

Globalization and Inflation: Evidence from a Time Varying VAR

Francesco Bianchi*

Duke University

CEPR and NBER

Andrea Civelli[†]

University of Arkansas

Abstract

According to the Globalization Hypothesis, global economic slack should progressively replace the domestic output gap in driving inflation as globalization increases. We investigate the empirical evidence in favor of this prediction by using a Time-varying VAR. Two main results emerge from the analysis: First, global slack is found to affect the dynamics of inflation in many countries, yet its influence did not become stronger over time. Second, a panel analysis that exploits the cross-section characteristics of our dataset shows that globalization, measured in terms of trade and financial openness, is positively related to the effects of global slack on inflation. We conclude that integration in the global economy is in fact important, but globalization has not yet induced changes in openness large enough to justify significant brakes in inflation dynamics.

JEL Classification: E31, F02, F41

Keywords: Globalization, Inflation, Time-variation, VAR

1 Introduction

The Globalization Hypothesis (GH) argues that the internationalization of goods and financial markets has been altering the determinants of national macroeconomic outcomes, such as inflation rates and business cycles, by replacing the traditional domestic determinants with global factors. This hypothesis originated from the concerns of some monetary policy makers, the Federal Reserve in particular, of an increasing disconnection between monetary policy on one side and domestic inflation and long term interest rates on the other. In a 2007 speech to the Stanford Institute for Economic Policy Research, Chairman Ben Bernanke analyzed these concerns and illustrated the efforts of the Federal Reserve to understand and monitor the effects of globalization on the U.S. economy (Bernanke, 2007):

*Duke University, 213 Social Sciences Building, Box 90097, Durham, NC 27708. Email: francesco.bianchi@duke.edu. URL: <http://public.econ.duke.edu/~fb36/>.

[†]Corresponding author: University of Arkansas, Business Building 402, Fayetteville, AR 72701. Email: andrea.civelli@gmail.com. URL: <http://comp.uark.edu/~acivelli/>.

"At the broadest level, globalization influences the conduct of monetary policy through its powerful effects on the economic and financial environment in which monetary policy must operate. As you know, several decades of global economic integration have left a large imprint on the structure of the U.S. economy, including changes in patterns of production, employment, trade, and financial flows. ... [M]onetary policy can do little to affect these structural changes or the powerful economic forces that drive them. However, to make effective policy, the Federal Reserve must have as full an understanding as possible of the factors determining economic growth, employment, and inflation in the U.S. economy, whether those influences originate at home or abroad. Consequently, one direct effect of globalization on Federal Reserve operations has been to increase the time and attention that policymakers and staff must devote to following and understanding developments in other economies, in the world trading system, and in world capital markets".

Richard Fisher, president of the Federal Reserve Bank of Dallas, expressed the same view in a speech at the 2006 ASSA meetings, in which he also invited economists to improve on the traditional inflation models in order to account for the effects of globalization (Fisher, 2006):

"The econometric calculations behind the Phillips curve and the panoply of other domestic "capacity constraints" and "output gaps" were based on assumptions of a world that in my opinion exists no more... [H]ow can we calculate an "output gap" without knowing the present capacity of, say, the Chinese and Indian economies? How can we fashion a Phillips curve without imputing the behavioral patterns of foreign labor pools? How can we formulate regression analyses to capture what competition from all these new sources does to incentivize American management? The old models simply no longer apply in our globalized, interconnected and expanded economy... One cannot make monetary policy at the Federal Reserve without being cognizant of the forces of globalization acting upon our economy.

In spite of the large consensus in policy circles on the attention that a growing globalization deserves, the complexity of this phenomenon has prevented researchers from clearly identifying the effects of globalization on inflation. The GH has been successfully invoked to interpret some well documented empirical facts in the global dynamics of inflation, in particular the common reduction in volatility and levels of national inflations as reported by Figure 1.¹ Ciccarelli and Mojon (2010) and Mumtaz and Surico (2012) show that a common global factor has driven this reduction, and they relate this factor to the degree of openness of the world economy. On the contrary, the GH finds only limited support when applied to two other aspects of inflation dynamics. The first aspect is

¹Figure 1 plots the time series of national inflation rates for the countries included in the sample for the construction of the trade-based weights. The three thicker lines represent the average and top/bottom fifth percentiles of the distribution of the inflations.

the Phillips Curve relation, which in a closed economy has traditionally been used to link short run movements of inflation to the domestic output gap. The main implication of the GH in this respect is that global economic slack should have progressively replaced the domestic output gap in driving national inflation rates. The second is the so-called China effect, which is the view that lower import prices from emerging economies may have reduced prices in the industrialized countries.²

In this paper, we focus on the implications of the GH for the relation between inflation and domestic and foreign output gaps in light of the literature that studies the Phillips Curve under globalization which started with the evidence provided by Borio and Filardo (2007) in favor of the GH. The analysis tackles two main questions. First of all, it is important to understand whether globalization matters for the dynamics of domestic inflation at all. This point is important not only from the policy perspective but also from the theoretical one, since the New Keynesian open economy literature explicitly recognizes a role to the foreign output gap in the determination of the domestic inflation. The second interesting point is to verify whether the impact of the foreign output gap on domestic inflation rates has changed over time in a way consistent with the GH.

We answer our questions providing three key contributions. The first is the construction of a dataset comparable to the one used by Kamin, Marazzi, and Schindler (2006), which allows us to have a homogenous definition of the foreign gap and the real exchange rate across countries for a very large set of nations. Those measures are constructed using a set of trade-based weights computed by adopting the methodology presented by Loretan (2005), and, in particular, our weights take into account the changes in the trade relations among about 50 countries over the sample 1970 to 2006.

As a second contribution, our results are based on the estimates of time varying coefficients VARs with stochastic volatilities as in Cogley and Sargent (2006) and Primiceri (2005). The time varying VAR (TV-VAR) allows us to characterize the evolution of the statistical properties of the variables of interest. In particular, a more comprehensive knowledge of the trends and magnitude of the correlations between inflation and the two types of output gaps for a larger set of countries is necessary and extremely valuable to better inform the debate on globalization and inflation. Furthermore, we can explore the hypothesis of changes in the relation between inflation and domestic and foreign output gaps imposing a set of orthogonalizing restrictions on the reduced form innovations. Looking at the contribution of domestic and foreign shocks to the dynamics of inflation adds a further and interesting dimension to the analysis.

As a third and final contribution, we exploit the cross-section dimension of the dataset and of our estimates in a panel analysis to formally quantify the effects of globalization, defined in terms of trade and financial openness of a country, on the relation between domestic inflation and foreign output

²Numerous empirical papers have studied the relevance of the China effect. Among them, Chen, Imbs, and Scott (2009) use disaggregated data for the EU to show that openness lowers prices by both reducing markups and raising productivity. Gamber and Hung (2001) report that some U.S. sectorial prices are sensitive to prices of imports in the same sector. On the other hand, Kamin, Marazzi, and Schindler (2006) find a small impact of Chinese exports on global import prices and CPI inflation. More recently, Auer and Fisher (2010) and Auer, Degen, and Fisher (2012) propose an improved estimation methodology and find that import competition from low-wage countries has strong downward effects on sectorial prices and equilibrium inflation in the U.S. and Europe. The literature on the relationship between Phillips Curve and globalization is reviewed below.

gap. A particularly sensitive point of our analysis is the relatively moderate increase in trade openness observed for many countries. This problem makes a single-country analysis an unsatisfactory tool to assess the effects of openness on inflation. The large pool of countries that we study allows us to cope with this issue through the comparison of economies with very different degrees of openness and integration instead of relying only on the change in openness for an individual country.

We use the estimates from the TV-VAR to analyze the evolution of four statistical measures capturing the relation between inflation and the domestic and foreign output gaps: The unconditional correlation between inflation and the output gaps; the impulse responses of inflation to output gap shocks; the long term responses of inflation to permanent output gap shocks; and the share of inflation variance explained by the gap shocks. All of these measures lead us to the same conclusions. The effects of foreign slack on domestic inflation are consistently positive and significant across countries and periods; these effects are comparable to those of the domestic output gap, but they do not grow over time as expected according to the GH. In sum, the foreign output gap matters for the dynamics of inflation, yet it does not seem to replace the domestic gap. Even though we observe substantial fluctuations in the relation between inflation and the two output gaps, the lack of any common time pattern in the results casts some doubts on the general validity of the GH at this level of the analysis.

The absence of significant changes in the relative importance of domestic and foreign gaps in determining inflation dynamics could reflect two different phenomena. First, it could be that integration in the global economy does not substantially affect inflation dynamics. Alternatively, it could be that integration is in fact important but that historically we have not observed changes in openness large enough to induce structural breaks in inflation dynamics. In order to disentangle the relative importance of these two explanations, we resort to the panel analysis. This allows us to identify two factors that affect the effects of the foreign output gap on inflation: the degree of trade openness and the degree of financial openness of a country. Both of these two factors are linked to globalization, but they have quite independent rather than overlaid effects. We find that the effects of the global economic slack on inflation are positively related to the degree of openness and they can be stronger for higher degrees of financial integration. We conclude that integration in the global economy is in fact important, but that historically we have not observed changes in openness large enough to induce structural breaks in inflation dynamics.

Compared to the previous literature, our approach presents two advantages. The most important advantage is clearly determined by our econometric methodology. The crucial point in the analysis of this problem is to investigate the change of the relations between inflation and other relevant variables in the economy. In this respect, the time varying coefficients VAR is a very suitable and flexible tool, and it is a clear improvement over sub-sample analysis and rolling estimations. Furthermore, the model accounts for both the variation in the structure of the model and the differences due to changes in the volatility of the shocks. The second advantage is related to the treatment of the inflation expectations. An explicit empirical assumption about inflation expectations is required in a single equation model of the Phillips Curve to deal with expectations endogeneity. This issue is implicitly

resolved in the VAR analysis that does not aim to estimate microfounded equations, but rather to recover changes in the statistical properties of the variables of interest and only impose a minimal set of identifying assumptions when computing impulse responses and variance decomposition.

The debate about the effects of globalization on the Phillips Curve is well represented by the two opposing views expressed by Borio and Filardo (2007) and Ihrig, Kamin, Lindner, and Marquez (2010). Borio and Filardo (2007) study an open economy version of the domestic Phillips Curve for a large set of countries. They include in the Phillips Curve a measure of the specific foreign gap for each country in their sample and provide evidence in favor of the GH. They also show that their results hold for different measures of the foreign output gap. On the other hand, Ihrig, Kamin, Lindner, and Marquez (2010) study eleven industrial countries and find little support for the GH. Moreover, they show that Borio and Filardo's positive conclusions crucially depend on the specific reduced form of the regression they adopt in testing the hypothesis and on how they treat inflation expectations.

Tootell (1998) provides some earlier evidence against the GH for the Phillips Curve. Calza (2009) finds weak evidence that global capacity constraints matter for domestic inflation in the euro area. Wynne and Kersting (2007) document evidence that foreign resource utilization may play a role in U.S. inflation. Also Gamber and Hung (2001) find a support of the GH for the U.S. Ihrig, Kamin, Lindner, and Marquez (2010) provide an exhaustive review of the empirical literature on the GH. Galati and William (2006) present a broader overview of the changes in inflation and of the factors that influence the inflation process, which include globalization. Milani (2010) estimates a structural model for the G7 economies and concludes that global output affects domestic inflation only indirectly through the aggregate demand of a country and that it should not be included in the specification of the Phillips Curve.

Even from the theoretical perspective, there is no full agreement on the impact of greater globalization and of the foreign business cycle on domestic inflation. Rogoff (2003) suggests that higher international competition should make the Phillips Curve steeper, but the empirical evidence definitely points in the opposite direction. Ball (2006) notices that, even though firms compete in more integrated markets, the output gap enters the Phillips Curve because it approximates firms' marginal costs. While competition reduces the average markup making the Phillips Curve potentially flatter, the foreign output gap would replace the domestic gap only if marginal costs had started to depend more on the foreign gap instead of the domestic one, but he does not see any particular reason to believe this. Sbordone (2007) explores the same point in a formal model with Calvo pricing in which the elasticity of demand depends on the variety of traded goods. She concludes that the increase in trade in the U.S. was not large enough to generate a sufficiently large increase in market competition in order to reduce the slope of the inflation-marginal cost relation.

The rest of the paper is organized as follows: Section 2 introduces the implications of the GH and relates it to the theoretical New Keynesian framework currently used in open economy general equilibrium models. Section 3 presents the motivations and goals of our approach and briefly outlines the estimation methodology. Section 4 describes the dataset we use. Sections 5 and 6 present

and interpret the results obtained from the reduced form estimates of the VAR model and from the orthogonalization of the VAR innovations for the eighteen countries in our sample. Section 7 undertakes the panel analysis of the output obtained in the previous two sections; and the final Section concludes.

2 The Globalization Hypothesis

In this section, we discuss both the theoretical and the empirical implications of the Globalization Hypothesis for inflation in the context of the Phillips Curve model.

2.1 Theoretical Considerations

The New Keynesian Phillips Curve is a well known result of modern general equilibrium models. It is a forward looking equation that relates CPI inflation to the marginal costs of optimizing firms that set prices according to a Calvo price setting scheme. The labor supply optimal condition of the consumer and the production function then allow us to express the marginal cost in function of the output gap and to derive the standard representation of the Phillips Curve.

The same modeling device has been applied to open economy models too. If firms can export their goods to a foreign country and are allowed to price discriminate between home and foreign markets, the cross border pricing decision introduces a dependence of the inflation of a country on the marginal cost of the exporting firms in the other country and, as a consequence, on the foreign country output gap. Clarida, Gali, and Gertler (2002) and Corsetti and Pesenti (2005) introduced this model for the analysis of international monetary policy; Gali and Monacelli (2008) and Monacelli (2005) refined it for the small open economy case; soon thereafter, it became the workhorse model in the open economy DSGE literature.

This can be regarded as the natural extension of the closed economy framework to the open economy, and it also provides a theoretical background in support of the policy speculation at the base of the Globalization Hypothesis and of the implications we are empirically discussing in this paper. The specific form taken by the open economy New Keynesian Phillips Curve varies according to the details of each model. However, with local currency pricing, home bias in consumption and perfect risk sharing, it would usually read

$$\pi_t = \mu E_t \pi_{t+1} + \nu \left[(1 - h) y_t^d + h y_t^f \right] + \Gamma_t \quad (1)$$

We simply point out a few characteristics of equation (1), since a rigorous micro foundation of this equation can be found in the papers cited above and in Steinsson (2005) and Zaniboni (2008), for heterogenous labor markets and for the difference between local currency and producer currency pricing respectively. CPI inflation π_t presents a forward looking term multiplied by μ , the intertemporal discount factor in the utility function of the consumer. Inflation also depends on the weighted

average of the domestic and foreign output gaps. The weight $(1 - h)$ is the consumption home bias coefficient, while ν summarizes the responsiveness of inflation to the marginal cost and of the marginal cost to the output gap.³ The last term Γ_t accounts for the impact on inflation of some measure of international competitiveness. This measure is model specific, but it can usually include the term of trade, the deviation from the law of one price of import prices, the deviations from purchasing power parity of the real exchange rate. Equation (2) adopted in the next section is an example of empirical specification derived from (1).

