# Inflation and Globalisation: A Dynamic Factor Model with Stochastic Volatility

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**Abstract**

National inflation rates reflect domestic and international (regional and global) influences. The relative importance of these components remains a controversial empirical issue. We extend the literature on inflation co-movement by utilising a dynamic factor model with stochastic volatility to account for shifts in the variance of inflation and endogenously determined regional groupings. We find that most of inflation variability is explained by the country specific disturbance term. Nevertheless, the contribution of the global component in explaining industrialised countries' inflation rates has increased over time.

**JEL Classification Codes:** C32, E31, E52.
**Key words:** Inflation, Dynamic Factor Model, Stochastic Volatility, Globalisation.

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## 1. Introduction

Industrialised countries have experienced similar developments in inflation during the last fifty years. The relative calm of the 1960s was followed by a burst in volatility during the 1970s, to be succeeded by the 'great moderation' period of lower and less volatile inflation from around the mid-1980s onwards. Since the 1990s especially, inflation rates across the industrialised economies have been remarkably low and stable. At the same time, globalisation has been advancing with newly industrialised countries rapidly integrating and becoming important players in the global trading system. Alan Greenspan has repeatedly emphasised the role of China's opening to world trade for global disinflation and the threat posed by the gradual evaporation of the benign effects of globalisation. As he points out, "...If my suppositions about the nature of the current grip of disinflationary pressure are anywhere near accurate, then wages and prices are being suppressed by a massive shift of low-cost labour, which, by its nature, must come to an end" (Greenspan, 2008; p. 479).[1]

From the monetary authorities' viewpoint, if global influences are indeed significant, then questions are raised about the ability of national central banks to control inflation (Monacelli and Sala, 2009). Therefore, establishing the extent to which national inflation rates are affected by international forces is extremely important, not only in order to understand the developments of the last decades but also to gain some insight on the possibilities that lay ahead when the newly industrialised countries' wages and export prices may start to rise.

The majority of previous empirical studies on the relationship between inflation and globalisation have focused on the relevance of the domestic and foreign output gap for

[1] Bernanke (2006) explains that two effects underlie the link between trade integration and inflation: a direct effect working via import prices, and an indirect effect working via competition and the power of domestic firms to set prices. Related arguments about the impact of globalisation on national inflation rates are explored in Rogoff (2003). Beyond globalisation, the decline in inflation from the high levels of the 1970s has been attributed to policy-related factors (improved monetary and fiscal policy) and higher productivity (see e.g. Rogoff, 2003).

domestic inflation determination. According to the globalisation hypothesis, the importance of the former (latter) should decrease (increase) over time. Overall, the empirical evidence on these channels is rather mixed and questions have been raised on whether the changes in the structure of the Phillips curve are due to better monetary policy or globalisation (see e.g. Ball, 2006; IMF, 2006). Similarly mixed evidence has been offered by studies that examine the link between import prices and domestic inflation (see e.g. Pain et al., 2006; Kamin et al., 2006).

Recently, a number of studies have utilised factor modelling to investigate whether inflation has become more globalized over time as suggested by the observed co-movement of the national inflation rates. This co-movement is typically attributed to common macroeconomic shocks (e.g. oil shocks) and/or similar responses to these shocks by the monetary authorities.[2] Dynamic factor models, pioneered by Geweke (1977), have become a standard econometric tool to measure co-movement in macroeconomic time series by decomposing their variability into common and idiosyncratic components.[3] The results from factor models of inflation suggest that the relative importance of international influences for domestic inflation varies considerably across studies. Estimates of the portion of inflation variability that can be explained by the global common factor range from 1/3, or less, (Monacelli and Sala, 2009; Neely and Rapach, 2009) to more than 2/3 (Cicarelli and Mojon, forthcoming).

This paper contributes to the debate on whether inflation is a global phenomenon by modelling the co-movement of 22 OECD countries' inflation rates over the period 1961-2008 using the Dynamic Factor Model with Stochastic Volatility (DFM-SV) of Stock and Watson (2008). The model decomposes national inflation rates into a single common factor (henceforth the global factor), several regional factors, and idiosyncratic (country-specific)

[2] As Cicarelli and Mojon (forthcoming) point out, an element of 'peer pressure' among central bankers' exists, which may lead to similar responses to shocks and may also explain, to a certain extent, the spread of inflation targeting monetary policy regimes during the 1990s.

