$\begin{aligned} \pi_{t+h} &= \tau_{t|t} + \gamma_t x_t + e_{t+h}, \quad \operatorname{var}(e_{t+h}) = \sigma^2_{e,t+h} \\ \gamma_t &= \gamma_{t-1} + \xi_t, \quad \operatorname{var}(\xi_t) = \sigma^2_{\xi,t}, \operatorname{cov}(e_{t+h}, \xi_t) = 0 \end{aligned} \tag{1}$$

where π_{t+h} is the 4-quarter rate of inflation at time *t+h*, $\tau_{t|t}$ is the best estimate of the trend at time *t* using the information available at time *t*, and e_{t+h} is an error term. In our empirical analysis we set the horizon *h* to 4 quarters, but we also checked the results for *h* = 1 quarter.[9] Note that unlike Stock and Watson (2010), we employ a time-varying parameter model where γ_t follows a random walk. This allows us to explicitly account for potential evolution in the relationship between inflation and economic activity measures[10] and ideally pin down the shifts to structural and/or policy changes. As the estimated path of the time-varying coefficient is sensitive to changes in the volatility of the error term (see, for example, Nakajima, 2011), we further assume that the variances of the disturbance terms in the observation equation and transition equation (1) may evolve over time.[11]

[7] In general, accounting for oil prices and other external factors corresponds to the logic of the triangle model by Gordon (1982), where current inflation is explained by its lag, a measure of domestic economic slack, and a supply-side variable (representing a cost-push shock).

[8] Some papers also use relative import prices as measured by the terms of trade, but in our view this may represent an endogeneity problem, as relative import prices can by definition be affected by the relative foreign vs. domestic price level, and hence also by the change in it. Some studies have also used measures of global slack such as the trade-weighted output gap (Borio and Filardo, 2007), but more recent research on the global dimension of inflation using factor models (e.g. Eickmeier and Pijnenburg, 2013) has cast some doubt on their importance.

[9] For some countries, the results for a shorter horizon appear to be slightly preferable in terms of economic intuition. However, we still use *h* = 4 as a benchmark in order to avoid bundling several horizons together. The results for *h* = 1 are available upon request.

[10] Stock and Watson (2010) claim that when their newly proposed measure of economic activity – called the unemployment recession gap – is used, the relationship implied by the Phillips curve is much more stable than that based on the real economy measures traditionally exploited in the literature. Our time-varying model approach represents a convenient and straightforward way to reinvestigate their findings.

[11] Details on estimation issues are presented in subsections 3.2 and 3.3.

3.1 Inflation and Inflation Gap

Inflation can have different drivers at different frequencies. Whereas the high-frequency dynamics can be driven by one-off non-systemic shocks, for example, shocks to oil prices, the low-frequency dynamics can be determined by institutional factors such as the central bank's inflation target and its credibility. However, most concern relates to the evolution of inflation at business cycle frequencies, which makes the concept of the inflation gap – the deviation of the inflation rate from the inflation trend – particularly appealing. Also, the inflation gap, in terms of deviations of inflation from the inflation target, enters most of the existing DSGE models aiming to analyze the effects of monetary policy.[12]

Following Ball and Mazumder (2011) we use a narrower definition of inflation, namely, core inflation, which excludes some non-systemic inflation components (food and energy)[13] (if this measure is not available for a sufficient time span, CPI inflation is used) and we additionally control for volatile external factors arguably driving the non-systemic component of inflation, which, by their very nature, cannot be attributed to the domestic economy. As noted above, we opt for removing the inflation trend, which is probably determined by other factors (e.g. monetary policy credibility, long-term developments in commodity prices) unrelated to economic activity. The inflation trend τ_t in (1) is estimated before the analysis by the univariate unobserved components model with stochastic volatility (UC-SV) proposed in Stock and Watson (2007).[14] This parsimonious model has gained some prominence in recent years as it seems to capture the main features of inflation dynamics very well.[15] The UC-SV model assumes that the rate of inflation can be decomposed into a permanent (stochastic trend) component and a transitory component

$$\begin{aligned} \pi_t &= \tau_t + \eta_t, \quad E\eta_t = 0, \operatorname{var}(\eta_t) = \sigma^2_{\eta,t} \\ \tau_t &= \tau_{t-1} + \varepsilon_t, \quad E\varepsilon_t = 0, \operatorname{var}(\varepsilon_t) = \sigma^2_{\varepsilon,t}, \operatorname{cov}(\eta_t, \varepsilon_t) = 0 \end{aligned} \tag{2}$$

where the variances of the permanent and transitory disturbances (ε_t and η_t, respectively) both vary randomly over time and can be well described by the stochastic volatility model. Stock and Watson (2010) suggest thinking of the trend τ_t as capturing long-term inflation expectations, where the degree to which they are "anchored" is allowed to change over time. To the extent that τ_t captures

[12] There are some differences in the literature in the consideration of the inflation trend and its related statistical treatment. See, for example, Cogley and Sbordone (2008) and Kim and Kim (2008). Ascari and Sbordone (2013) provide the most recent review on this issue.

[13] Particularly questionable is the presence of some non-systemic (and typically also the most volatile) components, such as food and energy, which are by nature unrelated to domestic economic activity (headline vs. core inflation) and increases in which generally do not spawn second-round effects (Cecchetti and Moessner, 2008). However, another problematic item is tax changes, whose effect on prices can be direct (first-round effects) and also indirect (second-round effects) in the sense that a tax increase can give rise to wage pressures.

[14] Note that in theory it is possible to estimate equations (1) and (2) jointly, which may potentially lead to some efficiency gains. We experimented with this possibility, but it is rather problematic in our setting due to different variability in the trend inflation and regression parameters, which are all regulated by a single forgetting factor (see section 3). It should be also noted that the confidence intervals presented below do not take into account the uncertainty related to the first step (estimation of the trend in inflation) and thus in general underestimate the true variability in the coefficients. We used a bootstrap procedure to assess how much the uncertainty in the first step inflates the final confidence intervals and we found that (once the prior parameters are set) the width of the reported intervals is not seriously affected.

[15] We refer the reader to the original paper for a detailed motivation of the UC-SV model and a thorough justification.

(forward-looking) inflation expectations, equation (1) can be viewed as a New-Keynesian Phillips curve model. On the other hand, since these "expectations" are solely based on past information, one can also show that (1) is just a tightly parameterized backward-looking Phillips curve with potentially long lags (see Stock and Watson, 2010, for details). Therefore, our approach to inflation expectations is eclectic, as it allows for a compromise between the accelerationist Phillips curve and the New Keynesian Phillips curve.

Once the inflation trend is estimated, one can clearly see that model (1) focuses on the issue of how the economic activity measure x_t helps to explain the deviation $\pi_{t+h} - \tau_{t|t}$, which is commonly referred to as the inflation gap (see Cogley, Primiceri, and Sargent, 2010). In addition to the interpretations of (1) offered above, we can think of the inflation gap as filtering out low frequencies, which are unlikely to be related to movements in economic activity and the business cycle. Recently, Andrle et al. (2013) and Basturk et al. (2013) showed that a blurred relationship between inflation and economic activity resurfaces once one focuses on business cycle frequencies. In this light, extraction of the trend in the rate of inflation seems necessary when analyzing the inflation–real activity nexus and makes model (1) empirically appealing.

In their analysis, Stock and Watson (2010) take several measures of economic activity and investigate how each of them in turn predicts movements in the inflation gap. This, however, leaves out the possibility that the predictive power of the variables may change dramatically over time depending on the phase of the cycle or as a result of long-term structural changes in the economy. In other words, it does not allow one to assess the uncertainty related to the relative strength of the signal in each variable at a particular point in time (or period). To overcome this shortcoming we consider a comprehensive set of competing models which may switch from one to another at any particular time. The switching mechanism is implemented through dynamic model averaging (Raftery et al., 2010; see the next subsection for details), which returns posterior model probabilities for each model in every given period.

We assume that all the models share the same economic structure as given by (1) and only differ by the economic activity variable(s) included in the model. Such a design can help us to answer several interesting research questions, such as (i) whether the information content of the economic activity variables varies over time, (ii) what the best-performing variables are in any given period, and importantly (iii) whether recently proposed measures (such as the unemployment recession gap) really outperform traditional measures over the entire sample, or at least in the period after the recent financial crisis. Contrary to Stock and Watson (2010) we also include external factors such as crude oil prices and effective exchange rates to analyze their impact on inflation dynamics. In order to set out a horse race between the individual variables, we only consider models which include one domestic activity measure at a time.[16] The list of 13 competing models is shown in Table 1.

It can be seen that we focus on the prediction of the inflation gap in all models, as the trend is always included. The first six models each contain one of the domestic economic activity measures, but no external factors are included. The cohort of the subsequent six models is the same as before, but this time the models also contain external factors. Finally, the very last model assumes that only external factors drive the inflation gap. It should be stressed again that the coefficients in all the models are

[16] Note, however, that the information content of the individual variables can be combined via the averaging techniques presented in the next subsection.

allowed to vary over time so as to capture the process of potential flattening of the Phillips curve in the recent decades (a phenomenon reported by several authors; see, for example, Ball and Mazumder, 2011, and IMF, 2013).

3.2 Model Specifications

Because all 13 models presented in Table 1 share the same economic structure, they also have the same state space representation (1) and can be estimated in the same way. Following Raftery et al. (2010), we will first turn to the estimation of the individual models and later describe how the switching between models can be done via dynamic model averaging (DMA).