It is evident from (1) that the foreign output gap should enter the Phillips Curve equation in a direct way and its coefficient should be smaller relative to that of the domestic output gap if there is home bias in consumption. The empirical studies based on univariate regressions of the Phillips Curve have focused only on this aspect. However, the foreign output gap can also matter in an indirect way if there exist relevant structural relations in the model not captured by the reduced form considerations. In particular, the foreign output gap may affect the level of natural domestic output and can influence the behavior of the Γ term. Furthermore, the degree of openness interacts with the foreign output gap in the determination of the domestic natural output and higher openness should reduce the elasticity of the marginal cost to the two output gaps.

2.2 Empirical Considerations

Although the Phillips Curve has a sound theoretical micro foundation in the new Keynesian model, it has not always been characterized by strong empirical regularity. The declining slope of the short term relation between inflation and domestic output gap which is typically found using the most recent data, along with the narrowing comovements of inflations across countries and the increasing integration of the global economy over the last decades have suggested a new role for international forces in driving national inflation outcomes.

In particular, the Globalization Hypothesis implies three main predictions with regard to the open economy version of the Phillips Curve presented in equation (2), where the foreign output gap y_t^f and the import price inflation π_t^m have been added to the domestic gap y_t^d and the expected inflation $E_t\pi_{t+1}$ in the regression equation of the domestic CPI inflation π_t .⁴

$$\pi_t = E_t\pi_{t+1} + \beta y_t^d + \delta y_t^f + \gamma \pi_t^m \quad (2)$$

1. The first prediction is that the role played by y_t^d should become less important as globalization increases, which implies declining estimates of β both in closed and open versions of the Phillips

³ ν is a combination of the deep structural coefficients of the model. These coefficients are: the probability firms have of adjusting the price at each period in the Calvo price setting, the elasticity of substitution between home and foreign goods, the intertemporal elasticity of substitution and the labor supply elasticity in the utility function of the consumer, the home bias parameter h , and the discount factor μ .

⁴The specification of the term π_t^m varies among authors. In some cases, it is the inflation of import prices or the unit labor cost, as in Borio and Filardo, while in other cases it is taken in deviation from the home country inflation as in Ihrig et al.

Curve.

2. The second is that y_t^f should progressively replace y_t^d as globalization increases, which means δ must be significantly positive and possibly increasing over time.
3. Finally, the third prediction is that also γ should increase, since the responsiveness of π_t to import prices should be greater when globalization is more intense.

These predictions of the GH sound very intuitive and appealing; however, there is no clear empirical evidence supporting this theory.⁵ Since empirical results are usually based on univariate estimates of equation (2), conflicting conclusions can be crucially determined by the specific empirical regression equation used to test the hypothesis. Furthermore, Ihrig, Kamin, Lindner, and Marquez (2010) (IEA henceforth) show also that the results can depend on the adopted definition of the foreign output gap, which introduces a delicate issue about the construction of homogenous measures of foreign output gap across countries.

One of the key aspects of equation (2) is the expectation term $E_t\pi_{t+1}$. Studies that find positive and increasing δ along with decreasing β , as Borio and Filardo (BF henceforth) for instance, use the HP-filtered inflation series as a proxy for the underlying trend CPI inflation. This choice for the expectations leaves enough variability in the dependent variable to detect the relative contribution of domestic and foreign gaps to the persistence of inflation, but it causes the residuals of the regression to be autocorrelated. Even though autocorrelated residuals do not bias the estimates of the coefficients of a regression, this is commonly taken as an indication of misspecification of the equation. A more correct econometric specification is recovered dropping the filtered series and including some lagged values of π in the regression instead, as shown by IEA. Under this specification, the statistical significance of δ vanishes almost completely, although the significance of β is critically reduced for many countries too.

The effects of import prices on domestic inflation are usually weak. The estimated γ is only marginally significant and extremely small compared to δ and β ; it does not increase over time and it is not particularly related to changes in trade openness. BF report similar conclusions for other international prices that might be relevant in explaining domestic inflation, such as the price of oil and a measure of the global unit labor cost.

One of the advantages of a multivariate approach is that even if the reduced form estimates do not reveal a particularly significant role of the foreign output gap it is still possible to explore less direct relations between the variables of the model related to the structural dimension of the VAR. A simple theoretical exercise illustrates that these effects can be plausibly large: Zaniboni (2008) considers a few different open economy models and he theoretically shows that under standard calibrations of the parameters the coefficient of the foreign output gap in the Phillips Curve is small relative to

⁵This is not necessarily in contradiction with the presence of global dynamics since global factors can be attributed to a stronger international coordination of monetary policy practices or to tighter international linkages, which do not necessarily have to go through the impact of foreign slackness on domestic inflation.

that of the domestic gap. He also shows that the foreign gap coefficient only slightly increases in function of the degree of openness for realistic ranges of openness. In spite of the smaller role of the foreign output gap in the Phillips Curve, it is still possible to find interesting responses of inflation to a foreign output gap shock. Figure 2 reports the impulse response functions of inflation to the two output gap shocks for the local currency pricing model in Zaniboni using his main calibration and a home bias parameter of 0.8, which implies a Phillips Curve coefficient of 0.42 and 0.1 for the domestic and foreign output gap respectively.⁶ The impact responses of inflation to a 1% shock to the domestic and foreign output gap are about 0.7% and 0.15% respectively. The response to the foreign gap is always smaller than that to the domestic shock, but it is definitely not negligible and it is also growing in the degree of openness. These simple theoretical results suggest an interesting, albeit less significant, role for global slack too.

Finally, the definition and measurement of globalization is an important issue too. Globalization is commonly defined as the degree of international integration of national markets. This is a quite complex phenomenon that can be measured over several dimensions such as real markets coordination, financial markets integration, and trade or labor markets openness. In this paper, we will measure it in terms of trade and financial openness. A trade openness index is constructed as the ratio to *GDP* of the sum of imports and exports, while the financial openness index is constructed as the ratio to *GDP* of the sum of total international assets and liabilities. This choice is justified by three considerations. First, since the scope of the paper is to study the relation between inflation and output gaps, real market linkages are naturally considered the most relevant factor. Previous empirical literature has already looked at trade openness as an indicator of globalization without finding strong links to the Globalization Hypothesis for inflation. Second, also in the theoretical models of the open-economy Phillips Curve trade openness boosts the importance of the foreign output gap on domestic inflation. Third, financial openness has grown even faster than trade openness in the last two decades and it represents a quite different channel of globalization.

3 Our Approach

We propose to study the GH by using time varying coefficients VAR (TV-VAR) models with stochastic volatilities. We use the reduced form estimates of the VAR and the responses of inflation to temporary and permanent output gap shocks to mainly assess implication 1 and 2 of the GH.

For each country in our sample, we estimate the time varying coefficients VAR in (3), in which five variables and two lags have been included in the model.

$$X_t = a_t + \sum_{p=1}^2 B_{t,p} X_{t-p} + \varepsilon_t \quad (3)$$

⁶We add an autoregressive shock to the two output gaps, assuming the standard deviation of these innovations to be half of the standard deviation of the technological shocks and an autoregressive coefficient of 0.8. More details about the model used to generate these impulse response functions are provided in the Appendix.

The vector of variables $X'_t = \left[y_t^f \quad y_t^d \quad \pi_t \quad \tau_t \quad i_t \right]$ includes the domestic and foreign real output gaps y_t^d and y_t^f , the 4-quarter domestic CPI inflation π_t , the real exchange rate τ_t , and a policy (short term) interest rate i_t . The coefficients matrixes $B_{t,p}$, the intercept term a_t , and the variance covariance matrix of the innovations ε_t are allowed to vary over time and are freely estimated by the regression model.⁷ The frequency of the data is quarterly and the period sample goes from 1971:1 to 2006:4. Given the sample length, quarterly data provide an adequate amount of observations to estimate these time varying regressions.

The real exchange rate is introduced as a proxy of the import prices used in equation (2). The choice of the real exchange rate finds a justification also from a theoretical point of view. In fact, the term of trade, a term measuring the deviations of import prices from the law of one price, or the real exchange rate are typically present in the Phillips Curve equation of a new Keynesian model. Our measure of real exchange rate is a perfect empirical counterpart of this variable.

Instead of looking only at the time variation of the coefficients of the model, which has been studied by the other papers using more basic sub-period or rolling regressions, we can use the reduced form estimates of the VAR to report the time evolution of the descriptive statistics of the variables of the model. In particular, the standard deviations and the unconditional correlations of inflation and domestic and foreign output gaps are extremely informative in the context of the debate on the globalization effects on inflation. We then analyze the responses of the domestic inflation to temporary and permanent shocks to the domestic and foreign gap at different points in time, relying on a simple orthogonalization of the VAR innovations discussed below. The evidence from the reduced form estimates along with the results from a more structural analysis of the responses provide a corroborative assessment of the changes over time of the relations between domestic inflation and the other variables of the model.

This approach offers three advantages over the simple univariate model in (2). First of all, the TV-VAR is a technique specifically designed to capture time variations in the relations among the variables of the model. Given the extreme importance of the time dimension in the GH's implications we are testing, it seems opportune to pursue a more reliable assessment of this aspect. The second advantage of using a VAR model is that it allows for a more formal decomposition of the partial effects of the two output gaps on inflation after imposing a minimal set of identifying restrictions. Adding this type of analysis to the reduced form evidence can uncover important dynamics otherwise impossible to reveal by the simple univariate regressions. Furthermore, our approach does not aim to recover microfounded equations, implying that we do not have to address the problem of how to deal with endogeneity of inflation expectations. Finally, the model also estimates the variance covariance matrix of the shocks at each point in time. This allows to disentangle possible effects due to changes in the volatility of the shocks from those caused by changes in the structure of the model.

Our empirical analysis is enhanced by a new dataset in which accurate and homogeneous mea-

⁷Following Primiceri (2005), both the standard deviations and the contemporaneous covariances of the structural innovations are time varying. The technical details of the estimation are presented in the next section and in the Appendix.

asures of the foreign gap and the real exchange rate for each country are constructed. Following the methodology described by Loretan for the construction of the American real exchange rate, we compute a set of trade-based weights for about fifty countries that we use to aggregate pair-wise exchange rates and national output gaps in order to form the real exchange rate and foreign output gap of each country. Our dataset improves on that of IEA by broadening the definition of the world (i.e. increasing the number of countries) used to construct the weights and by extending the time series to the beginning of the 70's.⁸

The time sample is a sensitive aspect of the results we obtain. Our data cover almost four decades in the post Bretton Woods era; a period characterized by a regime of more flexible exchange rates and the increase in the globalization of the world economy at the heart of the GH intuition. In principle, every country used to construct the trade-based weights could also be used to estimate a TV-VAR, the difficulty of finding consistent series for the short term policy rates going back to the early 70's has been the biggest limitation to our analysis.

3.1 Estimation of the TV-VAR

Let X_t be a $(n \times 1)$ vector containing observations at time t of the macroeconomic variables of interest. In our case $n = 5$ and $X_t = \left[y_t^f \quad y_t^d \quad \pi_t \quad \tau_t \quad i_t \right]'$, for example.

In a general case, variables evolve over time following a time varying VAR

$$X_t = a_t + \sum_{p=1}^P B_{t,p} X_{t-p} + \varepsilon_t, \quad \varepsilon_t \sim N(0, \Omega_t) \quad (4)$$

where a_t is a n -dimensional column vector of intercepts and $B_{t,p}$ is a $(n \times n)$ matrix containing the p -lag time-varying autoregressive coefficients. Note that the variance covariance matrix of the residuals is also time varying.

Following Cogley and Sargent and Primiceri among others, we postulate a random walk for the evolution of the VAR coefficients: $\Phi_t = \Phi_{t-1} + \eta_t$, where $\Phi_t = [vec(a_t)', vec(B_{t,1})', \dots, vec(B_{t,p})']'$.

The covariance matrix of the VAR innovations Ω_t is factored as $VAR(\varepsilon_t) \equiv \Omega_t = A_t^{-1} H_t (A_t^{-1})'$. The time-varying matrices H_t and A_t are defined as:

$$H_t \equiv \begin{bmatrix} h_{1,t} & 0 & \dots & 0 \\ 0 & h_{2,t} & \dots & 0 \\ \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & h_{n,t} \end{bmatrix} \quad (5)$$

⁸More details about the construction of the data and the sources used are left for section 4 and the Appendix.

$$A_t \equiv \begin{bmatrix} 1 & 0 & 0 & \dots & 0 & 0 \\ \alpha_{2,1,t} & 1 & 0 & \dots & 0 & 0 \\ \alpha_{3,1,t} & \alpha_{3,2,t} & 1 & \dots & 0 & 0 \\ \dots & \dots & \dots & \dots & \dots & \dots \\ \alpha_{n-1,1,t} & \alpha_{n-1,2,t} & \alpha_{n-1,3,t} & \dots & 1 & 0 \\ \alpha_{n,1,t} & \alpha_{n,2,t} & \alpha_{n,3,t} & \dots & \alpha_{n,n-1,t} & 1 \end{bmatrix} \quad (6)$$

with the $h_{i,t}$ evolving as geometric random walks $\ln h_{i,t} = \ln h_{i,t-1} + u_t$.

Following Primiceri, we postulate that the non-zero and non-one elements of the matrix A_t evolve as driftless random walks, $\alpha_t = \alpha_{t-1} + e_t$, and we assume that the vector $[\eta'_t, u'_t, e'_t]'$ is distributed as $[\eta'_t, u'_t, e'_t]' \sim N(0, V)$, where

$$V = \begin{bmatrix} Q & 0 & 0 \\ 0 & G & 0 \\ 0 & 0 & S \end{bmatrix} \quad \text{and} \quad G = \begin{bmatrix} \sigma_1^2 & & \\ & \ddots & \\ & & \sigma_n^2 \end{bmatrix} \quad (7)$$

The VAR is then estimated using the Bayesian methods described by Kim and Nelson (1999). In particular, we employ a Gibbs sampling algorithm that approximates the posterior distribution of the model (see Appendix C for details). The priors and the starting values for the VAR coefficients are based on a fixed coefficient VAR estimated over the first 24 quarters of the sample.

4 Characteristics of the Dataset

The first part of the dataset comprises the time evolution of the trade shares and trade-based weights that are used to construct the foreign output gap and effective real exchange rates for each country in the sample. The weights are obtained starting from the time series of the pair-wise import and export flows among a set of about 50 countries which include all the OECD countries, the major Asian economies, and some other emerging countries.⁹ The flows data come from the IMF-DOT database; we cover the sample 1971:1 through 2006:4 at quarterly frequency.

We calculate the weights following the approach of the FED to the construction of the effective exchange rate presented by Loretan. The weights are meant to provide a measure of the relative importance of an international partner for a country. This is achieved accounting both for the direct relations between two countries, given by the relative share of imports and exports from one country to the other, and for the so-called third-party relations, which are used to keep into account the indirect effects due to international competition among countries.