[3] For example, Kose, Otrok and Whiteman (2008) use factor models to examine the changes in world business cycles. Byrne, Fazio and Fiess (2009) use factor models to analyze saving and investment.

components. In contrast to previous studies that either disregard regional factors (see e.g. Ciccarelli and Mojon, forthcoming; Mumtaz and Surico, 2008) or exogenously fix regional membership,[4] following Stock and Watson (2008) we allow the data to determine regional composition using K-means clustering analysis. The DFM-SV model allows for stochastic volatility in the factors and the idiosyncratic disturbance terms. Given the significant shifts in the volatility of inflation over time, that is, the 1970s' boom, and 'great moderation' bust, it is essential to take into account this aspect of the behaviour of inflation. To do so, in addition to the DFM-SV estimates, we report restricted split sample estimates, where the variance of the disturbances was allowed to be different over two subsamples split around the commencement of the 'great moderation' (1961-1982 and 1983-2008), and unrestricted split sample estimates.

The rest of the paper is set out as follows. Section 2 reviews the related literature. Section 3 explains our data and provides some preliminary statistical analysis. Section four outlines the econometric methodology, while the empirical results are presented and discussed in Section 5. Section 6 concludes with a summary of our main findings.

## 2. A review of the issues and previous empirical evidence

There is a growing literature that investigates the impact of globalisation on inflation. Three aspects of the inflation-globalisation nexus are typically assessed in literature. First, there is the hypothesis that the role of foreign capacity utilisation, or foreign output gap, as a determinant of domestic inflation has increased over time in tandem with advances in globalisation. A Phillips curve framework augmented with 'global' variables is usually estimated to test this conjecture. The empirical evidence on the role of foreign output gap for domestic inflation is mixed. For example, Tootell (1998) finds that the foreign output gap does not affect U.S. inflation. More evidence against the

[4] Neely and Rapach (2009) allow for regional factors and consider seven geographic regions: North America, Latin America, Europe, Africa, Asia, the Middle East, and Australasia.

role of foreign output gap in determination of domestic inflation is provided by Hooper, Slok and Dobridge (2006) and Ball (2006) among others. On the other hand, Milani's (2009) results suggest that since 1985 the global output gap has become an important determinant of the domestic inflation (see also Gamber and Hung, 2001; Wynne and Kersting, 2007). Furthermore, Borio and Filardo (2007) present evidence in favour of the view that the foreign output gap is important for the determination of domestic inflation in 16 OECD countries.[5]

The second related conjecture on the relationship between inflation and globalisation is that the sensitivity of domestic inflation to the domestic output gap has decreased over time, implying a flatter Phillips curve. Evidence on flattening Phillips curves is abundant in industrialised economies.[6] However, there is a debate in the literature on whether this is due improved monetary policy frameworks or increased globalisation. Ball (2006) and Mishkin (2008) argue that low and stable inflation in U.S. since 1990s is result of improvements in monetary policy and well-anchored inflation expectations. Moreover, Temple (2002) and Wynne and Kersting (2007) find no significant impact from trade openness on the slope of Phillips curve.[7] Ball (2006) points out, that even with greater international competition, firm's marginal cost depends on the firms' own level of output rather than global ones. Therefore, globalisation has neither reduced the long run inflation nor has it affected the structure of inflation process.[8] On the other hand, a study by the IMF (2006) concludes the key factor behind the reduced sensitivity of domestic inflation to

[5] This is challenged by Ihrig et al. (2007) who show that Borio and Filardo's (2007) results are not robust to alternate measures of foreign output gap. Borio and Filardo (2007) use five proxies for the global output gap with the weights given by exports plus imports, imports, exchange rate, a mix of exchange rate and trade and global GDP. Ihrig et al. (2007) calculate the foreign output gap as a time varying weighted average of the output gaps of a fixed group of thirty five trading partners, with the weights given by annual bilateral imports from and exports to other countries along with measure of competition with third party markets.

[6] See for instance, IMF (2006), Roberts (2006) and Williams (2006).