We start by noting that if the variances $\sigma^2_{e,t+h}$ and $\sigma^2_{\xi,t}$ in (1) were known then a filtered estimate of the time-varying coefficient γ_t could easily be obtained by standard Kalman filter prediction and updating formulas with almost no computational effort. If $\sigma^2_{e,t+h}$ and $\sigma^2_{\xi,t}$ are not known, it is always possible to estimate them, but this can be computationally demanding, especially if we assume time-varying volatility, which is usually modeled by stochastic volatility models and estimated via MCMC techniques.

Table 1: Summary of the Model Used for the DMA Estimation

Model	Trend $\tau_{t\|t}$	Output gap	RULC	Growth in employment	Short-term unemployment	Unemployment recession gap	Unemployment expansion gap	Oil price	Effective Exchange rate
1	●	●							
2	●		●						
3	●			●					
4	●				●				
5	●					●			
6	●						●		
7	●	●						●	●
8	●		●					●	●
9	●			●				●	●
10	●				●			●	●
11	●					●		●	●
12	●						●	●	●
13	●							●	●

Note: RULC stands for real unit labor costs. Inclusion of the variable in the model is indicated by "●". The models can be divided into three subgroups depending on whether they contain domestic economic activity variables and/or external factors.

Since we potentially work with large sets of competing models, the total computational burden may become prohibitive when the variances need to be estimated. For this reason, Raftery et al. (2010) suggest following earlier literature (e.g. Fagin, 1964, and Jazwinsky, 1970) and using fairly simple but generally effective approximations of $\sigma^2_{e,t+h}$ and $\sigma^2_{\xi,t}$. If we restrict our attention only to the relevant Kalman filter formulas, then the traditional prediction formula for the variance of the prediction error

$$P_{t|t-1} = P_{t-1|t-1} + \text{var}(\xi_t) \quad (3)$$

can be specified in terms of a forgetting factor λ and replaced by

$$P_{t|t-1} = \frac{1}{\lambda} P_{t-1|t-1} \tag{4}$$

where the forgetting factor λ is typically set slightly below 1. The resulting approximation still leads to a properly defined state space model, with $\sigma^2_{\xi,t} = (\lambda^{-1} - 1)P_{t-1|t-1}$. The forgetting factor λ regulates the uncertainty in the state (i.e., time-varying coefficient) evolution. Values close to one would lead to a fairly stable model. On the contrary, lower values enable higher variation in the coefficients (see Raftery et al., 2010, for the detailed motivation of this approach). Typically, λ is set to a fixed value by the user prior to the estimation; however, we follow Koop and Korobilis (2012) and estimate λ in a time-varying, data-driven manner. In our analysis we replace λ by λ_t, where

$$\lambda_t = \lambda_{\min} + (1 - \lambda_{\min})L^{f_t} \tag{5}$$

where $\lambda_{\min}$ and L are values pre-specified by the researcher that control the time-varyingness of the estimated coefficients:[17] $\lambda_{\min}$ is the minimum value of the forgetting factor and L defines the sensitivity of the coefficients' variation to (large) prediction errors. We further define f_t as $f_t = -round(\hat{e}'_{t-1+h}\hat{e}_{t-1+h})$, where $\hat{e}_{t-1+h}$ is a one-step-ahead prediction error produced by the Kalman filter and the *round* function rounds to the nearest integer. In the empirical analysis we set $\lambda_{\min} = 0.9$ and L = 1.2. We also experimented with other values, but the main story remained unchanged.

To obtain the value of $\sigma^2_{e,t+h}$ Koop and Korobilis (2012) suggest replacing it with an Exponentially Weighted Moving Average estimate, which can be computed recursively as

$$\hat{\sigma}^2_{e,t+h} = \kappa\hat{\sigma}^2_{e,t+h-1} + (1-\kappa)(\pi_{t+h} - \tau_{t|t} - \gamma_t x_t)^2 \tag{6}$$

where κ is called a decay factor and has a proposed value of 0.98 for quarterly data. Armed with these approximations, we can now obtain estimates of γ_t for all the models in Table 1 in a standard way. To initialize the Kalman filter we set our prior on γ_t to zero for each model and, following Raftery et al. (2010), we use $\mathrm{P}_{0|0} = \mathrm{Var}(\mathrm{y}_t)/\mathrm{Var}(\mathrm{x}_t)$. The data-driven choice of $\mathrm{P}_{0|0}$ can be advocated on the grounds of Cauchy-Schwarz inequality. In the sample of countries and variables selected, its value varied between 3 and 15. As a robustness check we also initialized the filter with $\mathrm{P}_{0|0}$ = 10 and $\mathrm{P}_{0|0}$ = 100 uniformly across all models and obtained almost identical results. Below we report the results after discarding the first two years, which were used as an initialization period.

Before we move to the problem of switching, let us note that the unobserved components model for inflation (2) also has a standard state space representation where both time-varying variances can be obtained using the approximations presented above. Thus, model (2) can potentially be estimated in a fast manner without the need to resort to the stochastic volatility model and MCMC techniques. To spare computation time, we will submit to this temptation and estimate (2) in a similar fashion as (1). This is not only a practical, but in some respects also a more flexible approach which opens the door to new interpretations of the model output.[18] However, in this case it is necessary to take into account

[17] In a certain sense, they can be interpreted similarly as the tightness of the priors on the coefficients.

[18] We will comment on the results in the Results section.

the specific nature of model (2) and adjust the values of $\lambda_{\min}$, L, and κ correspondingly. To estimate the inflation trend in (2), we set (after some experimenting) L = 1.2, κ = 0.94, and $\lambda_{\min}$ between 0.6 and 0.8 depending on the overall volatility of the observed inflation.

3.3 Model Switching

We now consider the multiple case where the model universe is formed by *K* competing models and there is uncertainty about the "true" model governing the inflation process at time *t*. There are several approaches to producing switching between individual models, with Markov-switching models being arguably the most popular. However, some evidence (see, for example, Belmonte and Koop, 2013) suggests that they only provide satisfactory results for a relatively small number of competing models, as it is quite difficult to specify (or estimate) large transition matrices. In addition, even up-to-date algorithms would require long computational time. Raftery et al. (2010) offer a solution to this problem in the form of dynamic model averaging (DMA). They propose to avoid specifying the transition matrix explicitly by introducing another forgetting factor α, which is again typically set to a value slightly below 1. The simplification consists in replacing the traditional model prediction equation (which requires knowledge of the probability transition matrix) by

$$\rho_{t|t-1,k} = \frac{\rho^{\alpha}_{t-1|t-1,k}}{\sum_{l=1}^{K} \rho^{\alpha}_{t-1|t-1,l}} \quad (7)$$

where $\rho_{t|t-1,k}$ denotes the probability[19] of model *k* being "true" at time *t*. Forgetting factor α works similarly as λ in (4), as it slightly inflates the distribution of model probabilities. Although this step is computationally simple, Raftery et al. (2010) argue that it represents an empirically sensible approach. Recent empirical evidence (Belmonte et al., 2013) seems to support this claim.

Obtaining the updated model probabilities is also computationally simple. The model-updating equation takes the form

$$\rho_{t|t,k} = \frac{\rho_{t|t-1,k}\, p_k(y_t \mid y^{t-1})}{\sum_{l=1}^{K} \rho_{t|t-1,l}\, p_l(y_t \mid y^{t-1})} \quad (8)$$

where $p_l(y_t \mid y^{t-1})$ is the predictive density for model *l* obtained by the Kalman filter and evaluated at y_t. Similarly to traditional BMA, model probabilities $\rho_{t|t-1,k}$ can then be used for model averaging (DMA) and model selection (DMS) purposes or for summarizing the relative performance of each model and variable. We make a non-informative choice on the model probability prior and set $\rho_{0|0,k} = \frac{1}{K}$, which means that at the beginning all the models are equally probable.

To better understand the role of the forgetting factor, Raftery et al. (2010) and Koop and Korobilis (2012) show that $\rho_{t|t-1,k}$ can be related to the weighted product of the predictive densities

[19] We use the symbol ρ for the model probability instead of the traditional π so as not to be confused with the rate of inflation.

$$\rho_{t|t-1,k} \propto \prod_{i=1}^{t-1} \left[p_k(y_{t-i} \mid y^{t-i-1}) \right]^{\alpha^i} . \tag{9}$$

This means that model k will receive higher probability at time t if it has exhibited good forecast performance in the recent past, where the performance is measured by the predictive density. The definition of the "recent" past depends on the value of the forgetting factor. Values close to unity imply that the forecast performance in the relatively distant past still receives quite a high weight, while lower values of the forgetting factor tend to ignore the forecasting ability of the model in more distant periods. In our empirical analysis, we use $\alpha = 0.95$ as a benchmark value, but values closer to one did not alter the overall picture substantially.

4. Results

The basic intuition behind our research is that there is substantial uncertainty about which real economy measure represents the most relevant information (i.e., provides the right signal) with respect to potential inflation pressures. Moreover, the relationship between (any measure of) real economic activity and inflation is prone to change over time given the presence of diverse nonlinear effects. Besides the time dimension, it is likely that there is also variation across space. Therefore, in order to be able generalize the empirical findings on this nexus, we believe that a cross-country focus is very useful. We aim at the G7 countries[20] given their share in world output, and also due to superior data quality. However, space restrictions prevent us from providing a detailed account for all the selected countries. Therefore, we opt for a more detailed description of the results for the U.S. as a benchmark, with the results for the other countries being used as a robustness check where only the cross-country aggregation is commented on and more detailed results are relegated to the Appendix II. This choice is mainly motivated by the importance of the U.S. economy, by the fact that most comparable studies have been carried out for the U.S., and last but not least by the fact that the data quality and span are by far the best.[21]

4.1 Role of Economic Activity in U.S. Inflation Dynamics

4.1.1 Estimated Trend Inflation and Expectations

First, we report the estimates of the UC-SV model of Stock and Watson (2007), which we use to estimate the inflation trend (Figure 1). To assess the degree of coherence with inflation expectations we compare the trend with one-year-ahead inflation expectations taken from the Survey of Professional Forecasters (SPF).[22] Overall, the model-based trend tracks the long-term signal in

[20] We provide also an extension with Czech data, but given the substantially shorter span of the sample as compared to the G7 countries, these results should be taken with a lot of caution.