In the second part of the dataset, we construct the five variables used in the estimation of the TV-VAR models. First of all, we collect the domestic output gap for the entire set of countries in

⁹A complete list of the countries can be found in the Appendix. The Appendix defines also the trade-based weights, the formulas applied for the real exchange rate, and describes the data sources more in detail.

the trade-based weights dataset. If the gap is not directly provided by the OECD National Account Statistics, it is constructed as the percentage deviation from the HP-filtered real *GDP* series taken as a proxy for the potential *GDP*. The sources for the real *GDP* are the OECD and the IMF for almost all the countries; the *GDP* series are first seasonally adjusted. For each of the eighteen countries in the time varying analysis, the domestic output gaps of the full set of countries are then weighted to form the trade-based measure of the foreign gap.

The same procedure applies to the construction of the country-specific real exchange rates. The pair-wise nominal exchange rates, obtained either from the KEYIND database of Global Insight or from the Global Financial Data database, are seasonally adjusted, deflated by the CPI index of the respective country, and aggregated using the same trade-based weights.

We compute the inflation rate as the log-difference of the domestic CPI index relative to the same quarter of the previous year; the 4-quarter inflation has been used by BF while IEA prefer to use the quarter-to-quarter inflation in order to reduce the autocorrelation of the residuals of their regressions. The CPI indices usually come from the IMF database or that of the OECD-MEI; the base year is set to 2000 and the series have been seasonally adjusted.

Finally, we take short term deposit and money markets interest rates as policy rates. The main source for these is the Global Financial Data database.

5 Reduced Form Results

This section and the next present the empirical evidence obtained from the VAR estimates. We study eighteen Western countries and emerging economies with a large variety of sizes and degrees of openness being represented. The countries are U.S., U.K., Germany, France, Italy, Spain, Ireland, Denmark, Netherlands, Austria, Switzerland, Canada, Mexico, Australia, Japan, South Korea, South Africa, and New Zealand.

We first look at the descriptive statistics implied by the reduced form estimates of the VAR model. In particular, we focus on the evolution of the volatilities of the endogenous variables and of the correlations between the two output gaps and inflation, which correspond to the key relations between variables that the theoretical Phillips Curve formalizes. We can reinterpret the predictions of the GH in terms of these correlations. If Prediction 1 is correct, we should observe a weakening of the link between inflation and domestic gap; at the same time, if Prediction 2 is correct, a stronger correlation between inflation and foreign output gap should be expected. It is worth noting again that, although the GH arises from the common belief that global forces must have become more influential on national economies, a more reliable and comprehensive reduced form evidence on these global trends is still missing; in this respect, our estimates provide a valuable description of the implications of globalization.

Figure 3 illustrates the changes in the volatilities of inflation and of the two output gaps for some of the countries in the sample. For the sake of clarity in the exposition, we do not report the

plots for U.K., Canada, Switzerland, France, Germany, Italy, Netherlands, and Austria in this figure because they are very similar to the U.S.; a plot for these countries is reported in Figure E1 in the *Supplementary Material* instead. The majority of the countries share the same pattern with a fall in volatility starting in the second half of the eighties and continuing through the end of the sample; there are, however, some interesting exceptions. The volatility of the domestic gap of Spain remains high also in the nineties, this is not observed in the other European countries; Ireland shows a spike of volatility since 1995, which roughly corresponds to the beginning of the Celtic Tiger era and to the period of its large liberalizations of labor and credit markets; it is possible to recognize the period of the Asian financial distress in the 1997 spike of volatility for the Korean economy; the Mexican hyperinflation of the eighties and the Mexican peso crisis of mid nineties are very clear, as well as the reduction in volatility in New Zealand after the adoption of inflation targeting in 1990.

The declining volatility of the inflation process over the last two decades has raised some concern about the possibility of effectively estimating the coefficients of domestic and foreign output gaps in the empirical Phillips Curve (2), especially when lagged values of inflation are used in the specification of the equation. For instance, in the estimates by IEA, not only δ is small and not significant, but also β is often overturned. The use of stochastic volatilities and time varying coefficients in the VAR allows for the necessary statistical flexibility to directly assess this kind of issue.

Figures 4 and 5 describe the time variation of the unconditional correlations between inflation and, respectively, domestic and foreign output gaps. The correlation between π and y^d is only marginally significant for the majority of the countries in Figure 4; it is usually small and positive, but a few negative cases, as for Austria or Mexico, are observed too. The first prediction of the GH, a declining correlation, is satisfied only by three countries: Spain, Switzerland, and Japan. Overall, in spite of a quite large variation over time and across countries, a clear common trend of these correlations is definitely missing. Small correlations are consistent with the small, and declining, estimates of β in the Phillips Curve found in the literature. A very similar outlook is given by Figure 5 for the correlation between π and y^f . Only U.S. and Switzerland show a positive correlation; for few other countries, such as Germany, U.K., Denmark, Spain, and South Africa, this correlation is only marginally positive. However, the correlations are generally not increasing and none of these cases would actually support the second implication of the GH.¹⁰

In sum, these results are not supportive of the GH. The foreign output gap does not seem to play a significant role and the second hypothesis is completely unfulfilled. Even for those countries in which the correlation between inflation and foreign gap is positive for most of the sample, the importance of the foreign output gap does not seem to increase over time. On the other hand, when positive, the median estimates of the correlation between inflation and domestic gap are only around .2, which is a quite small value. The lack of a meaningful evolution of the relation between

¹⁰ Although Prediction 3 of the GH is not explicitly a main point of our investigation, we also report the unconditional correlation of inflation and real exchange rate in Figure E2 of the *Supplementary Material* section. The correlations are negative for most of the countries, as expected based on the GH, with exception of a few countries among which U.K., Canada, and in part Spain and U.S. are the most evident cases. However, the correlations are almost never very significant and, also in this case, do not grow in magnitude.

inflation, output gaps, and globalization emerges quite clearly from these figures. Any common time profile of the correlations is missing and the time variation in each country seems to be due more to specific characteristic of an economy rather than being related to the degree of globalization per se. Nevertheless, it is still possible to find a positive effect of trade integration on the correlation between inflation and foreign gap once the cross-sectional dimension is added to the time series analysis. We undertake this panel study in Section 7.

Finally, we take a look at the unconditional correlation between the two output gaps in Figure 6. We interpret this correlation as an indicator of business cycle synchronization of domestic output with respect to global output. Synchronization can depend on economic and financial integration, but also on the relative occurrence of idiosyncratic and common shocks or on the sectorial structure of production, and the net effects of these determinants, primarily related to globalization, are very difficult to predict. For instance, financial integration has been found to reduce business cycle synchronization, while trade integration is usually believed to enhance it.¹¹ Nevertheless, these correlations can help in understanding the evolution of the degree of globalization of a country in its complexity and it is definitely interesting to provide them as part of our reduced form general description of the data. Unlike for the correlation between inflation and gaps, it is easier to recognize more common patterns in the plots of Figure 6. First of all, the correlations are basically always positive. Then, many of the countries in the sample, including U.S., Canada, and most of the European countries, share a declining trend with synchronization falling by about a third since the eighties. With the exception of Ireland and Mexico, the correlation is quite stable for the other nations.

Our results, consistently with the view expressed especially by IEA, would reject the GH so far. The TV-VAR approach, however, allows us to carry out a further step in the analysis of the relation between inflation and the two output gaps by taking into account some new information missing from the simple univariate studies. We turn to this new information in the next sections.

6 Structural Analysis

Even though the reduced form evidence does not support the GH implications, changes in inflation dynamics might be disclosed for the conditional effects of the foreign output gap once the partial effects of the other variables of the model are controlled for. At this level of analysis, the contribution of the foreign output gap to the dynamics of inflation livens up again. We obtain some new evidence that definitely undoes the clear-cut conclusions from the reduced form analysis and that can be interpreted as in favor of the GH, especially of Prediction 2.

¹¹There is a large and interesting literature on the determinants of business cycle synchronization. See, among many others, Kose, Prasad, and Terrones (2003), for a general study of the impact of financial and trade integration; or Kalemli-Ozcan, Papaioannou, and Peydro (2013), for evidence on the negative effects of financial integration on synchronization.

6.1 Identification Scheme

In this section we map the first two implications of the GH into predictions about the evolution of the response functions of inflation to domestic and foreign output gap shocks and into changes of the long run responses of inflation to permanent shifts in the two gaps. In order to do that, we must first identify the structural innovations from the reduced form innovations of the VAR model. We rely upon a Cholesky recursive decomposition of the reduced form residuals covariance matrix Ω_t .

The Cholesky decomposition is a convenient and popular way to derive orthogonalized residuals for a VAR, and it is particularly useful in the context of a time varying coefficients model where the stochastic volatilities have also to be identified. For instance, the Cholesky factorization has been extensively used in empirical work to identify monetary policy shocks. Taking the experience from the monetary policy literature and the information from the Phillips Curve as a guidance, we choose a benchmark ordering of the variables in the Cholesky decomposition in which inflation is allowed to respond on impact to the two output gaps. In what follows, we motivate our ordering in some detail.¹²

We start separating the interest rate, i , and the real exchange rate, τ , from the block of the three real variables. The policy rate is normally ordered as last in the monetary VAR literature, which is used as an identification assumption to isolate the monetary shock. It is assumed that the interest rate does not affect output and inflation in the same period while at the same time it is able to respond on impact to them. We follow Leeper, Sims, and Zha (1996), Christiano, Eichenbaum, and Evans (1999), and Primiceri (2005) among others in this choice. Being essentially a financial variable free to adjust continuously, it seems relative safe to order the exchange rate as fourth. The correct relative position of these two variables is hard to define a priori, it would depend on the monetary policy characteristics of a country. For a country with a central bank concerned with stabilization of the exchange rate, as for example smaller and export oriented economies, i should be ordered as the last variable; for bigger and closer countries, as, for example, the U.S., it could be more reasonable to order τ as last. We must notice that this does not really matter for the analysis of the relations between π and the two output gaps in the context of a recursive orthogonalization, and, for this reason, we keep i in the last position in our applications.¹³

We turn then to the relative order of the three real macro variables: the inflation rate, π , and the two output gaps, y^d and y^f . It is quite reasonable to assume that the foreign output gap is less responsive to the domestic output gap than the vice versa. This is definitely true for a small open economy, and this basically refers to most of the countries in our sample; it might be a less suitable assumption for large economies such as the U.S., but the impulse responses of inflation to foreign

¹²An alternative approach would consist of deriving sign restrictions based on a microfounded model or to directly estimate the model itself. We are planning to undertake this more theory-oriented approach in future research.

¹³Our identification strategy is similar to that used by Peersman and Smets (2003) to study the monetary policy transmission in the Euro Area. They treat the foreign output as an exogenous variable, while we keep it as endogenous in the VAR, and they prefer to order the exchange rate last. This is a good assumption for Europe, but not in general for smaller economies. In fact, Mojon and Peersman (2003) adopt a specification like ours when studying the transmission inside single countries of the European Union.

gap shocks are generally less sensitive to the chosen ordering for those large countries. In terms of identification assumptions, these observations lead us to consider an ordering in which y^f comes before y^d .

The crucial element of the identification is the relative position of π and y^d . Primiceri uses a TV-VAR framework to study a small macro model for the U.S. monetary policy. He includes only π , y , and i in his VAR and considers the relative ordering of π and y as a normalization once the monetary shock has been identified. He is interested in the responses of the variables to policy shocks, and his results are not affected by the specific choice about the ordering of π and y . However, given the focus of our analysis, the relative ordering of these two variables is a more sensitive choice to make. In this respect, the Phillips Curve equation provides some guidance. In the Phillips Curve, inflation responds to the current (and future) values of the two output gaps, implying that the ordering of the variables in the Cholesky decomposition should allow for a contemporaneous response of inflation to y^d and y^f . We therefore adopt as the baseline identification scheme the ordering $(y^f y^d \pi \tau i)$.¹⁴

6.2 Inflation responses and the GH

The Cholesky orthogonalization of the residuals allows us to explore three further dimensions of the relation between inflation and output gaps: the impulse response functions of inflation to temporary gap shocks, the long run responses of inflation to permanent shifts in the two gaps, and the variance decomposition of inflation. As done for the reduced form correlations, we can translate the predictions of the GH in terms of the output of this section. Based on Prediction 1, we should expect the responses to temporary and permanent domestic output gap shocks and the variance share explained by the domestic gap to fall over time. On the other hand, based on Prediction 2, we should observe an increase in the responses and the variance share obtained for the foreign output gap.

6.2.1 Impulse response functions

As an illustrative and relevant example, we start the analysis of the impulse response functions focusing on the United States. Figure 7 illustrates the responses of inflation to a unit shock to the domestic and foreign output gaps for the baseline identification. The responses are presented for the sample 1980:3 to 2006:4 and for a sixteen-quarter horizon. The solid, light-grey lines are the median response for each period; the shaded surfaces indicate significance of the posterior distribution of the responses at the 14th/86th percentiles (light blue) and at the 5th/95th percentiles (darker blue).

This figure shows that both output gaps matter for the dynamics of U.S. inflation. The response functions are nicely hump-shaped, and they can be significant up to eight quarters in many periods for the domestic shock and for four to six quarters for the foreign shock. The responses at the

¹⁴As a robustness check, we take into consideration the alternative identification ordering $(\pi y^f y^d \tau i)$, in which the impact responses of π to the two output gap shocks are constrained to zero. This second specification scheme represents the opposite extreme of the range of possible identification orderings of the three real variables of the VAR. The results, reported in the *Supplementary Material*, are largely confirmed for this ordering too.

beginning of the sample are stronger than those observed after the nineties in both cases, and the domestic output gap shocks generate more persistent responses than the foreign gap shocks. This outcome is broadly consistent with the theoretical impulse response functions reported in Figure 2. Summarizing, in spite of the undeniable role of the foreign output gap, the time predictions of the GH seem to fail because the importance of the foreign output gap does not grow at the expense of the domestic gap over time.

We can now broaden the analysis to the full set of countries in Figures 8 and 9, which show the responses of inflation to a positive shock to the domestic and foreign output gap respectively.¹⁵ With a few exceptions, among which Austria and Netherlands are the most evident, the responses to the domestic gap shocks are mostly positive and, typically, significant in the first quarters after the shock; they revert then to zero within two years. Turning to the responses of inflation to the foreign gap shocks in Figures 9, we observe positive and significant responses. This result is robust across countries and periods. As mentioned above for the U.S., these responses are somewhat less persistent.

A first important conclusion is suggested by this set of figures. In spite of the small and irregular unconditional correlations between inflation and foreign output gap found from the reduced form estimates, the impulse response functions reveal the importance of the foreign output gap for the dynamics of inflation. Not only does the foreign output gap matter, but it also has effects comparable in magnitude to those of the domestic output gap. This evidence is in line with the theoretical implications of the open economy New Keynesian models discussed in Section 2.1 and the effects predicted by the theory for standard calibrations as reported in Figure 2.^{16,17}

6.2.2 Long run responses

Under the baseline Cholesky identification scheme of the contemporaneous effects, and abstracting from the policy rate and the exchange rate, the inflation equation of the VAR reads

$$\pi_t = c_t + \alpha_{1t}\pi_{t-1} + \alpha_{2t}\pi_{t-2} + \beta_{0t}y_t^d + \beta_{1t}y_{t-1}^d + \beta_{2t}y_{t-2}^d + \delta_{0t}y_t^f + \delta_{1t}y_{t-1}^f + \delta_{2t}y_{t-2}^f + \omega_{\pi,t} \quad (8)$$

¹⁵These two figures share the same characteristics as Figure 7.