[7] Trade openness is typically measured as the share of trade (exports plus imports) in total GDP.

[8] The effect of globalisation on the slope of Phillips curve is investigated from a theoretical perspective by Woodford (2007) using a two-country new Keynesian Phillips curve model. He shows that the slope of Phillips curve is not reduced by global integration and global slack has no role in the determination of supply-side inflationary pressures.

domestic output is trade openness. Similar findings are reported by Pain et al. (2006), Borio and Filardo (2007) and Dexter et al. (2005).

The third mechanism via which globalisation could affect inflation is imports from low cost countries. Pain et al. (2006) use an accounting framework to estimate the direct impact of import prices from non-OECD countries on OECD economies. They find that the contribution of import prices on consumer prices has become increasingly important since the mid 1990s. Gamber and Hung (2001) analyse U.S. data over the period 1987-1992 and find that domestic sectoral prices were sensitive to the prices of corresponding sectoral imports and that the sensitivity was greater in the sectors faced with greater import penetration. Nevertheless, Kamin et al. (2006), IMF (2006), Ihrig et al. (2007) and Guilloux and Kharroubi (2008) report a small impact of import prices on inflation.

Thus, overall, existing evidence on the inflation-globalisation nexus using the Phillips curve framework and analyses of import prices nexus is inconclusive. An alternative approach, which has only recently emerged, involves assessing the global dimension of inflation using factor modelling.[9] Factor models are used to study the co-movements of macroeconomic variables by decomposing the variable under investigation into common and idiosyncratic components. Ciccarelli and Mojon (forthcoming) compute the portion of national inflation's variance that is explained by four alternative measures of global inflation: a cross country average, the aggregate OECD inflation, and measures based on static and dynamic factor analysis. They focus their analysis on the first measure, and show that between 1960 and 2003 a simple average of 22 OECD countries inflation rates accounts for 70% of inflation variability in these countries. They also find that global inflation acts as an attractor for national inflation rates since deviations from the common factor are reversed. On the other hand, Monacelli and Sala (2009) estimate a dynamic factor model and find that, on average, only 15 to 30% of the variance of inflation can be

[9] See Forni et al. (2000) and Stock and Watson (2002) for early contributions to the literature on dynamic factor modelling.

explained by the international common factor, depending on whether inflation is calculated on a month-on-month as opposed to year-on-year basis. Monacelli and Sala (2009) use more recent disaggregated data for France, Germany, the United Kingdom and the United States and point out that given the high level of disaggregation in their dataset, their estimate should be best viewed as a lower bound for the contribution of international factors to inflation dynamics.[10]

Mumtaz and Surico (2008) examine the role of national and international factors in the evolution of inflation dynamics in 11 industrialised countries during the period 1961-2004 by applying a time-varying dynamic factor model with stochastic volatility, which they estimate using Bayesian techniques. They find that while the decline in the level and persistence of national inflation rates during the past two decades has coincided with a substantial increase in their degree of co-movement, the increased volatility of inflation during the seventies was generally an idiosyncratic phenomenon.[11] Neely and Rapach (2009) apply dynamic factor modelling with Bayesian techniques on a sample of 65 countries between 1951 and 2006 to decompose inflation rates to world, regional, and idiosyncratic components. They find that out of the three components of inflation, the idiosyncratic factor is dominant in explaining the variance of inflation. In particular, according to their results, world and regional factors explain on average 34% and 16%, respectively, of inflation variability with the remaining 50% being attributed to idiosyncratic variation. Furthermore, they show that while the importance of the world and regional factors differs substantially across countries, over time the factors' importance is

[10] Given the relatively late availability of highly disaggregated inflation datasets, Monacelli and Sala (2009) use a more recent sample. In particular, the common sample across the four countries in their study is 1991–2004. In an effort to explain the striking difference between their (disaggregate data) results and the (aggregate data) results of Ciccarelli and Mojon (forthcoming), Monacelli and Sala (2009) argue that aggregation matters in the estimation of the common factor's contribution to the total variance of a panel, with more aggregate data being likely to boost the role of commonalities.