[21] The data availability is limited mainly by the availability of the short-term or long-term unemployment rate. For European countries, these data are available since 1983.

[22] Note that we compare the UC-SV trend in core CPI with the SPF forecast of overall inflation because the core inflation expectations forecasts are not available for a sufficiently long period of time. Additionally, Ball and Mazumder (2011) argue that survey inflation expectations have been "shock-anchored" since the 1980s, that is, supply shocks have had little effect on inflation expectations and so the survey expectations track core inflation.

inflation expectations quite well, which suggests that it can be considered a candidate measure for the former. Notably, the model-based expectations reflect the stabilization of inflation expectations after the sharp disinflation of the early 1980s. Initially, inflation expectations are anchored to a 4% level of inflation, and then, starting at the beginning of the 1990s, the survey expectations and the UC-SV trend gradually decrease and approach the 2% level. Inflation expectations stabilize at 2% and somewhat surprisingly stay at that level during the Great Recession. In particular, the downturn in SPF expectations around 2008 was subsequently revised back to the 2% level.

Figure 1: Net Inflation, One-Year-Ahead Inflation Expectations (SPF), and UC-SV Inflation Trend, U.S.

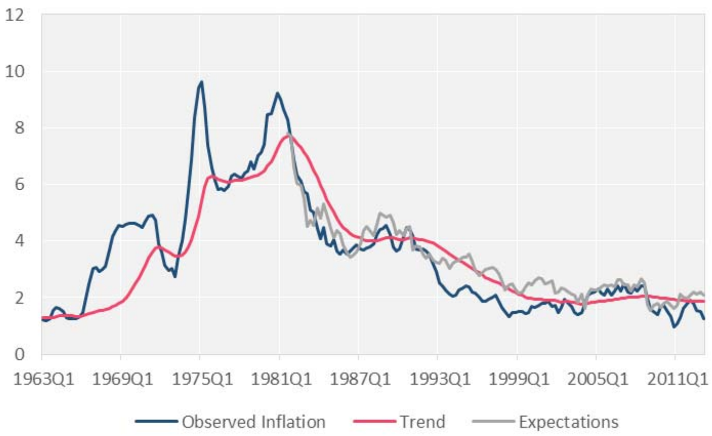


Figure 2: Estimated Value of Forgetting Factor and Standard Deviation of Transitory Component, U.S.

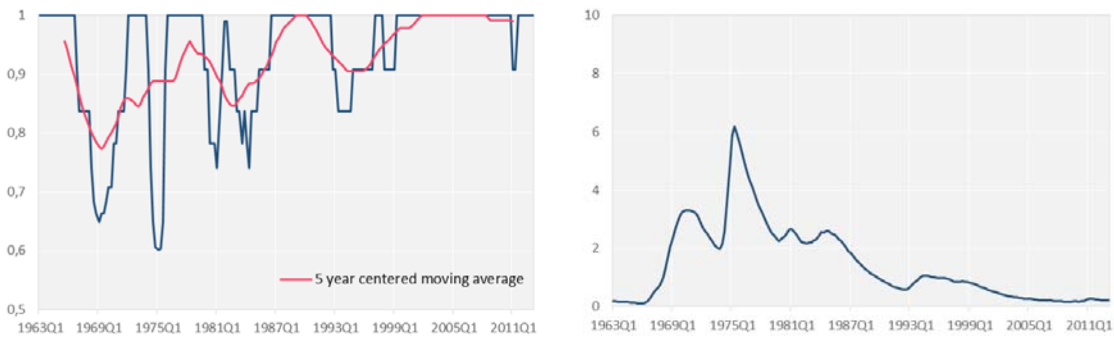


Figure 2 documents changes in the variability of the trend and transitory components of U.S. inflation. The volatility of the trend, as measured by the value of the forgetting factor, has been decreasing steadily to historical lows over the last decade, with the trend broadly exhibiting quite stable levels. Similar developments can be observed in the variability of the transitory component, which also shows a gradual decline.

Our results seem to support the hypothesis that inflation expectations were not anchored in the U.S. before the sequence of supply shocks hit the U.S. economy in the 1970s. As found by Benati and Goodhart (2011) and Clarida et al. (2000), the start of the Great Inflation seems to coincide with the monetary policy loosening in the second half of the 1960s. To the degree that the estimated trend tracks inflation expectations, the former claim can be nicely re-interpreted in terms of the forgetting factor. Roughly speaking, very low values of the forgetting factor indicate that economic agents take into account only actual (and the most recent) level of inflation to adjust their expectations. This means that expectations are not anchored and react instantly to changes in the price level. For example, the forgetting factor of 0.6 reached during the 1970s suggests that the inflation rate observed a year ago receives only 13% as much weight as the very last observation when the formation of expectations takes place.[23]

With respect to the Great Moderation, our results support the interpretation given by Ball and Mazumder (2011) that the anchoring of inflation expectations was a gradual process consisting of two stages: First, *shock anchoring* occurred, with inflation expectations becoming unresponsive to temporary changes in inflation after the inflation trend stabilized in the first half of the 1980s. Second, inflation expectations gradually became *level-anchored* to an inflation level of 2% and continued to be level-anchored in the Great Recession.

4.1.2 Which Variable Drives the Inflation Gap?

Following Stock and Watson (2010) we focus on the impact of economic activity on the size of the inflation gap, employing six different variables to represent domestic economic activity and the effect of external inflation drivers stemming from oil prices.[24] Figure 3 presents the posterior model probabilities of all the models. Not to clutter the figure, we sum the probabilities of the models without the external variables and the models augmented for the external variables (for example, the model probability of the output gap corresponds to the sum of the probabilities of models 1 and 7 in Table 1). Our results show that in general economic activity has explanatory power with respect to the inflation gap (see also Figure 6); however, the contributions of the candidate measures of domestic economic activity differ and change significantly over time. The results point to the importance of the model-switching approach in accounting for changes in inflation drivers in the context of the inflation–activity nexus, alongside the traditionally considered parameter instability.

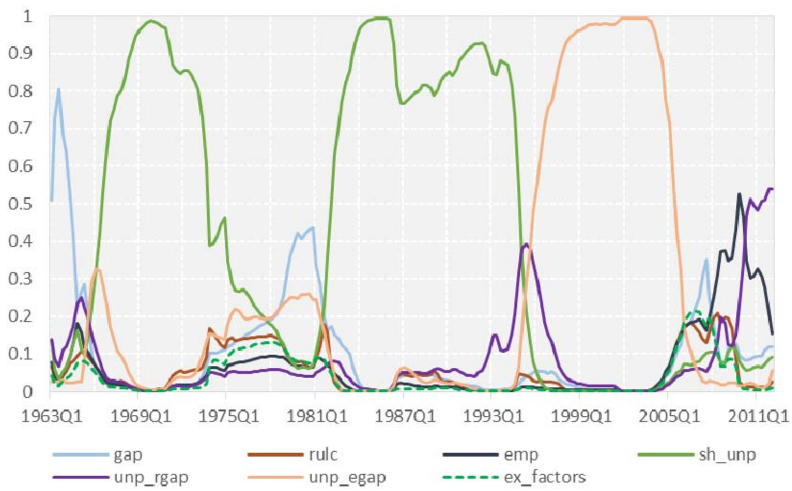
Overall, the short-term unemployment rate (sh_unp) and the unemployment expansion gap (unp_egap) dominate the other variables in most parts of the sample. The traditional output gap (gap) and the unemployment recession gap (unp_rgap) have the highest inclusion probabilities only on a few, temporary occasions, pointing to the importance of disaggregation of economic activity and to the possibility of changing inflation drivers in the context of the inflation–activity nexus. On the contrary, (the changes of) total employment (emp) and real unit labor costs (rucl) emerge as the worst performers. Whereas the failure of the traditional output gap to take a lead in the steeplechase might resonate with the views of some practitioners, the results for some of the other variables might be seen (vis-à-vis some previous empirical findings) as disappointing.In particular, the real unit labor costs fiercely advocated by Galí and Gertler (1999) and their followers do not seem to leave much

[23] It would be an interesting matching exercise to set the path of the forgetting factors so as to track SPF expectations as closely as possible. This could then be used to generate more elucidating insights into the process of formation of inflation expectations.

[24] Given that the availability of the NEER would substantially limit our time span, and also given that the U.S. is a large and rather closed economy, we use oil prices as the only proxy of external inflation factors for the U.S. (unlike in the case of the other six countries).

footprint when compared with alternative variables.[25] Rather unconvincing results also apply to the unemployment recession gap, which was suggested by Stock and Watson (2010) as a measure of economic activity having a stable relationship with the inflation gap and outperforming other measures of economic activity. We find instead that this variable did not gain a considerable lead over its competitors and its relevance for explaining the inflation gap changes over time. However, it seems to be the best-performing variable in the very recent period, which is (rather paradoxically) not considered in Stock and Watson (2010).