¹⁶The section *Supplementary Material* replicates the output of Figures 8 and 9 also for the alternative identification ordering in Figures E3 and E4. Very similar figures and conclusions are obtained; the most interesting difference is the negative impact response of the Canadian inflation to the foreign output gap shock.

¹⁷Figure E3, reported in the *Supplementary Material*, looks at the responses of inflation to the real exchange rate shocks. As one would expect from the third prediction of the GH, these responses are mostly negative, in particular in the first six quarters after the impulse (Australia and Denmark are the only exceptions). The responses are quite significant too, even though smaller in magnitude than those found for the two previous shocks. Downward shift effects on domestic producer price inflation due to low import prices have been recently documented by Auer and Fischer for the U.S. and Europe too. Even though not directly comparable to their results, our estimates definitely point in the same direction

Auer and Fisher (2010) find, for example, an annual downward effect between 40 and 60 basis points on the aggregate PPI inflation of the U.S. caused by import competition from low wage countries. In our estimates, the accumulated response of inflation to a unit real exchange rate shock approximately ranges between 5 and 10 basis points in the first year after the shock. Their effect would be roughly consistent with the effects of a 5–8% annual domestic real appreciation in our framework.

This framework allows us to study the long run responses of inflation to permanent shocks to the two output gaps, measured as the ratio of the sums of the distributed lags of inflation and the respective output gap in equation (8). More specifically, the time t long run responses of inflation to the domestic and foreign gap are respectively defined as $LR_{d,t} = \frac{\sum_{j=0}^2 \beta_{jt}}{1 - \sum_{j=1}^2 \alpha_{jt}}$ and $LR_{f,t} = \frac{\sum_{j=0}^2 \delta_{jt}}{1 - \sum_{j=1}^2 \alpha_{jt}}$.

Figures 10 and 11 report the long run responses of inflation to a unit permanent increase in the domestic and foreign output gap respectively. Both responses are re-scaled by the time t standard deviation of inflation. The outlook described by these two figures is not dissimilar to that found for the impulse responses in the previous section. The majority of the long run responses to both the domestic and foreign gap are positive, even though not always strongly significant. Some of the European countries display negative $LR_{d,t}$ responses over the entire sample; this is the case of Austria and Netherlands, or for part of it, such as France, Switzerland, and Denmark. Interestingly, the evolution of $LR_{d,t}$ of Austria, Denmark, and France mirrors that of the unconditional correlation between inflation and domestic gap in Figure 4. On the other hand, the $LR_{f,t}$ responses are noticeably negative only for Germany, Canada, and Italy.

The long run responses tend to be positive (negative) when the impulse responses to a temporary shock are also positive (negative); this correspondence is more evident for the responses to the domestic output gap. An interesting comparison between the two types of responses can be made for the U.S. Although smaller and less persistent than the responses to the domestic gap shocks, the impulse responses to the foreign gap shocks are consistently positive and fairly significant. Looking at the long run responses instead, while $LR_{d,t}$ is significantly positive and stable over time, $LR_{f,t}$ is always close to zero. However, beyond specific, individual cases, it is not immediate to identify a general trend in these long run responses consistent with the GH predictions.

6.2.3 Variance decomposition

Our last exercise consists of inspecting changes in the variance decomposition of inflation. Figure 12 illustrates that the share of variance attributed to the foreign gap shocks usually ranges between 5 and 20%; this share is smaller for some countries, for example Australia, but it can be quite large for others, as France, Spain, or Korea show. According to the GH, we would expect the share of the foreign gap to grow over time; it is actually possible to observe an increase in this share in some countries, but this trend is only weak and quite irregular.

In Figure 13, we focus on the relative contribution of the two output gap shocks to the inflation variance. The GH predicts a contraction of the importance of the domestic gap shock relative to the foreign one. The figure shows that foreign and domestic output gap shocks normally explain comparable portions of the inflation variance; this observation reinforces the conclusion that foreign slackness matters for the dynamics of the domestic inflation. However, the two shares follow very similar time patterns and a gain of the foreign gap does not occur.

Finally, we analyze the spectral decomposition of the contributions of the two gap shocks to the inflation variance in Figures 14 and 15, where frequencies are reported on the vertical axis

and time on the horizontal one. For sake of quality of the graphical rendering, the figures report the decomposition only for the lower portion of the spectrum; lighter colorations indicate higher incidence of a frequency.¹⁸ Most of the interaction between inflation and output gaps is expected to take place at business cycle frequencies, and this is confirmed by the two figures in a fairly uniform way over the sample for both the gaps. Although there is no particular time evolution in the spectra, a very interesting characteristic of these spectral decompositions is a sort of complementarity between the two gaps in this range of frequencies, in the sense that the effects of one gap seems to be stronger when those of the other are weaker. This is, for instance, very clear for the U.S. where the contribution to the variance of inflation from the domestic gap shock is stronger at the lowest frequencies, while the foreign gap shocks are more influential in the upper range of the business cycle frequencies. A similar case, even though with different patterns over frequencies and periods, holds for many of the other countries, primarily Germany, Switzerland, Italy, Netherlands, New Zealand, Canada, Austria, but also Korea, Japan, France, and U.K.

7 Panel Analysis

Based on the results so far, it is fair to conclude that there is very little evidence of changes in the relative importance of the domestic and output gaps for inflation dynamics. In this section we show that such a result should not lead us to conclude that the degree of integration in the global economy is not important for inflation dynamics. Instead, the absence of significant time variation is more likely to reflect the fact that the economies considered in our sample did not experience changes in the degree of integration large enough to induce visible breaks in the relation between inflation and the foreign output gap.

Specifically, we want to test for the main implication of the GH, which is the positive relation between globalization and the effects of global economic slack on inflation. As globalization grows, the foreign output gap is expected to progressively become the driving force of domestic inflation. This prediction has usually been verified studying the change over time of the coefficients of an univariate Phillips Curve model. We check instead for a formal link between the unconditional correlations, the responses to two gap shocks, and the variance shares obtained in Sections 5 and 6, on one side, and trade openness, on the other, by estimating a set of panel regressions in order to provide a more accurate quantitative assessment of the GH predictions.

As already mentioned in Section 2.2, it is difficult to characterize the numerous aspects of globalization in a parsimonious model. Our interest in the GH for inflation justifies the choice of focusing on the role of trade openness in the following baseline panel regressions, since good markets provide the main transmission channel of the real forces embedded in the foreign output gap; however, we augment the basic regression specification by including a financial openness index too. This vari-

¹⁸In these two figures, we set a saturation level of the frequency incidence at .3. A more detailed representation of the saturated regions can be found in Figures E6 and E7 of the *Supplementary Material*, in which each spectral decomposition is normalized by its largest value in the sample.

able allows us to add a second dimension of globalization to the analysis in order to check for the robustness of our results.

We estimate variations of the specification of the panel regression model in (9):

$$m_{it} = \lambda_1 open_{it} + \boldsymbol{\lambda}' X_{it} + u_{it} \quad (9)$$

where the index i identifies the countries and m_{it} are measures of the intensity of the relation between inflation and the output gaps derived from the VAR analysis and specified below. These measures are regressed on the degree of trade openness of the country, $open_{it}$, and a set of other variables, X_{it} , which can include financial openness, fin_{it} , a time trend, $trend_{it}$, or, alternatively, period fixed effects. The error term of the regression, u_{it} , is defined as the sum of a country fixed effect, λ_{0i} , and an idiosyncratic residual, v_{it} . The country fixed effects controls for unobserved characteristics of a country that can affect both the degree of openness and the influence of the foreign output gap on inflation; period fixed effects would account for common shocks that affect globalization. Trade openness is measured as the ratio to GDP of the sum of imports and exports and it is reported in Table 2 by half-decade since 1980 to 2006; financial openness is measured as the ratio to GDP of the sum of international total assets and liabilities.¹⁹ Finally, there is common agreement that the slope of the Phillips Curve with respect to the domestic output gap has become flatter over time. Also in our estimates, the responses of inflation to both output gaps have become weaker over time; on the contrary, the shares of the the two output gaps in the variance decomposition seem more stable across this dimension. It can be important, then, to control also for a possible time trend in the regressions since it may undermine some of the effects we are looking for.

The m_{it} measures are obtained from the reduced form and the structural estimates of the VAR, in function of the prediction of the GH that we want to test. Assessing Prediction 1, the loss of importance of the domestic gap, m_{it} represents: the median unconditional correlation between inflation and domestic output gap, the cumulative response of inflation to a temporary domestic output gap shock based on the significant and positive median responses, the median long run inflation responses to a permanent domestic gap shock, and the share attributed to the domestic gap shock in the variance decomposition of inflation. Prediction 2, the increase in influence of the foreign gap, is similarly assessed by defining the corresponding measures m_{it} for the foreign output gap. Finally, we can jointly assess the implications of the two predictions considering the difference between a measure for the foreign gap and the corresponding measure for the domestic one; based on the GH, this difference should increase as globalization grows.

We can now formally translate and test the two GH predictions directly in terms of the estimates of the coefficient of trade openness, λ_1 , in equation (9). Prediction 1 implies $\lambda_1 < 0$, while Prediction

¹⁹The international securities data is obtained from the updated and extended version of the dataset constructed by Lane and Milesi-Ferretti (2007). Since this data is annual, a linear interpolation is used to convert the dataset to quarterly frequency as the rest of our series. In spite of the large number of financial integration indeces available in the literature, this type of conversion is basically unavoidable due to the lack of reliable sources of indeces at quarterly frequency.

2 translates into $\lambda_1 > 0$; a positive λ_1 is also expected for the difference of the measures computed for the two gaps. Furthermore, when the financial openness variable fin_{it} is also included in equation (9), we have a second indicator of globalization to compare with trade openness; the signs of the fin_{it} coefficient expected for the GH predictions are the same as for $open_{it}$.

The estimates of the panel regressions are presented in Tables 3-5 for the baseline identification ordering of the VAR innovations. Each panel in the table refers to one of the four definitions of m_{it} ; estimates are obtained by OLS with robust White period standard errors to correct for arbitrary autocorrelation within cross-section in the residuals.

Prediction 1 is studied in Table 3. The estimates in the table provide only mild, and somewhat contradictory, evidence in favor of this prediction of the GH. The coefficient of trade openness is negative as expected for three out of four measures m_{it} , but actually significant only for specifications (a) and (b) of the responses to a temporary shock. On the contrary, financial openness has a positive and statistically significant effect across all the definitions of the measures. As suggested by the graphical analysis in the previous sections, there is a significant downward sloping trend in the responses to temporary y^d shocks, but also to the permanent shocks. When controlling for the trend, the effects of *open* typically become smaller.

Prediction 2 is presented in Table 4. In this case, we find interesting evidence in favor of this prediction of the GH from equation (9). The estimates of the trade openness coefficient are positive and often significant at the standard levels of confidence, and we find very strong effects for the long run responses to permanent y^f shocks. Similar results are obtained for the financial openness coefficient, which is particularly strong for the responses to temporary shocks instead. Actually, it is interesting to notice that the two indices of openness seem to capture rather independent aspects of globalization. Similarly to the previous case, we observe a negative trend for the responses to both types of shocks; in this case, controlling for the time trend reduces, but does not wipe away, the effects of *open*. The y^f share in the inflation variance decomposition, which was illustrated in Figure 12, is not very responsive to either measure of globalization.

In Table 5, we jointly assess Prediction 1 and 2 reporting the estimates for the relative effects of the two output gaps. As expected based on the GH predictions, the coefficient for trade openness is positive and strongly significant across the definitions of m_{it} , with the exception of the variance decomposition measure. On the other hand, the effects of the financial openness become smaller and remain statistically positive and significant only for the difference of the responses to temporary shocks. The difference in the variance shares inherits the features of the y^d share and it displays a significant, negative coefficient for the financial openness which is in clear contradiction with the GH and the estimates for the responses to temporary shocks. Overall, the results are in line with those in the previous two tables and they also confirm the positive impact of trade openness on the effects of global slackness on domestic inflation found for Prediction 2. However, in this case it is harder to extend this conclusion to the role of financial integration.

We provide a simple evaluation of the economic magnitude of these effects for the long run

responses to a permanent foreign output gap shock. A trade openness coefficient equal to 1 would imply a 10 basis points larger long run response of inflation to a 1% permanent increase in the foreign gap for every 10 extra percent points in the openness index, which can be considered a relatively small difference in openness between two countries. Given the estimates for the three specifications in Table 4, which are around 1.5, this implies that a slightly more open country would have a higher long run response of inflation to the same 1% permanent shock to global slackness of about 15 basis points. Table 2 shows that a ten percent variation in the trade openness degree of an individual country turns out to be a quite large change even over three decades; however, this would be just a small difference across countries since the openness index goes from 20 to more than 100 percent. This explains why adding the cross-section dimension to the analysis allows us to detect the effects of openness in the panel regressions, while those effects do not come to light from the time analysis.²⁰

8 Conclusions

The goal of this paper is to empirically assess whether the implications of the globalization hypothesis for domestic inflation holds. In particular, we focus on the relation between global slack, represented by the foreign output gap, and inflation. The majority of the previous literature has tackled this question checking for the right changes in the estimates of the coefficients of univariate estimates of the Phillips Curve equation under the assumption that globalization has pervasively increased in the past decades. Mixed empirical evidence is typically found. Our approach aims to provide a more comprehensive analysis of this issue based on a time varying coefficients VAR approach. First, we estimate the VAR models for a broad set of countries, using a homogenous data set covering the sample from 1970 to 2006. From these estimates, we obtain a set of reduced form correlations that can be use to study the evolution of the relation between inflation and domestic and foreign output gaps. Second, we propose an orthogonalization of the innovations of the VAR and we derive a further decomposition of the conditional effects of domestic and foreign output gap shocks on inflation. Finally, we use the output of our VAR analysis in order to quantitatively assess the effects of the foreign output gap on domestic inflation in a panel analysis.

Three main results emerge from our analysis. First, global economic fluctuations affect the dynamics of domestic inflation in many countries. This conclusion clearly emerges from the structural analysis of our TV-VAR estimates. The result is robust across countries and periods and it shows that univariate studies of the Phillips Curve could easily underestimate the potential role of globalization. Second, in spite of the importance of global slack, its effects on inflation do not reveal a clear time trend consistent with the GH. In other words, the foreign output gap does not seem to become

²⁰In order to have a better sense of the relative importance of the cross-sectional and time-series dimensions in the panel regressions, we note that the standard deviation of the time averages of $open_{it}$ is 4 times larger than the standard deviations of the cross-section averages. For the foreign output gap measures in Table 4, for instance, the same ratio is 9 for $LONG_{it}$, the long run responses, 1.6 for $TEMP_{it}$, the cumulative responses to temporary shocks, 2 for $CORR_{it}$, the unconditional correlations, and 7.4 for $DECO_{it}$, the share in the variance decomposition.

relatively more important than the domestic output gap for inflation dynamics. Finally, while the time series dimension does not clearly reveal the effects of globalization, adding the cross-section dimension to the analysis shows that trade openness is positively related to the effects of global slack on inflation. Specifically, when the two predictions of the GH are tested jointly in a panel regression, we find that in fact trade openness enhances the relative importance of the foreign output gap on domestic inflation.