[11] Furthermore, Mumtaz and Surico (2008) document a fall in the ability of shocks inherited from the past to explain current inflation variability. Cogley and Sargent (2006) point out that this finding is closely related to the decline in inflation persistence.

fairly stable.[12] To summarise, the empirical literature which attempts to identify co-movements in international inflation rates is still developing and a debate has arisen regarding the relative importance of the global factor.

## 3. Data and preliminary analysis

We collect quarterly data on the Consumer Price Index ($CPI_{it}$) from the OECD's Main Economic Indicators database for 22 OECD countries: Austria, Australia, Belgium, Canada, France, Finland, Germany, Greece, Italy, Japan, Korea, Luxembourg, New Zealand, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, South Africa, the United Kingdom, and the United States. The sample period under investigation is 1961Q1-2008Q4. We calculate the quarterly year-on-year[13] inflation rate for country *i* as:

$$\pi_{it} = 100 * \ln(CPI_{it} / CPI_{it-4}) \quad (1)$$

Figure 1 plots inflation rates for the G7 subset of our sample of countries. Two features are noteworthy. First, we observe three distinct phases in the behaviour of inflation: a relatively moderate phase during the 1960s, followed by a burst in average inflation and inflation volatility from the 1970s up until the early 1980s, and finally a period of relative calm from the mid-1980s onwards. Especially since the 1990s, inflation rates across the G7 economies are low and quite stable. The second striking feature in Figure 1 is that inflation rates appear to co-move to a great extent throughout the entire sample period indicating the presence of a common component. The cross country correlation coefficient of inflation rates is positive in all sample countries. It exhibits an

[12] More specifically, Neely and Rapach (2009) point out that the relative importance of the world, regional, and idiosyncratic factors is generally stable across the two subsamples that they employed (1951–1978 and 1979–2006). Nevertheless, they also find that the world factor becomes more important in a number of Asian countries during the second subsample, and attribute this finding to the adoption of outward-looking growth strategies by these countries.

[13] As Ciccarelli and Mojon (forthcoming) point out, this measure of inflation that they too employ, by construction, has no seasonal pattern. Annual inflation was also considered by Neely and Rapach (2009).

average value of 0.64, with standard deviation of 0.17, indicating a significant degree of inflation co-movement.

[FIGURE 1 HERE]

As Table 1 indicates the average inflation rate across the sample countries ranges from 2.9% in Germany to 9.4% in Portugal. In the second and third column of Table 1, standard deviations of inflation rates for the subsample periods 1961Q1-1982Q4 and 1983Q1-2008Q4 are reported. We split the sample around 1983, since by that time Volcker's U.S. disinflation was largely accomplished. Inflation has been largely brought under control in the other OECD economies too marking the beginning of the 'great moderation' period, which was characterised by lower inflation, interest rates and overall macroeconomic volatility.[14] Table 1 shows that inflation volatility is substantially lower during the latter part of the sample which is consistent with the idea of the 'great moderation'. The average standard deviation of inflation across our sample countries declines from 3.3% (1961-1982) to 0.7% (1983-2008).

[TABLE 1 HERE]

In order to gain insight on the persistence of OECD inflation rates we construct 95% confidence intervals for the largest autoregressive root by inverting the Augmented Dickey Fuller test statistic. We also compute the DF-GLS unit root tests statistic proposed by Elliot, Rothenberg and Stock (1996) as well as the Ng and Perron (2001) unit root test statistic. All the estimated 95% confidence intervals that reported in columns 2 and 3 of Table 2 contain a unit root. Moreover, the results from DF-GLS and Ng and Perron unit root tests do not overall support inflation stationarity since the null hypothesis of a unit root is rejected only in 5/22 and 4/22 cases, respectively. In our empirical approach, the

[14] The idea of a structural break in the inflation process around that period has received support in the literature. See for example Corvoisier and Mojon (2005) who identify a structural break around the mid-1980s in most of the OECD countries.

pervasive evidence of non-stationarity of inflation will be accounted for by allowing for non-stationary factors.[15]

[TABLE 2 HERE]