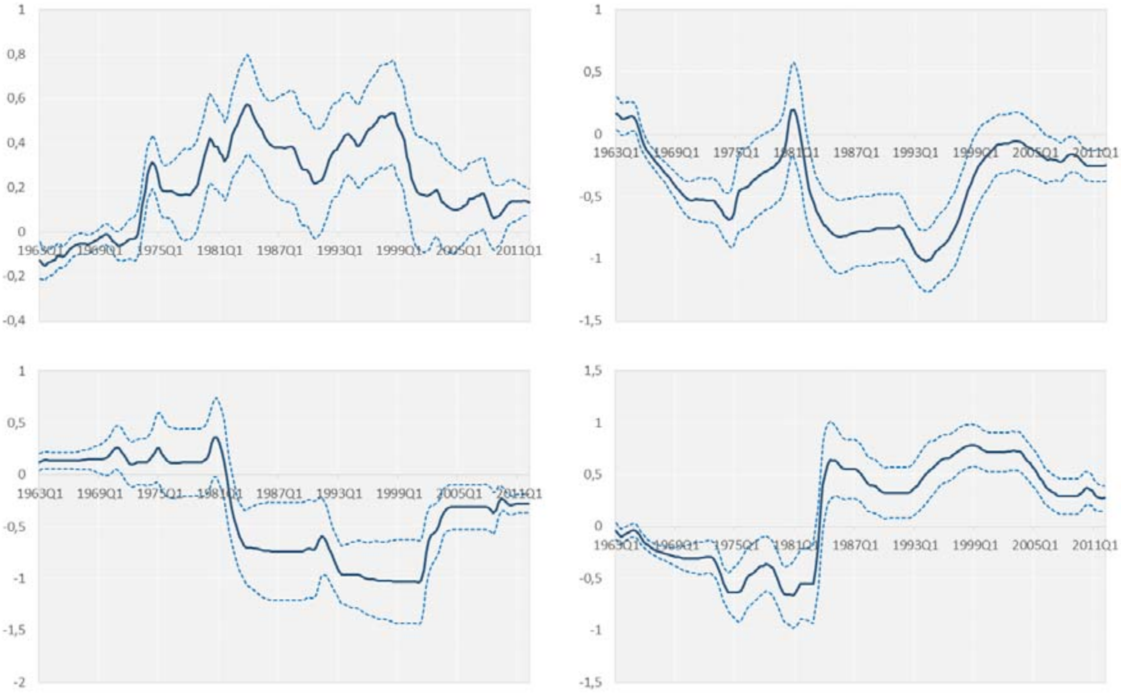
Figure 3: Posterior Model Probabilities, U.S.



From our point of view, the most promising results are obtained for short-term unemployment, which dominates from the 1960s to the mid-1990s. More specifically, the short-term unemployment rate has the highest posterior model probability from the second half of the 1960s until the first oil shock in 1973, especially when supply shocks are also considered as additional inflation drivers. In the Great Inflation, the picture is rather blurred and none of the models dominates strongly over the others. Nevertheless, beside the supply shock stemming from rising oil prices, inflation is still driven by short-term unemployment, the output gap, and the unemployment expansion gap. After the Volcker disinflation and the early 1980s recession, the pattern of the inflation dynamics changes and the short-term unemployment rate again takes the lead over the other variables. The robust growth of the 1990s, a decreasing NAIRU, and low inflation lead to a decrease in the posterior probabilities of all the other variables besides the unemployment expansion gap, which emerges as the most relevant measure of real economy pressures in this period of bonanza ending in 2007. Since the global financial crisis and the Great Recession the picture has become a bit more blurred, with no variable being clearly dominant, but with the unemployment recession gap gaining in relevance.

[25] In fact, the certain degree of correlation between real unit labor costs and the output gap that was apparent between 1960 and 1997, which was analyzed in Galí and Gertler (1999), entirely disappears in the subsequent period and it is hard to argue that there is any proportionality between these two variables at all. As noted above, we believe that alternative ways of modeling inflation expectations should not significantly affect the relationship between inflation and economic activity. Besides, our approach is close in spirit to the hybrid New Keynesian Phillips curve, which allows for both adaptive and rational expectations formation.

Figure 4: Time-Varying Coefficients of Selected Measures of Economic Activity, U.S.



Note: output gap (upper left), short-term unemployment (upper right), unemployment recession gap (lower left), unemployment expansion gap (lower right)

Besides the posterior model probabilities, which provide information on the relative performance of each model, it is also important to assess the individual impacts of the various real economy measures on the inflation gap. Figure 4 presents the time-varying coefficients (with 95% credible intervals) for the output gap and the unemployment-related variables that have the highest inclusion probabilities consistently throughout the sample. The first notable finding is that the impact of economic activity on inflation has decreased markedly over the last decades and this decrease is broad and visible across all the variables under consideration.

The contribution of the output gap to the inflation gap (upper left graph) is positive and significant throughout the sample (with the exception of the 1960s). However, the absolute values of all the coefficients decreased markedly in the 2000s, along with stabilization of inflation, a decrease in the deviations from trend inflation, and level-anchoring of inflation expectations. The coefficient on short-term unemployment (upper right graph) is again often significant with the correct negative sign and shows rather inverse movement to the coefficient on the output gap. The short-term unemployment coefficient shows an increasing impact (i.e., a lower coefficient) of economic activity up to the mid-1970s, when the impact starts decreasing, arguably as a consequence of commodity shocks (see also Figure 3), increasing again only in the early 1980s. The short-term unemployment coefficient enters insignificant territory (very similar to the coefficient on the output gap), confirming a flattening of the Phillips curve. Our results do not provide a clear-cut picture of what the forces behind this flattening might be.[26] The short-term unemployment coefficient significantly decreases

[26] Ball and Mazumder (2011) use unemployment as the only variable representing economic activity and they provide tests of several hypotheses of why the Phillips curve has flattened in recent years. Their hypotheses are that the causes lie in anchored inflation expectations and in overall lower levels and variability of inflation. The role of inflation expectations is further elaborated in chapter 3 of the IMF's WEO 2013 (IMF, 2013).

only in the late 1990s, which seems to coincide with the process of globalization. On the contrary, the output gap coefficient shows a decreasing trend from the mid-1980s onwards, which coincides with the period when a strong anti-inflationary monetary policy stance was adopted.

The coefficient on the unemployment recession gap (lower left graph) has a rather counterintuitive positive coefficient in the 1970s, which seems to be related to stagflation as a phenomenon that is entirely inconsistent with the inflation–employment trade-off and the Phillips curve. In the early 1980s the coefficient turns significant and stays so until the 2000s, confirming (similarly to the above-mentioned two coefficients) that the correspondence between inflation and economic activity has weakened in the last 15 years. Contrary to Stock and Watson (2010) we do not find that the impact of this variable on the inflation gap is stable over time or that the coefficient is significantly less volatile than that for other variables.

The coefficient on the unemployment expansion gap (lower right graph) has been positive over recent decades, meaning that decreasing unemployment has been accompanied by a reduction in the inflation gap. Although this result seems counterintuitive at first sight, it is in line with the observed non-inflationary growth of the 1990s, boosted by growth in productivity. Therefore, this result seems to be driven by the presence of a supply shock, e.g. productivity, which cannot be accounted for by any measure of economic activity, and as suggested recently by Gordon (2013), productivity might be explicitly considered an additional inflation driver (alongside measures of domestic economic activity and foreign variables).

Figure 5: Relative Importance of Domestic vs. Foreign Inflation Drivers, U.S.

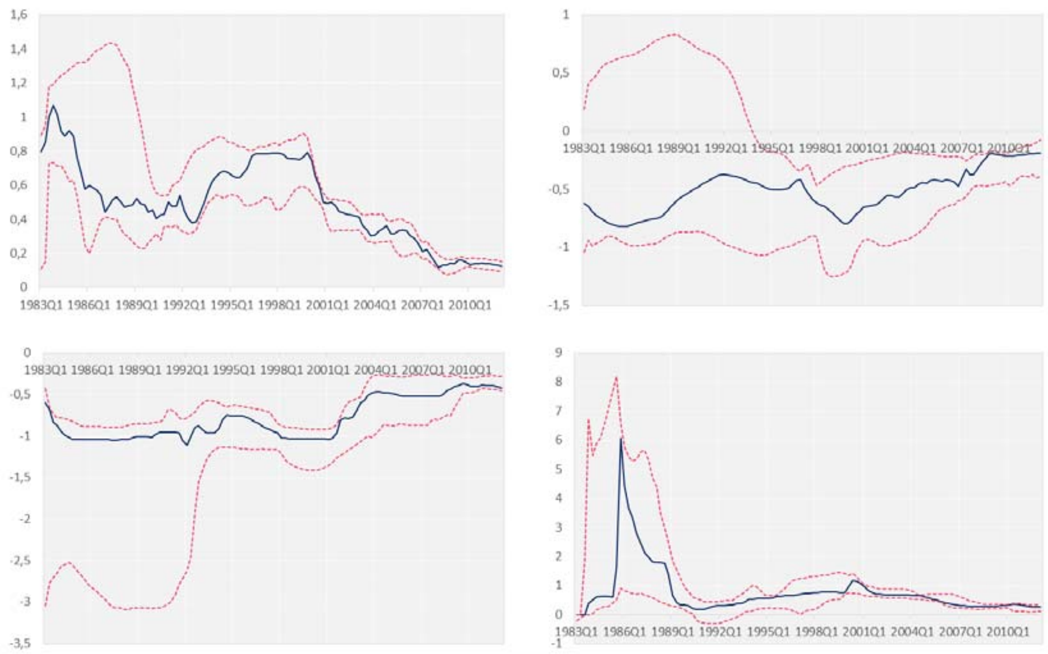
Figure 5 compares the relative performance (in terms of posterior model probability) of the models with external inflation drivers, namely, oil prices, and the models without this variable. The main finding is that the importance of external factors also varies over time. Although the model with oil prices but without any activity variable has generally low posterior model probabilities (below 0.2 – see Figure 3, dashed line), Figure 5 shows that the models augmented by oil prices and hence accounting for supply shocks have higher posterior probabilities than those with purely domestic inflation drivers, since the oil shocks hit in the 1970s until the mid-1980s and then again shortly before the Great Recession, when oil prices and prices of other commodities hit historical highs. It should be noted that the differences in the estimated coefficients between the models with and without external variables were negligible (the coefficients in the models without external variables are reported in Figure 4), so Figure 5 indicates the periods in which the external drivers contain additional explanatory power to the inflation gap given by the predictions based on domestic inflation drivers only.