Based on these results, we conclude that the effects of globalization require substantially large changes in the degree of openness in order to be economically significant. The small historical increase in the openness indices of the countries in our sample, only five percent on average, is not large enough to induce significant changes in inflation dynamics over time. On the contrary, the larger cross-section differences in openness provide the right conditions to detect the potential effects of globalization.

Acknowledgements

We are grateful to the editor Jesus Fernandez-Villaverde and two anonymous referees for exceptionally thoughtful comments. We would also like to thank Alan Blinder, Christopher Sims, Mark Watson, Sandra Eickmeier, John Seater, Paolo Surico, and seminar participants at Princeton University, University of Arkansas, NC State University, Duke University, and the "Inflation Dynamics in a Post-Crisis Globalized Economy" 2013 conference at the Swiss National Bank for very useful comments and discussions.

APPENDIX

A The Dataset

This Appendix provides further details about our dataset. We only focus on data sources and the main procedure to obtain the real exchange rates and the foreign output gaps. A full description of the dataset and country specific information are given in the note "The construction of a global trade-based dataset" which is available from the authors' webpage, along with all the matlab codes necessary to construct the database.

A.1 Countries

We run the TV-VAR for eighteen countries: U.S., U.K., Germany²¹, France, Italy, Spain, Ireland, Denmark, Netherlands, Austria, Switzerland, Canada, Mexico, Australia, Japan, Korea, South Africa, New Zealand.

In addition to these eighteen countries, the other countries included in the sample for the trade-based weights are: Belgium, Luxembourg, Norway, Sweden, Finland, Greece, Iceland, Portugal, Turkey, Yugoslavia (Croatia and Slovenia after 1993), Argentina, Brazil, Colombia, Peru, Venezuela, Israel, Hong-Kong, India, Indonesia, USSR (Russia, Latvia and Lithuania after 1993), China, Czechoslovakia (Czech Republic and Slovakia after 1993), Hungary, Poland.

A.2 Weights and other formulas

The formula for the imports, exports, and third party weights (w^m , w^x , and w^3 respectively) necessary to compute the foreign output gaps and the effective real exchange rates are the following:

$$\begin{aligned}w_{i,j,t}^m &= \frac{M_{i,j,t}}{\sum_{j=1}^{N_t} M_{i,j,t}} \\w_{i,j,t}^x &= \frac{EX_{i,j,t}}{\sum_{j=1}^{N_t} EX_{i,j,t}} \\w_{i,j,t}^3 &= \sum_{k \neq j, \neq i}^{N_t} w_{i,k,t}^x \frac{w_{k,j,t}^m}{1 - w_{k,i,t}^m}\end{aligned}$$

where $M_{i,j}$ and $EX_{i,j}$ indicate imports from country j to country i and exports from country i to country j . The presence of a time dependent N_t in the summations easily accommodates the

²¹East Germany is added to West Germany after the 1992 unification.

possibility of a varying pool of countries. The weights are then aggregated as in (10)

$$w_{i,j,t} = 0.5w_{i,j,t}^m + 0.5 \left(0.5w_{i,j,t}^x + 0.5w_{i,j,t}^3 \right) \quad (10)$$

The real exchange rate index $\hat{I}_{i,t}$ for country i at time t is obtained by combining these weights with the pair-wise exchange rates. We follow Loretan and apply the next formula

$$\hat{I}_{i,t} = \hat{I}_{i,t-1} \prod_{j=1}^{N_t} \left(\frac{\hat{e}_{i,j,t}}{\hat{e}_{i,j,t-1}} \right)^{w_{i,j,t}}$$

where $\hat{e}_{i,j,t}$ is the real exchange rate between country i and country j defined as

$$\hat{e}_{i,j,t} = e_{i,j,t} \frac{P_{i,t}}{P_{j,t}} \quad (11)$$

In (11), $P_{i,t}$ is the CPI of country i at period t and $e_{i,j,t}$ is the nominal exchange rate between country i and j expressed as the price of one unit of currency i in terms of currency j . So $\hat{e}_{i,j,t}$ can be defined as the value (or the price) of country i bundle of goods in terms of country j basket. Currency i (good i) becomes more valuable relative to its j 's counterpart when $e_{i,j}$ ($\hat{e}_{i,j}$) increases.

Whenever an official output gap measure is not available for a country, the potential output of that country is first obtained applying the HP filter to the real GDP ; we then compute the output gap for country i as the percentage deviation of the actual GDP from its potential

$$gap_{i,t} = \frac{gdp_{i,t}}{pot_{i,t}} - 1$$

The relevant foreign output gap for country i is finally computed as the weighted average of the domestic output gap of all the other countries in the sample, using the weights in (10).

A.3 Sources

The main sources for the data in this work are the OECD National Accounts Statistics (NAS) and Economic Outlook (EO), the OECD Main Economic Indicators (MEI), Global Insight (GI), and Global Financial Data (GFD).

Trade Flows. For all countries and throughout the entire sample the IMF Direction of Trade (DOT) provides the pair-wise trade flows among the countries in the sample. The data are available from 1960:1 to 2006:4, but the sample is reduced to 1970:1 to 2006:4 when working with GDP data and other series due to the shorter availability of most of these series. The flows are measured in current U.S. dollars for all the countries. Notice that DOT treats Belgium and Luxembourg as separate countries only after 1997 and that Germany is defined as West Germany alone before the 1991 reunification. We necessarily keep the same definitions for the other data too.

Real GDP. EO provides the output gaps for eight countries: U.S., U.K., Canada, Australia,

France, Germany²², Italy, and Japan. OECD follows a procedure very similar to ours to construct the output gap since our measure almost perfectly coincides with theirs for these countries. For the other countries, the real *GDP* series is used as explained in the previous section. The series are generally already seasonally adjusted, but, if not, we apply Census x12 to them. NAS covers all the OECD countries for the entire sample: Denmark, Netherlands, Norway, Sweden, Switzerland, Canada, Japan, Finland, Greece, Iceland, Ireland, Portugal, Spain, New Zealand, Mexico, Hong-Kong, Korea, Belgium, Luxembourg, South Africa, and Austria.²³ The other countries require some more manipulations; different sources (mostly GFD and Datastream) are combined to get the most consistent measure of *GDP* for the longest possible period. Time sample limitation is the main problem in these cases, with series of the emerging countries and youngest nations starting only in the late 80's. Yugoslavia, USSR, and Czechoslovakia are dropped from the output gap sample for lack of quality in their data. For their recent importance in the world economy, China and India are maintained for the entire sample even though their quarterly data start only in the 90's; a fitting on the annual data is implemented. The source for Chinese data is China Marketing Research Co.

Nominal GDP. The nominal *GDP* data are necessary only to compute the measure of openness of the country presented in Table 2, since the trade flows are expressed in current dollars. Therefore, we need to cover a much narrower sample of countries. However, given the real *GDP* series, the CPI and the exchange rates, we can construct the nominal series in dollar for most of the countries in the larger sample. Comparison with OECD_MEI and GFD data confirm the reliability of these series.

Nominal Exchange Rates. We use the U.S. dollar as pivotal currency for the bilateral exchange rates between the U.S. and the other countries in the sample; this allows the creation of a pair-wise dataset for each country. The main sources of these series are the KEYIND data base of GI and the GFD web data base. The data are originally reported in units of a currency necessary to buy one U.S. dollar and we express the exchange rates in units of foreign currency necessary to buy one unit of domestic currency. To avoid shifts in the definition of the accounting unit of the numeraire, we always use the most recent monetary unit adopted by a country as reference unit. If this is not possible, because of a change in both the accounting unit and the political definition of a country, we adopted ad hoc solutions.²⁴ Finally, the exchange rates in dollar terms are seasonally adjusted by using Census x12. The countries members of the EU switch to the common currency in 1999.

CPI. We set 2000 as the base year; the average of the CPI indices at that year is set to 100. The series are mainly from IMF (through GI), OECD_MEI is the main alternative source; some of them are from GFD too. We seasonally adjust them using Census x12; this adjustment is relevant only for few of the countries from GFD. In particular, the series for Germany and U.S., Slovakia and Czech Republic, Brazil, Hungary, and Poland are from MEI, while those for the Russian Republics, Slovenia, Croatia, and Hong Kong are from GFD. China needs again a special treatment. Since 1987

²²Only after the unification. For the years before 1992 the West Germany output gap is used.

²³Austria requires an integration with data from GFD.

²⁴These shifts in definition are typical for emerging economies and the new nations founded during the 90's. The note online provides a full description of them.

a mixed of MEI and China Marketing Research Co. data is used at quarterly frequency; before that we use annual figures for the CPI as we did for the *GDP*.

Interest Rates. Suitable interest rate series are usually available only starting from the 80's for most of the countries in our sample. For this reason, we focus only on the eighteen countries in the TV-VAR analysis. We select and construct the series following two criteria. First of all, short term interest rates are required. So, when possible, we take the 3-month treasury bill yields. If this type of series is not available for a country, we usually take a short term interbank or deposit rate. We obviously prefer continuous and homogenous series, however, in some cases we had to merge together more than one series in order to span the entire sample, in particular for the earlier years. GFD is the most useful source for this variable. Treasury bill rates are used for Japan, U.S., U.K., France, Germany, Australia, Canada, Italy, Belgium, Netherlands, Ireland, and South Africa. Interbank rates are used for Switzerland, Korea, Denmark, Mexico, and Spain. A mixed series is used for Austria and New Zealand.

B The Theoretical Model in Section 2.2

This appendix provides some details about the model used to generate the theoretical impulse response functions presented in Section 2.2 and Figure 2. The model is based on one of the examples studied by Zaniboni (2008) and a full derivation of it can be found in his paper.

The model is a standard two-country open economy New Keynesian model. The structure of the model is perfectly symmetric in the two countries and it comprises three main parts for each country. The three parts are the following:

1. Preferences are defined over consumption and labor. The utility function is separable in the two arguments and constant risk aversion is assumed. Consumption is defined in final goods, which is an aggregate of domestic and foreign intermediate goods. These tradable goods are imperfect substitutes and it is assumed that households are biased toward domestic goods. The degree of openness of a country is inversely related to the degree of home bias. Finally, it is assumed that international financial markets are complete. This component of the model is represented by a standard open economy Euler equation.
2. While the final good market is perfectly competitive, intermediate-good producers are monopolistically competitive and they set prices a la Calvo. Non-tradable goods are not included in the model for simplicity. Producers can price discriminate between domestic and foreign market and the exporting price is set in local-currency prices, which implies that deviations from the law of one price are possible given nominal price rigidities. This block produces one Phillips Curve equation for each type of inflation in a country: the inflation for domestically-produced goods, the imported-good inflation, and the overall CPI inflation.

The relevant Phillips Curve for our study is obviously the CPI inflation equation, which would

be very similar to equation (1) in the main body of the paper. For the domestic country it reads

$$\pi_t = \mu E_t \pi_{t+1} + \nu \left[(1-h) y_t^d + h y_t^f \right] + \Phi z_t$$

where the notation is the same as in (1), with the exception of the shift term $\Gamma_t = \Phi z_t$. In this specification of the model, z_t represents the deviations from the law of one price of the imported intermediate goods and Φ is a combination of the structural parameters of the model.

The slope of the relation between output gaps and inflation depends on the home bias parameter $(1-h)$, set to 0.8, and the coefficient ν , which summarizes the responsiveness of inflation to the marginal cost and of the marginal cost to the output gap. This coefficient is a function of the Calvo probability of adjusting prices (set to 0.25), the elasticity of substitution between home and foreign goods (set to 1), the risk aversion parameter (5), the inverse of the Frisch elasticity (3), the preferences discount factor μ (0.99), and the home bias parameter too. The coefficient Φ determines the sensitiveness of inflation to import prices. As well as ν , it depends on the Calvo probability of adjusting prices, the elasticity of substitution between home and foreign goods, the risk aversion parameter, the preferences discount factor μ , and the home bias parameter. Under this calibration, the domestic and foreign output gap coefficients are 0.42 and 0.1 respectively.

The output gap is defined as the difference between output and its flexible-price potential level. In this kind of model, the flexible-price output of a country depends on the output of the other. This is the main type of structural link between foreign output gap and domestic inflation that theoretically justifies the globalization hypothesis. Finally, we include an exogenous shock to the output gap equation in order to plot the impulse responses in Figure 2.

3. The model is closed by a Taylor rule, with inflation and output gap parameters respectively set to 1.5 and 0.125. The exogenous innovations are three: a technology, a monetary, and the output gap shock. They are assumed to follow an $AR(1)$ process with autoregressive parameter equal to 0.8. Finally, the two sides of the model are connected by an equation for z_t , the deviations of import prices from the law of one price, defined as the difference between the foreign currency price of the foreign good converted into domestic currency and the domestic currency price of the imported foreign good.

The model is log-linearized around a zero-inflation steady state and the solution is found using gensys by Chris Sims. The impulse response functions reported in Figure 2 are quite robust to nearby calibrations.

C Time-Varying VAR

The reader can make reference to Bianchi, Mumtaz, and Surico (2009) for more details about the estimation procedure of the time varying VAR model.

C.1 Priors

VAR coefficients

The prior for the VAR coefficients is obtained *via* a fixed coefficients VAR model estimated over the sample 1971:1 to 1979:4. Φ_0 is therefore set equal to

$$\Phi_0 \sim N(\hat{\phi}^{OLS}, V^{OLS})$$

Elements of H_t

Let \hat{v}^{ols} denote the OLS estimate of the VAR covariance matrix estimated on the pre-sample data described above. The prior for the diagonal elements of the VAR covariance matrix (5) is as follows:

$$\ln h_0 \sim N(\ln \mu_0, I_n)$$

where μ_0 are the diagonal elements of \hat{v}^{ols} .

Elements of A_t

The prior for the off-diagonal elements A_t is

$$A_0 \sim N\left(\hat{\alpha}^{ols}, V\left(\hat{\alpha}^{ols}\right)\right)$$

where $\hat{\alpha}^{ols}$ are the off-diagonal elements of \hat{v}^{ols} , with each row scaled by the corresponding element on the diagonal. $V\left(\hat{\alpha}^{ols}\right)$ is assumed to be diagonal with the diagonal elements set equal to 10 times the absolute value of the corresponding element of $\hat{\alpha}^{ols}$.

Hyperparameters

The prior on Q is assumed to be inverse Wishart

$$Q_0 \sim IW(\bar{Q}_0, T_0)$$

where \bar{Q}_0 is assumed to be $var(\hat{\phi}^{OLS}) \times 10^{-4}$ and T_0 is the length of the sample used for calibration.