We complete our preliminary analysis by computing the spatial correlation of the change in inflation across our sample countries and over a rolling window, which allows for time variation in the degree of co-movement (see also Stock and Watson, 2008). We use a measure based on *Moran's I* statistic (Moran, 1950), applied to a centred 21-quarter rolling window. The *I* statistic modified for our application is calculated as:

$$Moran's\,\tilde{I}_t = \frac{N}{N(N-1)/2}\left(\frac{\sum_{i=1}^{N}\sum_{j=1}^{N}\mathrm{cov}(\Delta\pi_{it},\Delta\pi_{jt})}{\sum_{i=1}^{N}\mathrm{var}(\Delta\pi_{it})}\right) \qquad (2)$$

where $\mathrm{cov}(\Delta\pi_{it},\Delta\pi_{jt}) = \frac{1}{21}\sum_{s=t-10}^{t+10}(\Delta\pi_{is} - \overline{\Delta\pi_{it}})(\Delta\pi_{js} - \overline{\Delta\pi_{jt}})$, $\mathrm{var}(\Delta\pi_{it}) = \frac{1}{21}\sum_{s=t-10}^{t+10}(\Delta\pi_{is} - \overline{\Delta\pi_{it}})^2$,

$\overline{\Delta\pi_{it}} = \frac{1}{21}\sum_{s=t-10}^{t+10}\Delta\pi_{is}$ and $N = 22$.

[FIGURE 2 HERE]

The modified *I* statistic is plotted for all countries in our sample in Figure 2. From the 1960s until the mid-1990s the degree of spatial correlation is relatively low and exhibits two local peaks around the early 1970s and late 1970s-to-early 1980s. These temporary increases in spatial correlation coincide with the oil prices shocks of 1973 and 1979 which led to increases in inflation rates across the OECD countries.[16] From the mid-to-late 1990s onwards, we notice a sharp increase in the degree of inflation co-movement. During this period the spatial correlation coefficient displays a strong upward trend, despite a

[15] We should point out that the debate on how persistent inflation is, in general, and whether it contains a unit root, in particular, is still active in the empirical literature. For example, Brunner and Hess (1993) do not reject the unit root hypothesis in a sample of OECD countries. O'Reilly and Whelan (2005) provide similar evidence for the Euro Area, Stock and Watson (2007) for the US, and Byrne et al. (2010) for UK aggregate data. However, more nuanced evidence on a unit root in inflation is provided by Ng and Perron (2001).

[16] These peaks in spatial correlation coincide with breaks in average inflation across OECD countries as documented by Corvoisier and Mojon (2005). Wang and Wen (2007) point out that that oil shocks are part of but not the whole story behind the international synchronization in inflation rates. They suggest that increased globalisation may have played an important role.

temporary setback early in the new millennium. It appears then that increases in the degree of inflation co-movement can take place during both periods of low overall inflation, such as the recent period, and periods of high inflation, such as the 1970s, with the evidence suggesting, however, that the former are much more pronounced.

## 4. Econometric methodology

### 4.1 Dynamic factor model with stochastic volatility

Here we outline Stock and Watson's (2008) dynamic factor methodology allowing for stochastic volatility (DFM-SV). The model is used to decompose our sample of national inflation rates into a global component, a regional component and an idiosyncratic component as follows:

$$\tilde{\pi}_{it} = \lambda_i F_t + \sum_{j=1}^{N_R} \gamma_{ij} R_{jt} + e_{it} \qquad (3)$$

where, $\tilde{\pi}_{it}$, $F_t$, $R_{jt}$ and $e_{it}$ denote the demeaned inflation rate, global factor, ($N_R$) regional factors and idiosyncratic disturbance, respectively. Global ($\lambda_i$) and regional ($\gamma_{ij}$) factor loadings vary across countries. Following Stock and Watson (2008), the global and the regional factors are allowed to follow random walk processes, while the idiosyncratic disturbance follows a first order autoregressive process (AR(1)):