4.2 Economic Activity and Inflation in G7 Countries

The economic activity–inflation nexus in the G7 countries shares a number of common features with that in the U.S. First of all, for no country is there a variable that can robustly be considered the best performer in predicting the inflation gap. Our country-level results (see Appendix II) show that models with the output gap, traditionally representing economic activity in macro models, dominate other models only rarely, with the exceptions of the UK and Germany in the 1990s. Other variables, such as unemployment and related gaps, usually perform better, as can be seen from the posterior model probabilities.

The results are also rather heterogeneous for the Great Recession. The Dynamic model selection selects the unemployment recession gap in Japan, the UK, and Germany, whereas in France and Italy short-term unemployment dominates the other variables. Hence, the unemployment-related variables recorded the highest posterior model probabilities in all countries in the period of the Great Recession. The richness of the dynamics over time in terms of both the size of the coefficients (Figure 6) and the model inclusion probabilities (see Appendix II) explains why most of the models estimated on the pre-Great Recession sample fail to predict the inflation gap correctly: the answer lies in the inherent instability of the forms of the inflation–activity nexus.

Figure 6: Time-Varying Coefficients of Various Measures of Economic Activity, Medians for G7 Countries



Note: output gap (upper left), short-term unemployment (upper right), unemployment recession gap (lower left), unemployment expansion gap (lower right). The intervals represent the 25%–75% quantiles.

The key observation that can be drawn from Figure 6 is that real activity has a significant but very time-dependent impact on inflation. The width of the "confidence" interval (constructed as the 25%–75% quantiles of the country observations) is substantial until the late 1990s, suggesting a lot of country heterogeneity that disappears during the next decade. This is arguably related to globalization. Whereas in the 1980s there was greater heterogeneity of the business cycle across countries and also greater heterogeneity in the strength of the relationship between inflation and economic activity, globalization has contributed to the alignment of both, and the evolution of the response coefficients has become much more similar across countries. A more detailed inspection of the time-varying coefficients reveals some similar findings as for the U.S. In particular, the coefficients on the output gap, unemployment, and the unemployment recession gap are consistent with the economic intuition about the slope of the Phillips curve, whereas the coefficient on the unemployment expansion gap is positive, with large dispersion across countries.[27] Specifically, the slopes of the Phillips curves have decreased over recent decades (due to the limited availability of data for some G7 countries the overall figures start only in 1983). This decrease is broad, shared by almost all the time series and all the countries under consideration, and not only for the output gap and the unemployment rate, which are traditionally reported in most of the recent studies. These results support the hypothesis that the slope of the Phillips curve is probably time-varying, depending on the level and variability of inflation, which are now at historically unprecedented low levels.

It has been an ongoing trial to augment the Phillips curves for the effects of external inflation drivers (Galí and Monacelli, 2005) to account for the openness of economies and possible inflationary supply shocks. We augmented all the models with oil prices and the nominal effective exchange rate, and these external drivers (see the second figure for each country in Appendix II for posterior probabilities of models without and with external inflation drivers) are generally significant in all the G7 countries except Italy and Germany, although usually only temporarily. As in the case of the United States, the posterior model probability is rather low for the model containing only external variables, so domestic economic activity can be considered the main determinant of the inflation gap.

4.3 Extension – Small Open Economy Perspective: The Case of the Czech Republic

The results for the G7 countries share interesting similarities. However, the perspective from a small open economy that adopted anti-inflationary policies to stabilize inflation and anchor inflation expectations around 2000 might offer some additional insights. In particular, we might expect steeper coefficients of the Phillips curve even before the Great Recession, and also the role of the external inflation drivers could be greater. The Czech Republic seems to be a natural candidate for such analysis: the Czech central bank adopted inflation targeting in 1998 as part of its disinflationary policies, and a few years later inflation expectations were anchored to the inflation target at a similar level to other new EU member states, while the second half of the 2000s is associated with robust economic growth.

[27] It should be noted that the unemployment expansion gap usually has low posterior probabilities in this period, with the exception of the U.S. and the UK – countries with robust non-inflationary growth in the 1990s fostered by increasing productivity (see the previous section and Appendix II for the posterior inclusion probabilities for individual countries).

The inclusion probabilities at the four-quarters-ahead forecasting horizon (see Appendix III) select real unit labor costs, the unemployment recession gap, and the unemployment expansion gap. At this horizon, the domestic driving factors clearly dominate. This finding corresponds to the evidence of Baxa et al. (2012), who estimated an open-economy version of the NKPC in a time-varying environment, and is a sign of quite fast transmission of the information contained in external inflation drivers to domestic variables. At the horizon of one quarter ahead (which is also included for the Czech Republic, as it provides more plausible results; see Appendix III) the role of the external inflation drivers increases in the late 1990s and again in 2008 in response to a sharp increase in the oil price and prices of other commodities. Similarly to the U.S. and the other G7 countries, the selection between the various measures of real economic activity has become rather uncertain since the onset of the Great Recession, which confirms the previous claim that the inflation dynamics have changed over the last few years.

The coefficients on the driving factors (not reported but available upon request) occasionally reach significant levels before the Great Recession, but flatten out afterwards. However, this observation is in line with the fact that in the Czech Republic disinflation from double-digit levels started in 1998 and the inflation rate used to be relatively volatile over the sample. The positive coefficient on the unemployment expansion gap implies non-inflationary growth powered by a continuously increasing probability in the late 2000s.

4.4 Overall Importance of Economic Activity for Inflation

Our steeplechase is not single race to determine the winner at the finish line, as it is apparent that different models can win in different historical phases of this race. The race results are summarized in Table 2, where we present the percentage of time each economic activity variable outperformed the others, i.e., the percentage of the time each model had the highest posterior probability, for each country. The cross-country variation is very significant. In general terms, the best-performing variable is the short-term unemployment rate. By contrast, the worst score is retained by total employment growth, while the importance of the other variables lies in between. Particularly notable is the predominance of the output gap for Germany and the UK and the unemployment recession gap for Japan. As noted, the external factors without any measure of domestic economic activity are hardly ever able to explain the inflation dynamics.

Table 2: Percentage of the Time Each Model With a Specific Measure of Economic Activity Outperformed the Others

Country	Output gap	RULC	Growth in employment	Short-term unemployment	Unemployment recession gap	Unemployment expansion gap	External factors
United States	12.69	0.00	4.57	50.76	5.58	24.87	1.52
Canada	11.68	8.76	0.73	50.36	11.68	16.79	0.00
Germany	50.46	10.09	0.92	22.94	15.60	0.00	0.00
France	0.00	18.35	2.75	36.70	22.94	19.26	0.00
Italy	14.68	23.85	5.50	33.94	6.42	15.60	0.00
United Kingdom	40.37	0.00	13.76	1.83	17.43	26.60	0.00
Japan	0.00	0.00	6.02	31.58	62.40	0.00	0.00
Czech Republic t+4	0.00	28.07	0.00	7.02	21.05	43.86	0.00
Czech Republic t+1	28.33	0.00	0.00	0.00	53.33	13.33	5.00

So far we have been dealing with the relative importance of various measures of economic activity in explaining inflation by means of the posterior probabilities of various models. Now we turn to assessing the overall importance of domestic economic activity in explaining inflation (the inflation gap). First, we compare the DMS and DMA pseudo out-of-sample predictions of the inflation gap over time. Figure 7 provides such a comparison for the U.S. The results for the other countries are given in Appendix II (see the third figure for each country). The figures suggest that the relationship between inflation and economic activity is strong and robust. Indeed, most of the major inflation upturns and downturns are well explained by the real economy variables. However, these results also confirm that the relationship between inflation and economic activity is rather complex and cannot be traced by a Phillips curve depending on a single measure of economic activity and assuming a stable and linear relationship between inflation and economic activity. Therefore, this nexus can only be seen when a more subtle approach that explicitly accounts for the uncertainty of this relationship, such as DMA/DMS, is used.

Table 3 then reports several statistics of the model's fit, with R squared ranging roughly between 0.2 and 0.5. While these results are far from being fully satisfactory from the perspective of an inflation analyst, they simply reflect the fact that inflation (the inflation gap) is rather difficult to predict. On the other hand, we note that using our approach we obtained considerably higher R squared than that reported in Stock and Watson (2010), which points to the importance of exploiting dynamically the information content of all competing variables characterizing economic activity. The same applies to the RMSE measure, where again one can see larger efficiency gains vis-à-vis Stock and Watson (2010) when compared to the null model (i.e., the model only capturing the long-term inflation trend without any other explanatory variables describing the real economy). It can also be seen that even if individual models do not always work better than the null model, their switching across time leads to significant improvements over the null model in all cases.