The prior distribution for the blocks of S is inverse Wishart:

$$S_{i,0} \sim IW(\bar{S}_i, K_i)$$

where $i = 1 \dots n$ indexes the blocks of S . \bar{S}_i is calibrated using \hat{a}^{ols} . Specifically, \bar{S}_i is a diagonal matrix with the relevant elements of \hat{a}^{ols} multiplied by 10^{-3} .

Following Cogley and Sargent, we postulate an inverse-Gamma distribution for the elements of G ,

$$\sigma_i^2 \sim IG\left(\frac{10^{-4}}{2}, \frac{1}{2}\right)$$

C.2 Simulating the Posterior Distributions

Time-Varying VAR

The model is a VAR with drifting coefficients and covariances. This model has become fairly standard in the literature and details on the posterior distributions can be found in a number of papers including Cogley and Sargent and Primiceri. Here, we briefly describe the algorithm.

VAR coefficients Φ_t

The time-varying VAR coefficients are drawn using the methods described by Kim and Nelson.

Elements of H_t

Following Cogley and Sargent, the diagonal elements of the VAR covariance matrix are sampled using the methods described by Jacquier, Polson, and Rossi (2004).

Element of A_t

Given a draw for Φ_t the VAR model can be written as

$$A_t \left(\tilde{X}_t \right) = H^{1/2} \omega_t$$

where $\tilde{X}_t = X_t - a_t - \sum_{p=1}^P B_{t,p} X_{t-p} = \varepsilon_t$ and $Var(H^{1/2} \omega_t) = H_t$. This is a system of equations with time-varying coefficients and given a block diagonal form for $Var(\varepsilon_t)$ the standard methods for state space models described by Kim and Nelson can be applied.

VAR hyperparameters

Conditional on X_t , $\phi_{t,t}$, H_t , and A_t , the innovations to $\Phi_{t,t}$, H_t , and A_t are observable, which allows us to draw the hyperparameters—the elements of Q , S , and the σ_i^2 —from their respective distributions.

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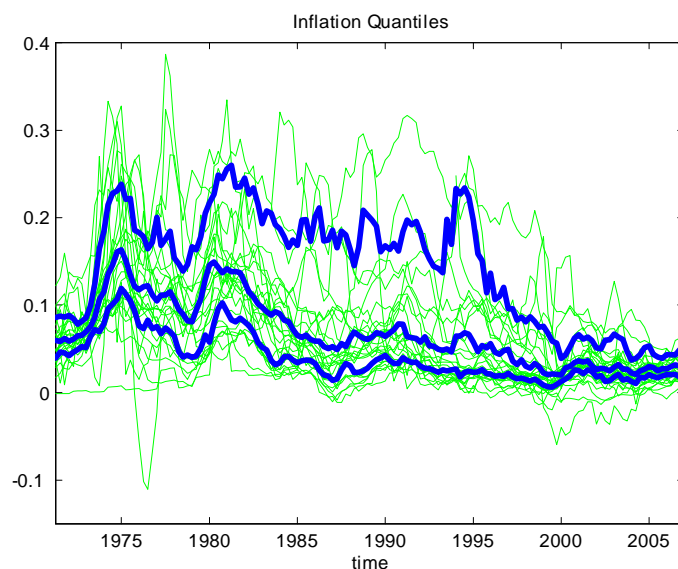


Figure 1: Inflation rates across the world. National inflation rates for a larger sample of countries. The thicker and darker lines represent the 5th, 50th, and 95th percentiles of the distribution of the inflation rates. Sample period 1971 to 2006.

Country	Abbr.	Country	Abbr.	Country	Abbr.
<i>United States</i>	<i>us</i>	<i>Australia</i>	<i>au</i>	<i>Italy</i>	<i>it</i>
<i>United Kingdom</i>	<i>uk</i>	<i>Japan</i>	<i>jp</i>	<i>Netherlands</i>	<i>nl</i>
<i>Canada</i>	<i>ca</i>	<i>South Korea</i>	<i>ko</i>	<i>Spain</i>	<i>es</i>
<i>Germany</i>	<i>ge</i>	<i>Austria</i>	<i>oe</i>	<i>Mexico</i>	<i>mx</i>
<i>France</i>	<i>fr</i>	<i>Ireland</i>	<i>ir</i>	<i>South Africa</i>	<i>sa</i>
<i>Switzerland</i>	<i>sw</i>	<i>Denmark</i>	<i>dk</i>	<i>New Zealand</i>	<i>nz</i>

Table 1: Abbreviations used as country codes in Figures and Tables.

	<i>us</i>	<i>uk</i>	<i>ca</i>	<i>ge</i>	<i>fr</i>	<i>sw</i>	<i>au</i>	<i>jp</i>	<i>ko</i>	<i>oe</i>	<i>ir</i>	<i>dk</i>	<i>it</i>	<i>nl</i>	<i>es</i>	<i>mx</i>	<i>sa</i>	<i>nz</i>	<i>all</i>
1980:85	.15	.43	.47	.48	.39	.56	.26	.24	.61	.86	.93	.57	.48	.97	.29	.17	.54	.55	.50
1986:90	.14	.40	.46	.47	.34	.53	.26	.17	.56	.68	.88	.49	.38	.84	.27	.21	.50	.46	.45
1991:95	.16	.39	.50	.39	.34	.51	.28	.15	.48	.58	.95	.48	.34	.77	.29	.32	.41	.48	.43
1996:00	.18	.42	.66	.44	.41	.57	.32	.17	.57	.62	1.20	.53	.37	.85	.38	.56	.49	.48	.51
2001:06	.19	.38	.63	.57	.45	.64	.32	.22	.62	.71	1.07	.58	.40	1.10	.40	.56	.57	.48	.55
Δopen	.05	-.05	.16	.09	.05	.08	.06	-.02	.02	-.15	.13	.01	-.08	.13	.11	.39	.04	-.07	.05

Table 2: Change in the degree of openness. The degree of openness is measured as the sum of imports and exports in ratio to GDP. Averages by five-year periods since 1980 are reported (six years are used at the initial and final part of the sample). The change of openness is defined as the variation in this measure of openness between period 1980:85 and period 2001:06. This is reported in the last row.

$m :$	CORR			TEMP			LONG			DECO		
	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)
<i>open</i>	-.025 (.069)	-.036 (.066)	-.073 (.08)	-2.086 (.896)**	-2.214 (.839)***	-.959 (1.058)	-.455 (.424)	-.505 (.379)	-.111 (.254)	.143 (.071)**	.103 (.079)	.055 (.09)
<i>fin</i>	.006 (.004)*	.006 (.003)*	.006 (.003)*	.075 (.041)*	.075 (.041)*	.095 (.045)**	.029 (.015)*	.029 (.015)*	.037 (.013)***	.024 (.006)***	.024 (.006)***	.021 (.006)***
<i>trend</i>			.031 (.043)			-1.185 (.433)***			-.474 (.177)***			.007 (.035)
<i>Country FE</i>	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
<i>Period FE</i>	Y	Y	N	Y	Y	N	Y	Y	N	Y	Y	N
R^2	.71	.71	.69	.41	.42	.38	.75	.76	.73	.61	.71	.69
<i>Obs</i>	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908

Table 3: Prediction 1: domestic output gap. Sample 1980:3 2006:4. Baseline identification ordering (y^f y^d π τ i). Estimates of the model in (9) for the measures m_{it} : the median unconditional correlation between π and y^d (*CORR*), the cumulative response of π to a temporary y^d shock based on the significant and positive median responses (*TEMP*), the median long run π responses to a permanent y^d shock (*LONG*), and the share attributed to the y^d shock in the variance decomposition of π (*DECO*). *open* is the ratio to *GDP* of the sum of imports and exports expressed in percentage; *fin* is the ratio to *GDP* of the sum of total assets and liabilities expressed in percentage; *trend* is the time trend. Robust White period standard errors are reported in parenthesis. 1, 5, and 10% significance levels are indicated by ***, **, and * respectively.

$m :$	CORR			TEMP			LONG			DECO		
	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)
<i>open</i>	.379 (.187)**	.344 (.182)*	.099 (.179)	4.066 (3.6)	3.571 (3.165)	3.408 (2.052)*	1.624 (.179)***	1.573 (.317)***	1.272 (.332)***	.104 (.098)	.105 (.091)	.087 (.09)
<i>fin</i>		.021 (.008)**	.015 (.008)*		.288 (.093)***	.288 (.073)***		.029 (.024)	.026 (.022)		-.001 (.005)	.000 (.005)
<i>trend</i>			.012 (.064)*			-2.702 (.625)***			-1.139 (.154)			.015 (.035)
<i>Country FE</i>	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
<i>Period FE</i>	Y	Y	N	Y	Y	N	Y	Y	N	Y	Y	N
R^2	.66	.68	.61	.27	.30	.27	.74	.75	.74	.71	.71	.70
<i>Obs</i>	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908

Table 4: Prediction 2: foreign output gap. Sample 1980:3 2006:4. Baseline identification ordering ($y^f y^d \pi \tau i$). Estimates of the model in (9) for the measures m_{it} : the median unconditional correlation between π and y^f (*CORR*), the cumulative response of π to a temporary y^f shock based on the significant and positive median responses (*TEMP*), the median long run π responses to a permanent y^f shock (*LONG*), and the share attributed to the y^f shock in the variance decomposition of π (*DECO*). *open* is the ratio to *GDP* of the sum of imports and exports expressed in percentage; *fin* is the ratio to *GDP* of the sum of total assets and liabilities expressed in percentage; *trend* is the time trend. Robust White period standard errors are reported in parenthesis. 1, 5, and 10% significance levels are indicated by ***, **, and * respectively.

<i>m</i> :	<i>CORR</i>			<i>TEMP</i>			<i>LONG</i>			<i>DECO</i>		
	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)
<i>open</i>	.004 (.002)**	.004 (.002)**	.002 (.001)	6.082 (3.024)**	5.673 (2.637)**	4.253 (1.461)**	2.029 (.509)**	2.027 (.526)**	1.348 (.448)**	-.040 (.071)	.002 (.101)	.032 (.075)
<i>fin</i>	.000 (.000)	.000 (.000)	.000 (.000)	.238 (.115)**	.238 (.115)**	.216 (.090)**	.001 (.024)	.001 (.024)	-.011 (.026)		-.024 (.004)**	-.021 (.004)**
<i>trend</i>			.001 (.001)			-1.604 (.579)**			.327 (.287)			.008 (.045)
<i>Country FE</i>	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
<i>Period FE</i>	Y	Y	N	Y	Y	N	Y	Y	N	Y	Y	N
<i>R</i> ²	.58	.59	.53	.29	.31	.28	.83	.83	.82	.46	.56	.52
<i>Obs</i>	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908

Table 5: Joint predictions 1 and 2: differences between the two output gaps. See notes for Table 3 and 4. The measures, m_{it} , are defined as the difference between the corresponding measures for the foreign and domestic output gap.

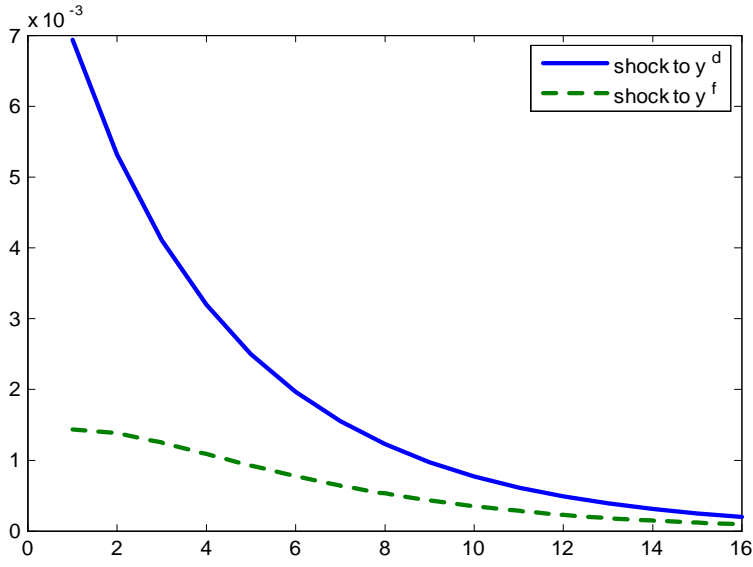


Figure 2: Theoretical response of inflation to domestic and foreign output gap shocks. Response of domestic inflation to a 1 in a standard New Keynesian open economy DSGE model (see Appendix for more details).

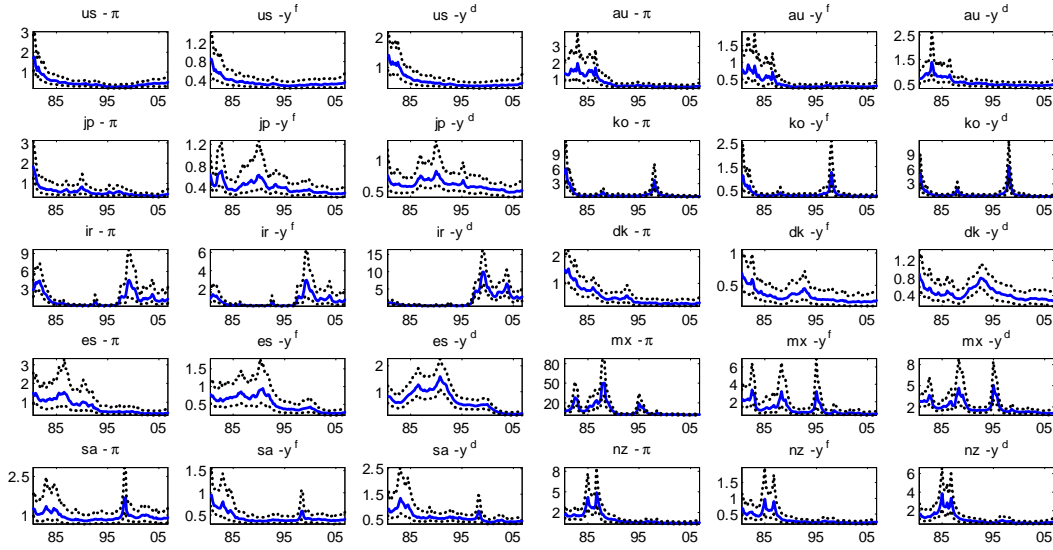


Figure 3: Standard deviations of inflation and output gaps. Time variation of the volatilities (standard deviations from the TV-VAR estimates) of inflation, domestic and foreign output gap. The blue line is the median of the posterior distribution; the black, dashed bands show the 14th/86th percentiles.