Figure 7: Inflation Gap vs. DMA/DMS Predictions, U.S.

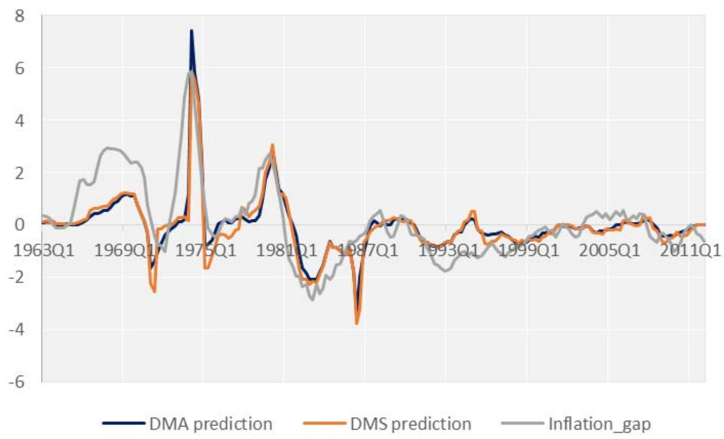


Table 3: Model Fit: R Squared, RMSE From Forecasting Regressions

Country	DMA model	DMS model
United States	0.514	0.480
Canada	0.661	0.611
Germany	0.424	0.378
France	0.493	0.174
Italy	0.354	0.232
United Kingdom	0.385	0.393
Japan	0.490	0.337
Czech Republic t+4	0.238	0.106
Czech Republic t+1	0.271	0.239

Country	Mean RMSE across models	DMA model	Null model	Relative RMSE DMA/Null
United States	1.302	1.007	1.500	0.784
Canada	1.430	0.927	1.523	0.575
Germany	1.604	0.932	1.207	0.772
France	1.169	0.674	0.893	0.755
Italy	2.070	0.991	1.132	0.875
United Kingdom	1.521	1.201	1.524	0.788
Japan	1.163	0.705	0.877	0.804
Czech Republic t+4	3.208	2.637	2.882	0.915
Czech Republic t+1	2.497	2.159	2.448	0.882

Note: RMSE stands for Root Mean Square Error. The mean RMSE across models was calculated as a simple average of the RMSEs obtained from all 13 individual models. The null model is a model without any explanatory variables characterizing the real economy, and its RMSE can be identified with the RMSE of the UC-SV model given by (2).

As expected the worst performance in all the statistics presented can be observed for the Czech Republic, where only short time series are available and where possibly some inflation dynamics unrelated to the business cycle (demand side) were not successfully filtered out due to the economic transition and administrative measures (the time series of core inflation was not used for the Czech Republic, as it is prohibitively short).

5. Conclusions

The aim of this paper is to shed some new light on the economic activity–inflation nexus through the lens of dynamic model averaging (DMA). This approach addresses the uncertainty inherent in the selection of an appropriate measure of real economic activity (vis-à-vis its impact on inflation). In particular, the DMA model allows both the most appropriate measure of real economic activity and the impact of any variable of real economic activity to change over time. In other words, time variance is allowed both for the probabilities of individual models (with different variables representing economic activity) and for the coefficients. Six variables tracking real economic activity took part in our steeplechase. Four of them are rather traditional: the output gap, real unit labor costs, growth of the employment rate, and the short-term unemployment rate. In addition, following the recent contribution by Stock and Watson (2010), we examine the unemployment recession gap, focused on periods with increasing unemployment, and also create its counterpart, the unemployment expansion gap, targeted at periods with decreasing unemployment rates. Finally, variables representing foreign supply shocks, in particular oil prices and the nominal effective exchange rate, also run in our steeplechase.

We find evidence in favor of both "model switching" and time variance of the individual coefficients in the context of the inflation–activity relationship. Our results show that inflation responds significantly to economic activity across time and space, but does so to a varying extent across different measures. Evidently, no measure of economic activity clearly dominates in all countries or over the whole sample. The traditional output gap is almost always outperformed by unemployment-related variables. The performance of real unit labor costs, which are employed in some empirical studies on the NKPC, is rather disappointing, limiting their potential as an inflation driver.

Our results also suggest that foreign factors play an important role for inflation even in relatively large and closed economies, as many G7 countries are. Although their relevance varies over time and across different horizons, there are long periods where external factors are significant inflation drivers. Nevertheless, it should be noted that external variables outperform variables representing domestic economic activity only in a few isolated periods. Thus they have additional rather than leading explanatory power for fitting and predicting the inflation gap.

Finally, we document a weakening of the inflation–activity relationship (i.e., a flattening of the Phillips curve) in the recent decades that is robust both across activity measures and across countries. Although there is still no consensus whether these developments shall be attributed to structural changes in the economy or rather to monetary policy, the fact that inflation has become the only target variable of most central banks supports the hypothesis that monetary policy contributed to some degree to the weakening of the trade-off. Besides, the flattening is conditional on inflation expectations remaining anchored in most countries. There is no guarantee that a flat Phillips curve would persist if inflation expectations were to break away from (more or less explicit) inflation targets.

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Appendix I: Data

G7 countries in our sample: Canada (1976:01–2013:01), France (1983:01–2013:01), Germany (1983:01–2013:01), Italy (1983:01–2013:01), Japan (1977:01–2013:01), the UK (1983:01–2013:01), and the U.S. (1961:01–2013:01). The Czech Republic (1996:01–2013:01). The data span varies according to data availability. All series are seasonally adjusted. Most series are from the OECD's Main Economic Indicators and Economic Outlook. Some series were taken from national sources.

Inflation: year-on-year difference of the price index measuring core inflation (i.e., the consumer price index excluding food and energy prices, OECD MEI). For the Czech Republic and the UK, where sufficiently long series are not available (CZ) or discontinued (UK), the entire consumer price index is used.

The inflation gap is defined as the deviation of year-on-year CPI inflation (in t+4 or t+1) from its trend value (for t) from the UC-SV model of Stock and Watson (2007). The survey inflation expectations series used for comparison with the UC trend are from the Survey of Professional Forecasters.

The various domestic forcing variables are:

- the output gap: derived using the Hodrick–Prescott (HP) filter for real GDP
- real unit labor costs: year-on-year change of the index
- the employment rate: year-on-year change
- the short-term unemployment rate
- the (short-term) unemployment recession gap
- the (short-term) unemployment expansion gap

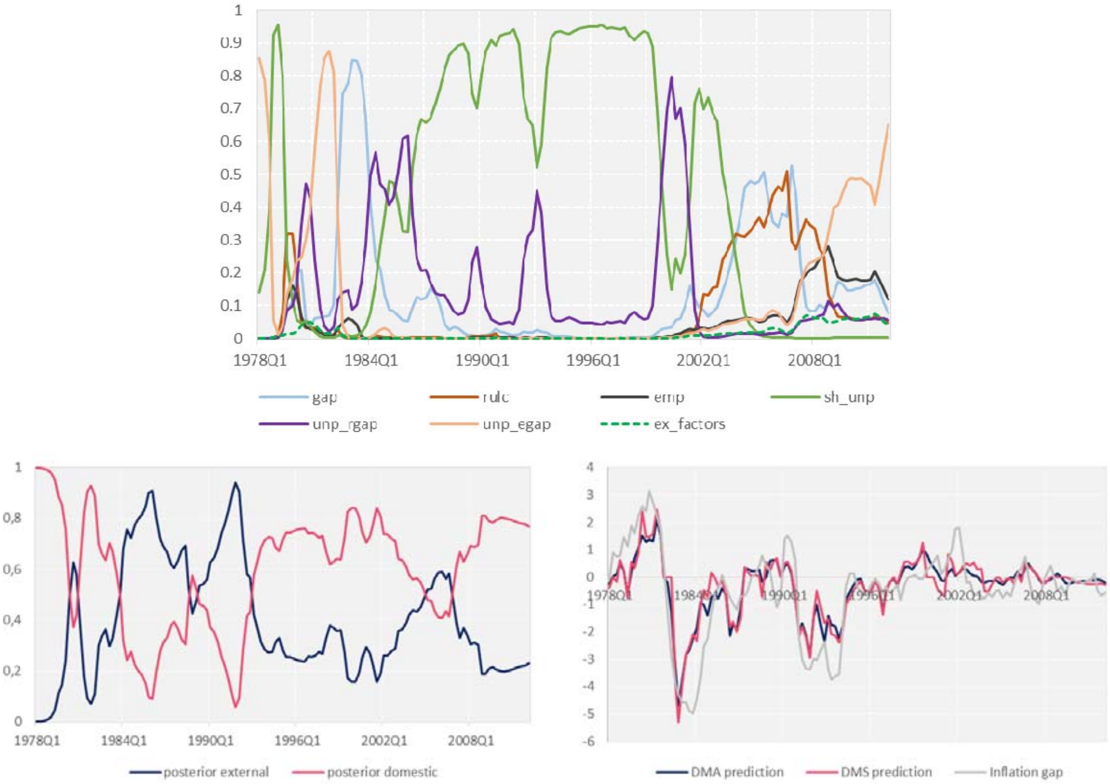
The external control variables are:

- the crude oil price: year-on-year change
- the nominal effective exchange rate: year-on-year change

Appendix II

1. Posterior model probabilities, 2. Relative importance of domestic vs. foreign inflation drivers, 3. Inflation gap vs. DMA/DMS predictions, individual G7 countries (besides the U.S.)