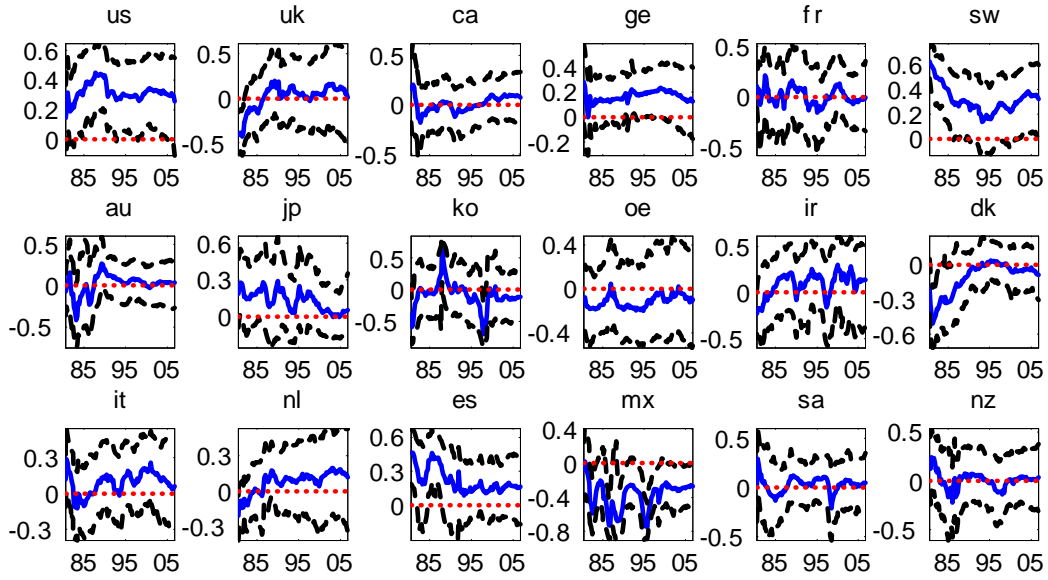


Figure 4: The time varying correlation between domestic gap and inflation. Time variation of the correlation between domestic output gap, y^d , and inflation, π , from the reduced form estimates of the VAR. The blue line is the median of the posterior distribution; the black, dashed bands show the 14th/86th percentiles.

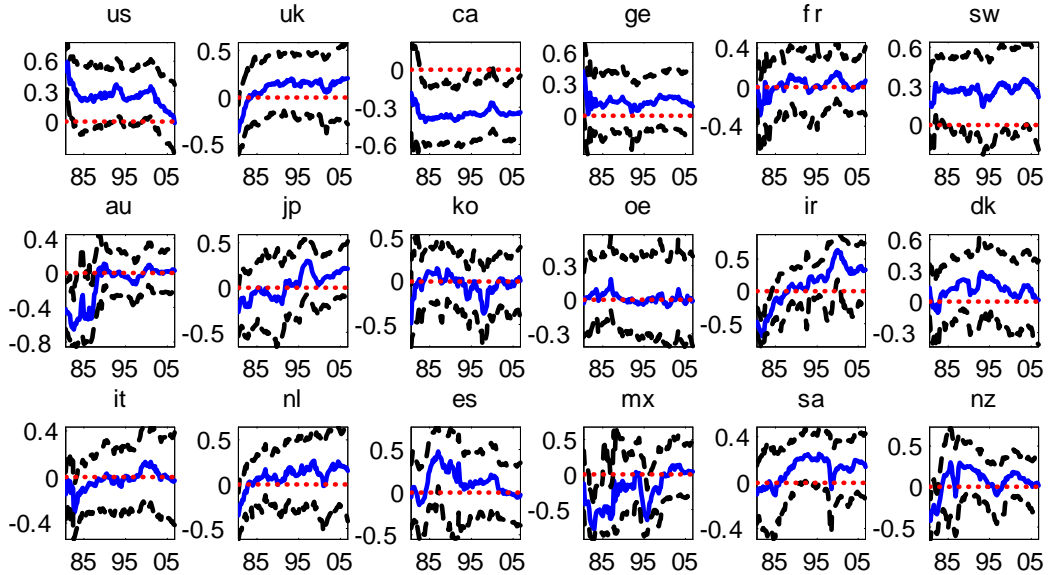


Figure 5: The time varying correlation between foreign gap and inflation. Time variation of the correlation between foreign output gap, y^f , and inflation, π , from the reduced form estimates of the VAR. The blue line is the median of the posterior distribution; the black, dashed bands show the 14th/86th percentiles.

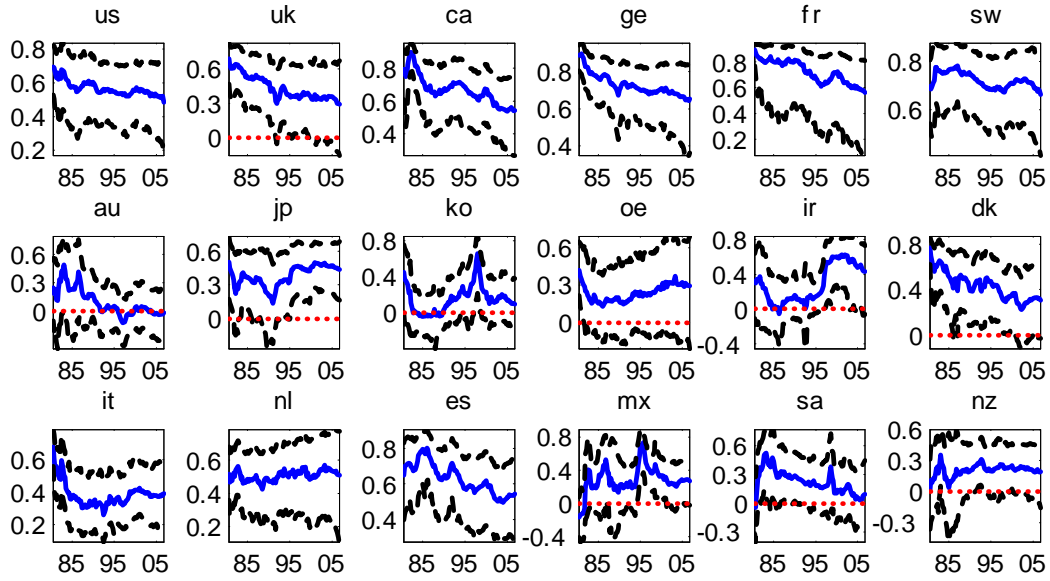


Figure 6: Business cycle synchronization. Time variation of the correlation between domestic and foreign gap from the reduced form estimates of the VAR. The blue line is the median of the posterior distribution; the black, dashed bands show the 14th/86th percentiles.

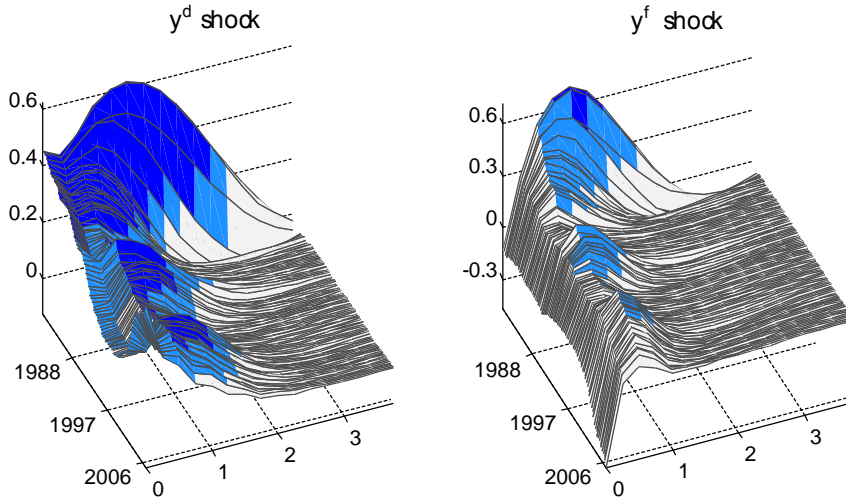


Figure 7: Responses of π to a unit shock to y^d and y^f for U.S. Responses of inflation π to domestic and foreign output gap shocks for U.S. for each quarter in the sample 1980:3 to 2006:4. The baseline identification ordering $(y^f y^d \pi \tau i)$ is adopted. The light blue shades indicate significance at the 14th/86th percentiles of the posterior distribution of the response. Darker blue shades indicate significance at the 5th/95th percentiles. Years from the shock on the x -axis.

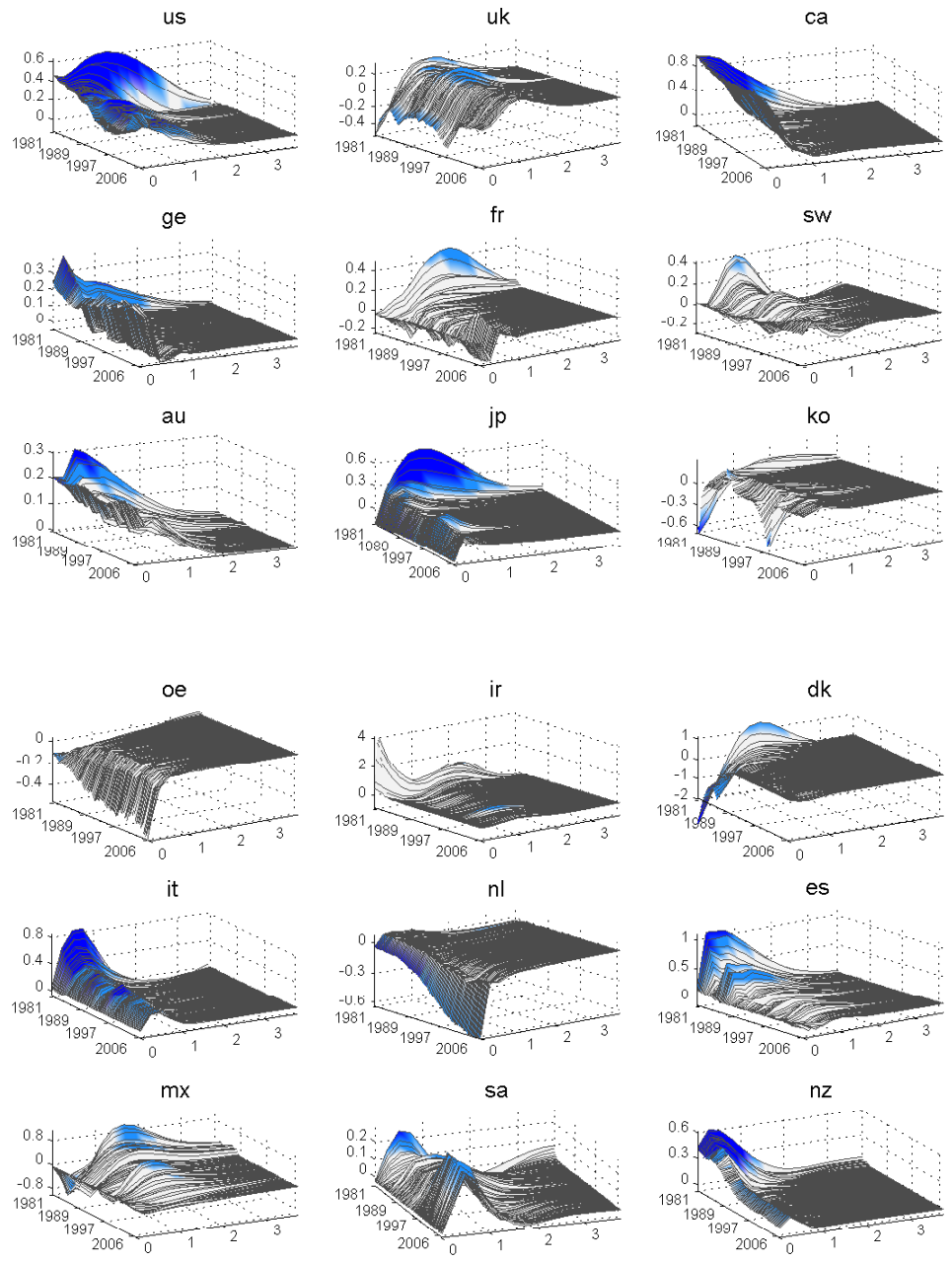


Figure 8: The response of inflation π to a unit shock to the domestic output gap y^d for each quarter in the sample 1980:3 to 2006:4. The baseline identification ordering $(y^d \ y^d \ \pi \ \tau \ i)$ is adopted. The light blue shades indicate significance at the 14th/86th percentiles of the posterior distribution of the response. Darker blue shades indicate significance at the 5th/95th percentiles. Years from the shock on the x-axis.

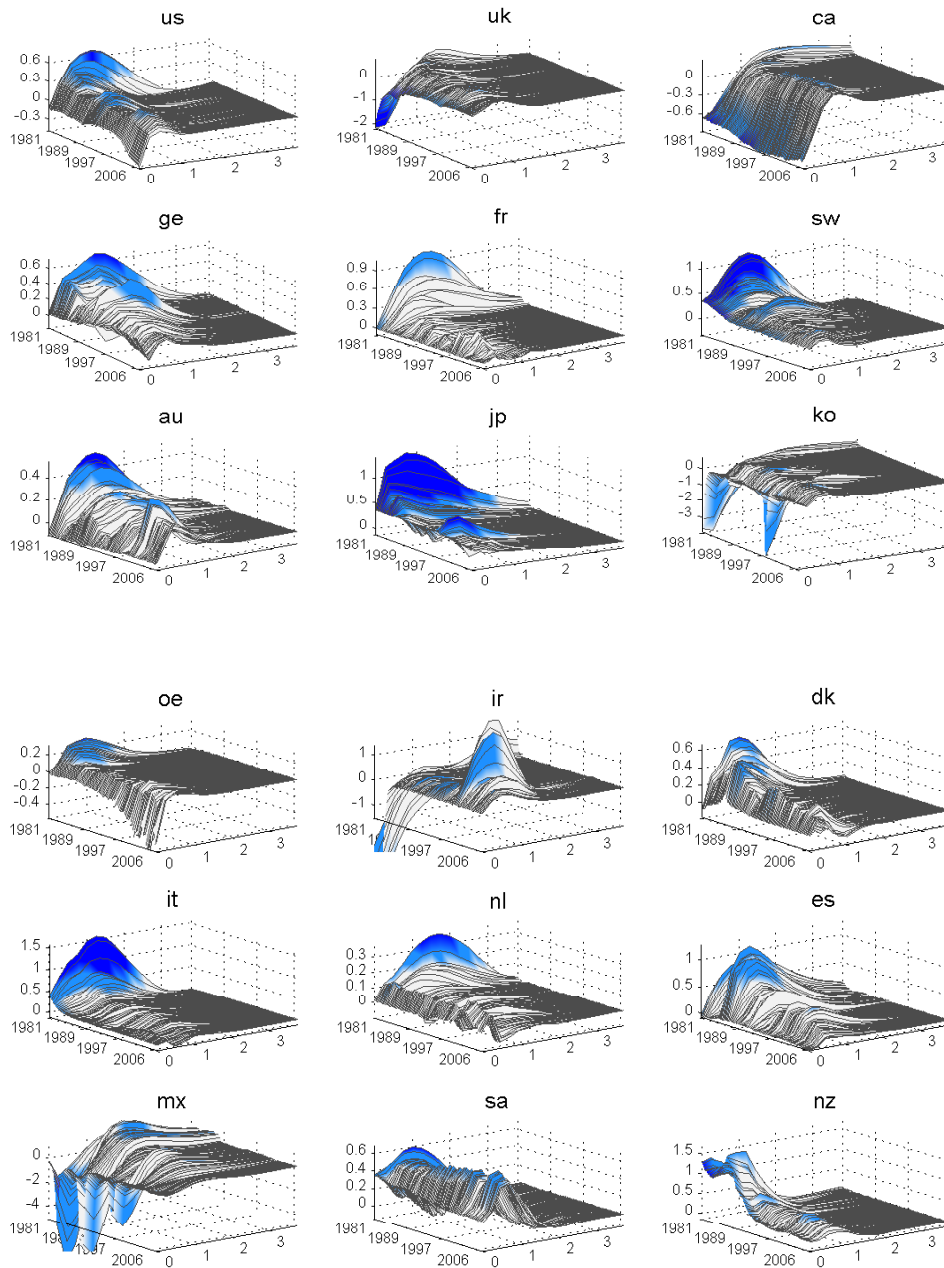


Figure 9: The response of inflation π to a unit shock to the foreign output gap y^f for each quarter in the sample 1980:3 to 2006:4. The baseline identification ordering ($y^d y^d \pi \tau i$) is adopted. The light blue shades indicate significance at the 14th/86th percentiles of the posterior distribution of the response. Darker blue shades indicate significance at the 5th/95th percentiles. Years from the shock on the x-axis.