Canada



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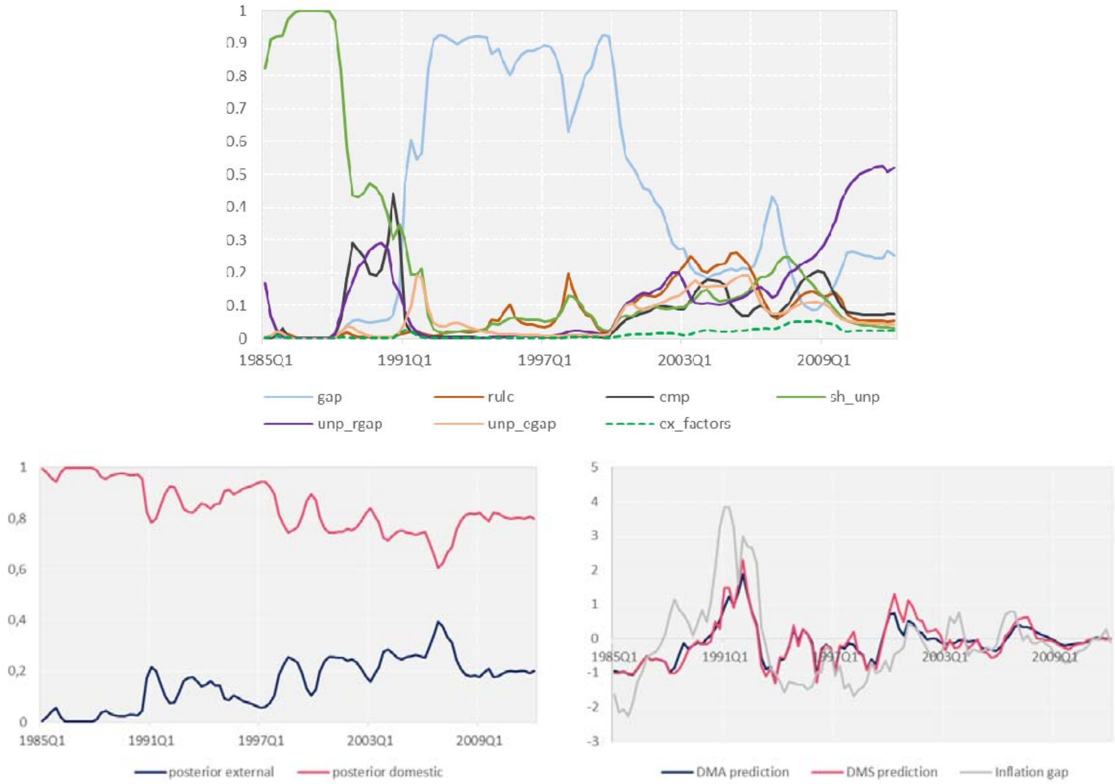
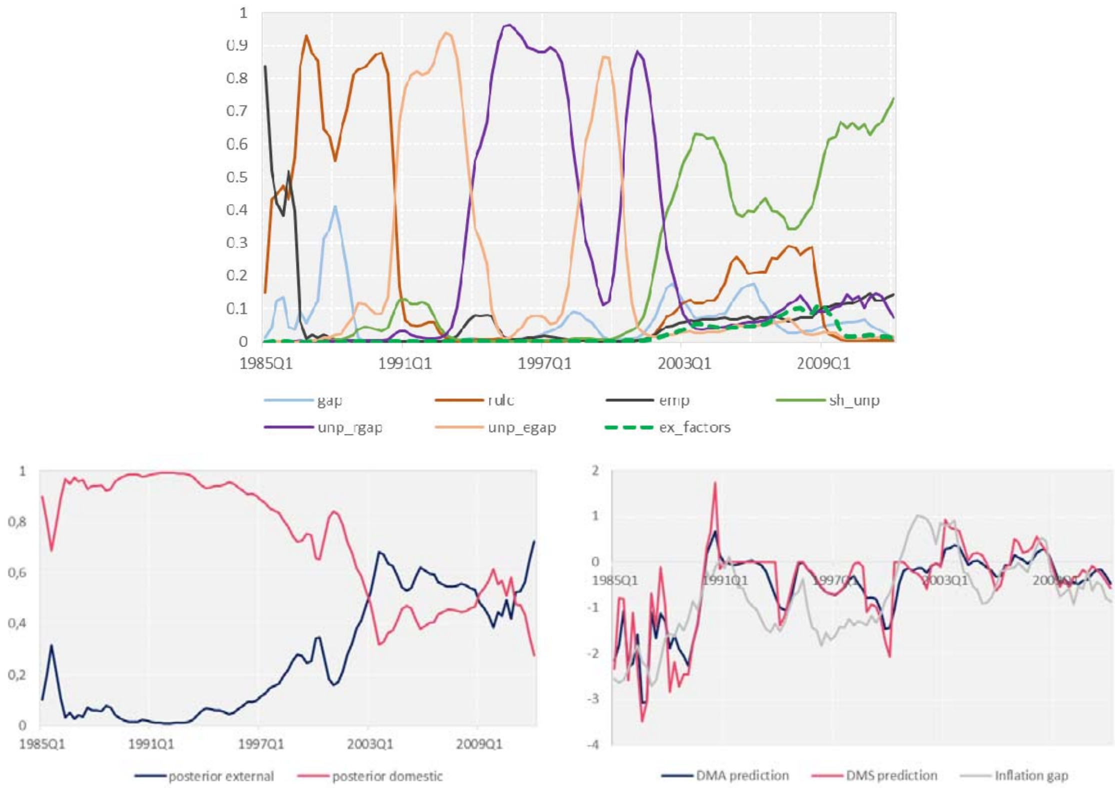
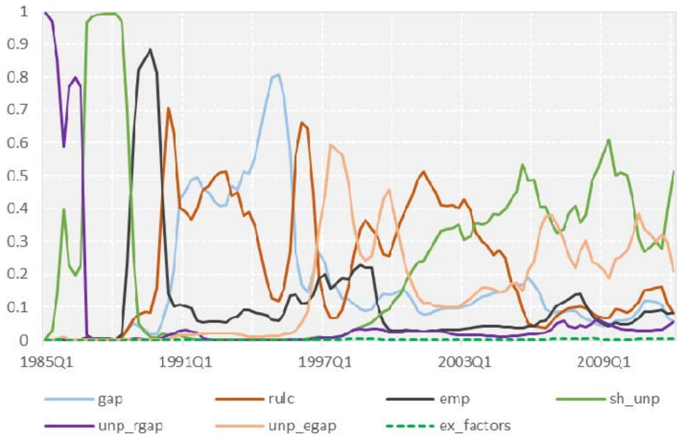


France



Italy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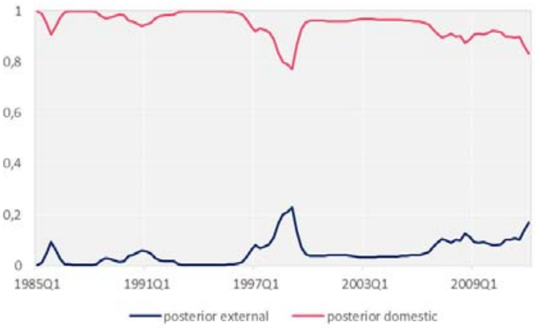
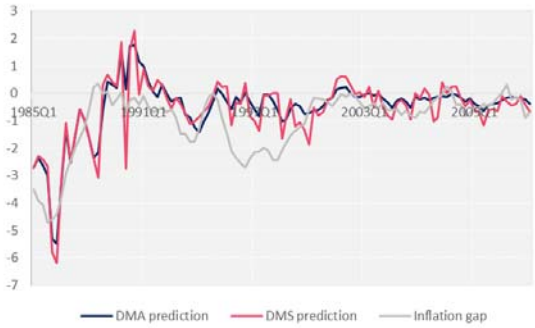
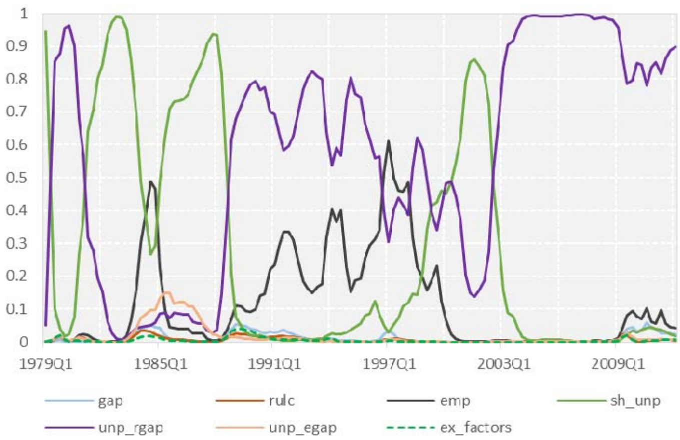
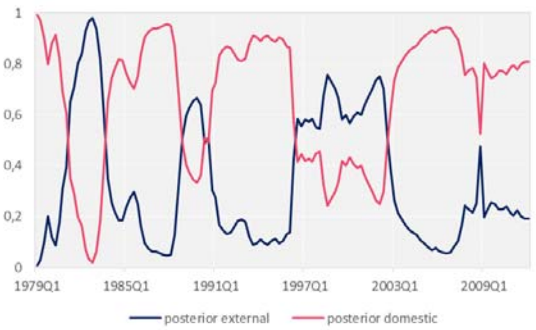
rulc
emp
sh_unp
unp_rgap
unp_egap
ex_factors