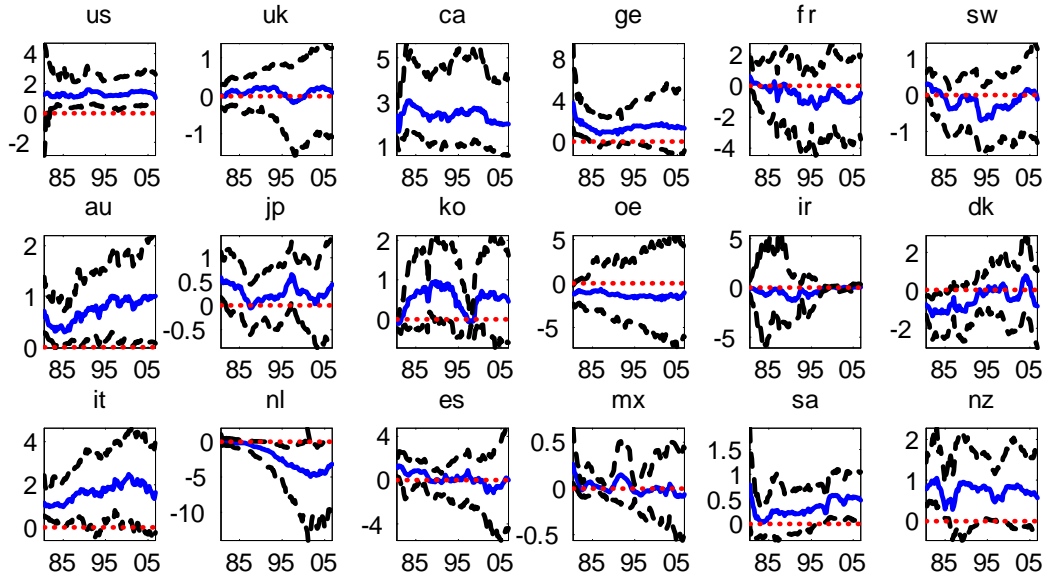


Figure 10: Long run responses of π to a permanent shock to y^d . Time evolution of the long run response of inflation to a permanent shift in the domestic output gap for each quarter in the sample 1980:3 to 2006:4. Baseline identification ordering $(y^f y^d \pi \tau i)$. The blue line is the median of the posterior distribution; the black, dashed bands show the 14th/86th percentiles.

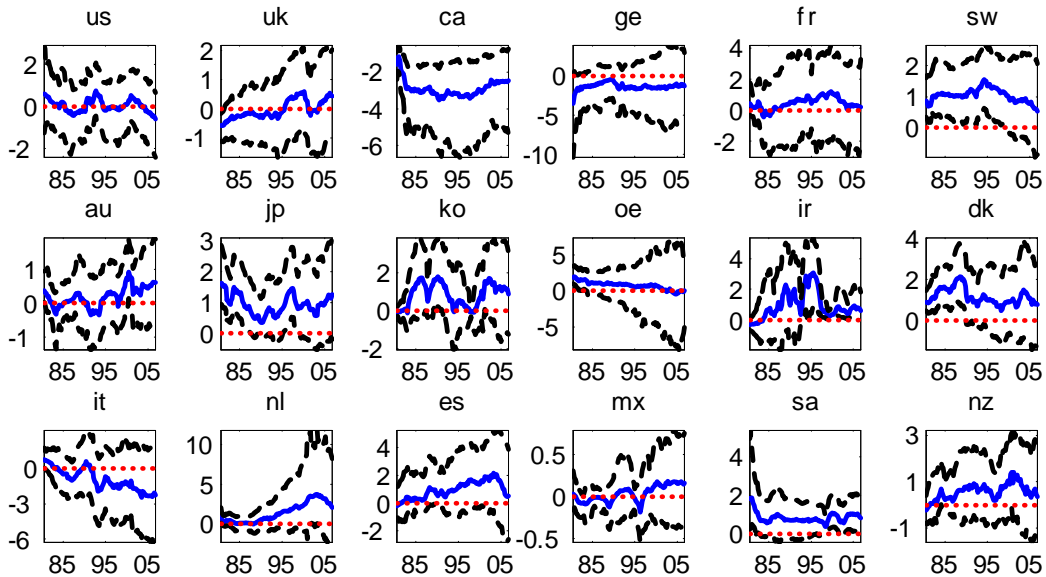


Figure 11: Long run responses of π to a permanent shock to y^f . Time evolution of the long run response of inflation to a permanent shift in the foreign output gap for each quarter in the sample 1980:3 to 2006:4. Baseline identification ordering $(y^f y^d \pi \tau i)$. The blue line is the median of the posterior distribution; the black, dashed bands show the 14th/86th percentiles.

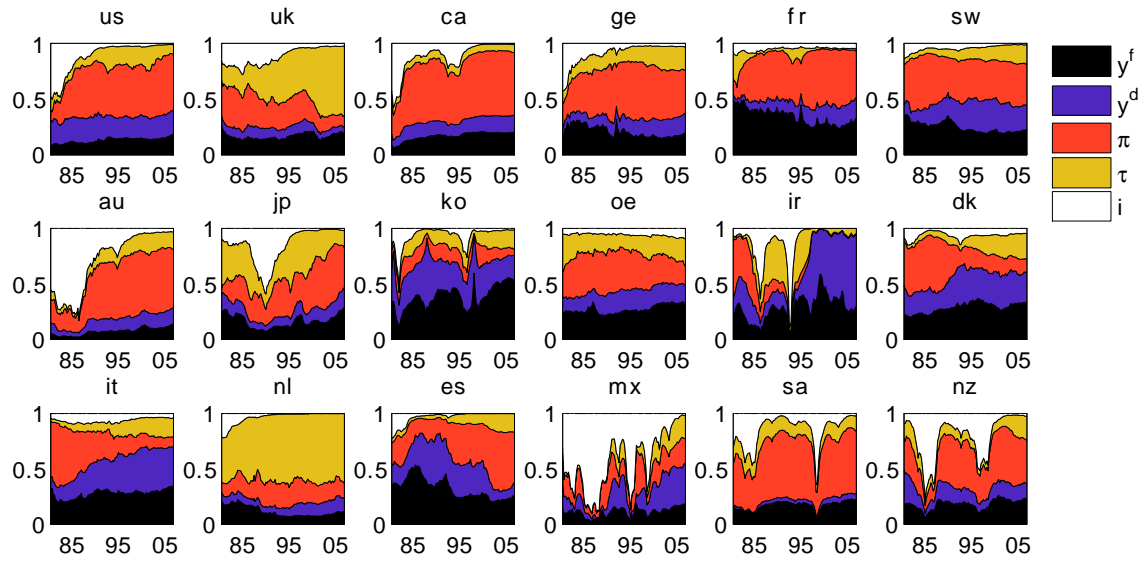


Figure 12: Variance decomposition of π . Time evolution of the variance decomposition of inflation for each quarter in the sample 1980:3 to 2006:4. Baseline identification ordering ($y^f y^d \pi \tau i$).

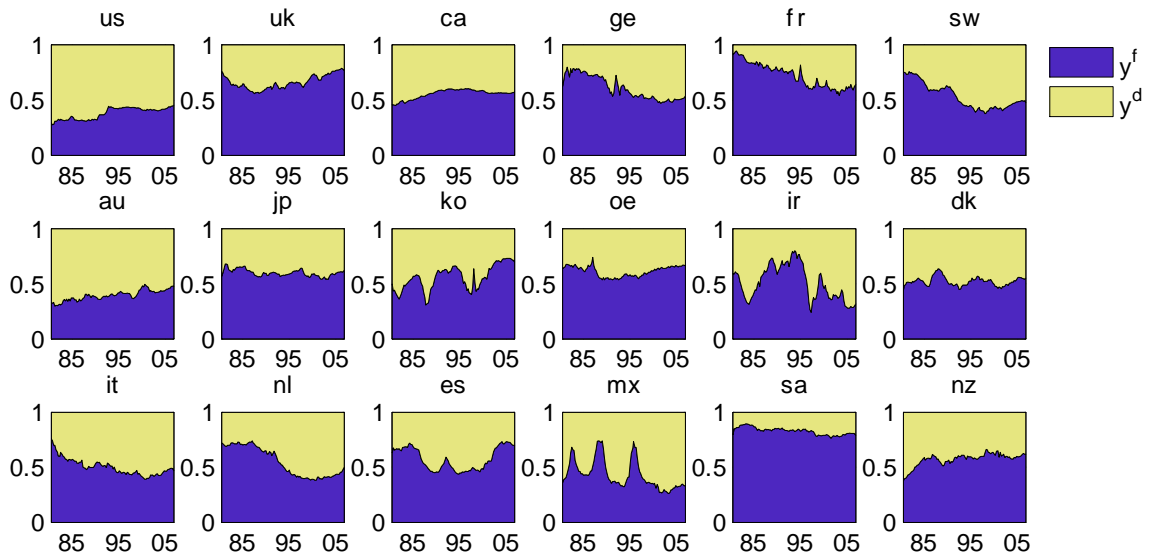


Figure 13: Relative contribution of y^d and y^f to the variance of π . Time evolution of the relative contribution of domestic and foreign output gaps, y^d and y^f respectively, to the variance decomposition of inflation, π , for each quarter in the sample 1980:3 to 2006:4. Baseline identification ordering ($y^f y^d \pi \tau i$).

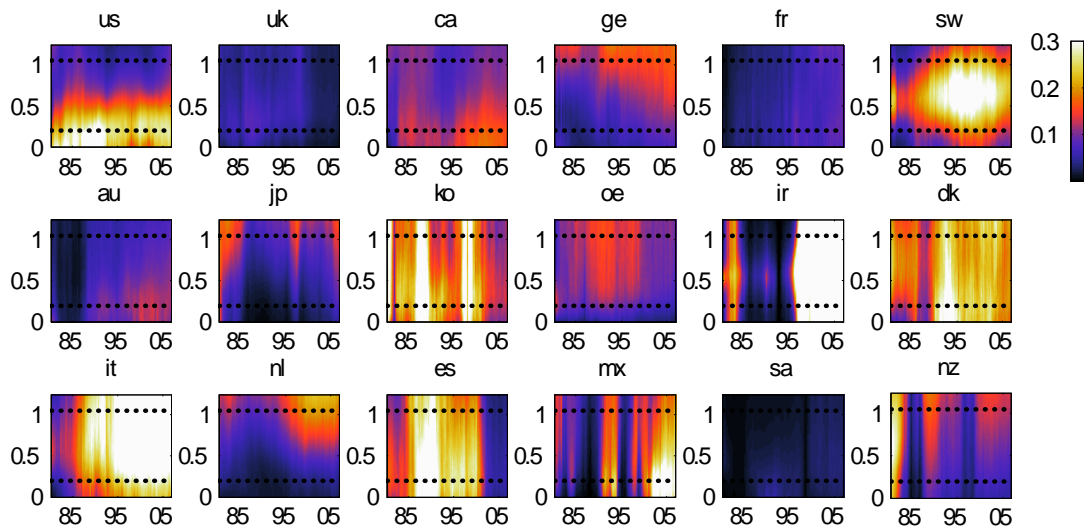


Figure 14: Contribution of y^d to the variance of π in the frequency domain. Time evolution of the contribution of domestic output gap to the variance of inflation in the frequency domain. Time is represented on the horizontal axis, while frequencies are on the vertical axis (truncated to 1.25). The two horizontal black dotted lines mark the range of business cycles frequencies. Baseline identification ordering $(y^f y^d \pi \tau i)$.

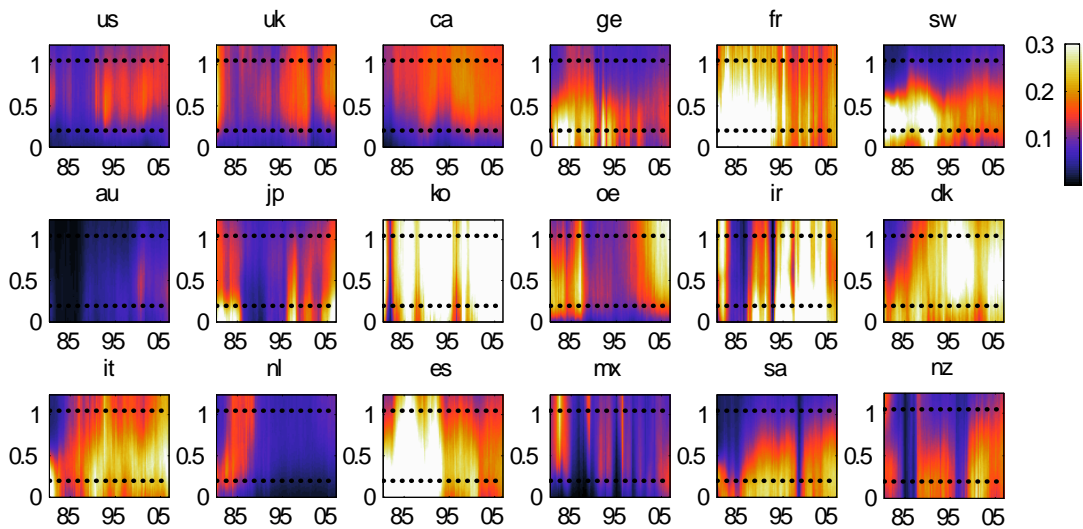


Figure 15: Contribution of y^f to the variance of π in the frequency domain. Time evolution of the contribution of foreign output gap to the variance of inflation in the frequency domain. Time is represented on the horizontal axis, while frequencies are on the vertical axis (truncated to 1.25). The two horizontal black dotted lines mark the range of business cycles frequencies. Baseline identification ordering $(y^f y^d \pi \tau i)$.