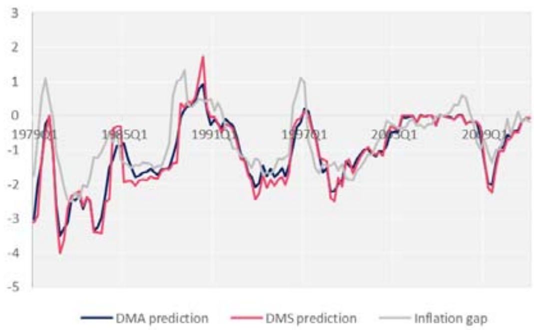

posterior external
posterior domestic


DMA prediction
DMS prediction
Inflation gap

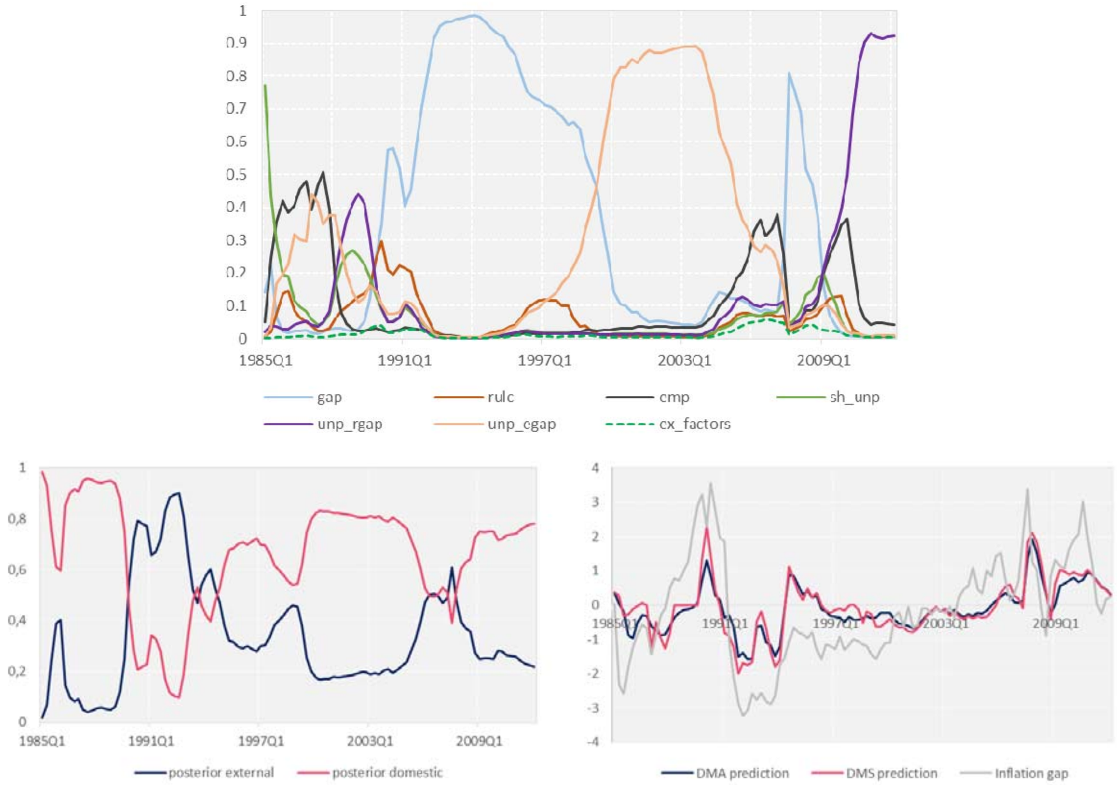
Japan


gap
rulc
emp
sh_unp
unp_rgap
unp_egap
ex_factors


posterior external
posterior domestic


DMA prediction
DMS prediction
Inflation gap

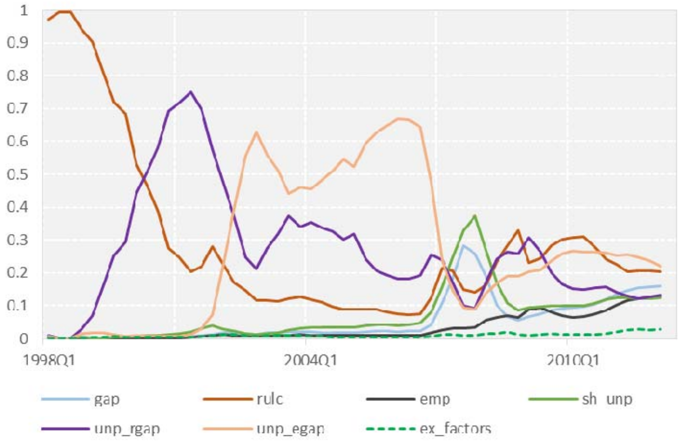
UK

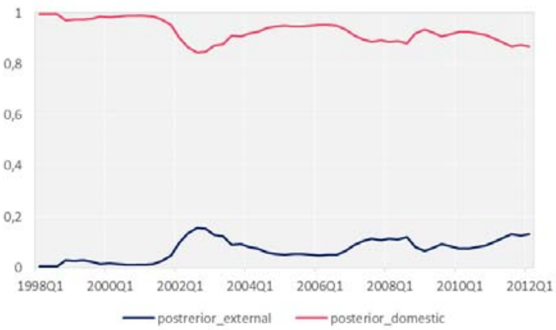

1985Q1
1991Q1
1997Q1
2003Q1
2009Q1
gap
rulc
cmp
sh_unp
unp_rgap
unp_cgap
cx_factors
posterior external
posterior domestic
DMA prediction
DMS prediction
Inflation gap

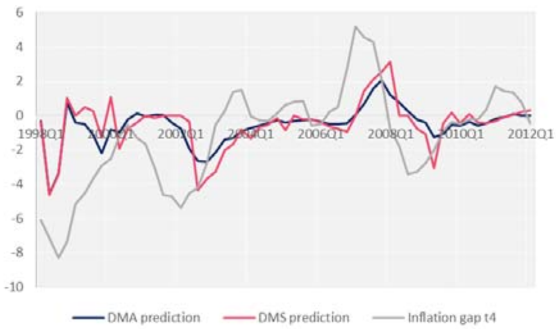
Appendix III

1. Posterior model probabilities, 2. Relative importance of domestic vs. foreign inflation drivers, 3. Inflation gap vs. DMA/DMS predictions, Czech Republic (infl.gap t+4 and t+1)

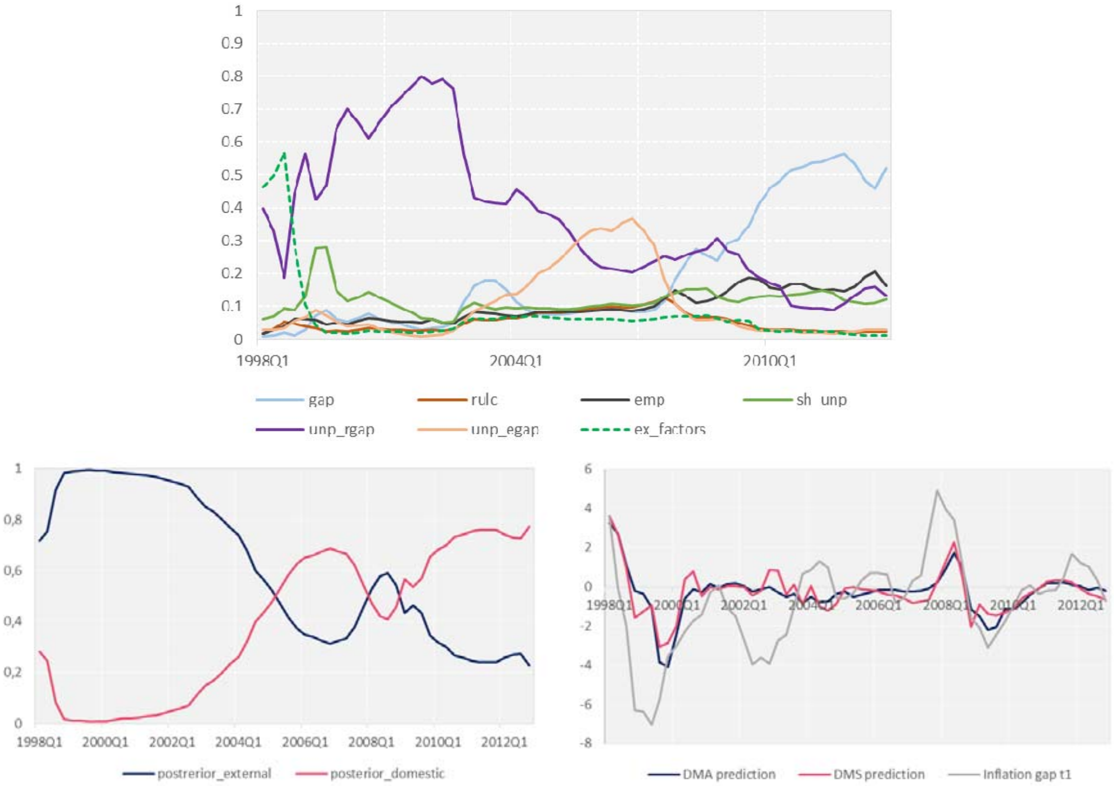
Czech Republic (inflation gap t+4)







Czech Republic (inflation gap t+1)



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