$$F_t = F_{t-1} + \eta_t \qquad (4)$$

$$R_{jt} = R_{jt-1} + \upsilon_{jt} \qquad (5)$$

$$e_{it} = \rho_i e_{it-1} + \varepsilon_{it} \qquad (6)$$

The model's disturbance terms, denoted by $\eta_t$, $\upsilon_{jt}$ and $\varepsilon_{it}$, are independently distributed and exhibit stochastic volatility: $\eta_t = \sigma_{\eta,t}\zeta_{\eta,t}$, $\upsilon_{jt} = \sigma_{\upsilon_j,t}\zeta_{\upsilon_j,t}$, $\varepsilon_{it} = \sigma_{\varepsilon_i,t}\zeta_{\varepsilon_i,t}$, $\ln\sigma^2_{\eta,t} = \ln\sigma^2_{\eta,t-1} + \nu_{\eta,t}$, $\ln\sigma^2_{\upsilon_j,t} = \ln\sigma^2_{\upsilon_j,t-1} + \nu_{\upsilon_j,t}$, $\ln\sigma^2_{\varepsilon_i,t} = \ln\sigma^2_{\varepsilon_i,t-1} + \nu_{\varepsilon_i,t}$, $\zeta_t$ = $(\zeta_{\eta,t}, \zeta_{\upsilon_j,t}, \ldots.\zeta_{\upsilon_{N_R},t}, \zeta_{\varepsilon_i,t}, \ldots\ldots..\zeta_{\varepsilon_N,t})$' ~ i.i.d. N(0, $I_{1+NR+N}$),

$\nu_t = (\nu_{\eta,t}, \nu_{\upsilon_j,t}, \ldots\ldots \nu_{\upsilon_{N_R},t}, \nu_{\varepsilon_1,t} \ldots\ldots\ldots \nu_{\varepsilon_N,t})' \sim$ i.i.d. N(0, $\varphi I_{1+NR+N}$), $\zeta_t$ and $\nu_t$ are independently distributed, and $\varphi$ is a scalar parameter.

Factor identification is achieved by restrictions on the factor loadings. The global factor enters all equations, so $\lambda_i$ is unrestricted. The regional factors are restricted to load onto only those variables that belong in a region, so $\gamma_{ij}$ is nonzero if country $i$ belongs in region $j$ and zero otherwise.[17]

The parameters $\lambda_i$, $\gamma_{ij}$ and $\rho_i$ ($i$ =1,..,22) are estimated by Gaussian maximum likelihood in a model in which the volatility of the factor disturbances ($\sigma^2_\eta$, $\sigma^2_{\upsilon_j}$, $\sigma^2_{\varepsilon_i}$) is subject to a break midway through the sample (1982Q4). The likelihood is maximized using the EM algorithm (see Dempster, Laird and Rubin, 1977). The scale parameter $\varphi$ is set equal to 0.04. Smoothed estimates of the factors and variances conditioning on the values of fixed parameters ($\lambda_i$, $\gamma_{ij}$ and $\rho_i$), are computed using Gibbs sampling (see Stock and Watson, 2008). For this purpose, the factor loadings $\lambda_i$, $\gamma_{ij}$ and $\rho_i$ are fixed at the full-sample MLEs, and the filtered estimates of the factors and their time-varying variances are computed by Markov Chain Monte Carlo (MCMC).

## 4.2 Estimation of regions

Regional variations are independent of global variations in the DFM-SV model so once the global factor is removed, by estimating a single common factor model for inflation, regional co-movement would be observable. In our analysis regions are endogenously determined from the data. Particularly, to estimate the regions, we follow Stock and Watson (2008) and apply the *k*-means method of clustering. In general, the *k*-means method solves:

$$\min_{\{\mu_j, S_j\}} \sum_{j=1}^{k} \sum_{i \in S_j} (X_i - \mu_j)'(X_i - \mu_j) \qquad (7)$$

[17] We normalized the scale of the factor by setting $\lambda'\lambda/N$ = 1 and $\gamma_j'\gamma_j/N_{R,j}$ = 1; where $\lambda = (\lambda_1, \ldots, \lambda_N)'$, $\gamma_j = (\gamma_{1j}, \ldots, \gamma_{Nj})'$. $N_R$ is the number of countries in region $j$.

where, $\{X_i\}$, $i = 1,\ldots,N$, is a $T$-dimensional vector and $\mu_j$ is the mean of $X_i$ if $i$ is in cluster $j$. $S_j$ denotes the set of indexes contained in cluster $j$. That is, the $k$-means method is the least-squares solution to the problem of assigning entity $i$ with data vector $X_i$ to group $j$. Our approach can be perceived to be an extension of the approach of Neely and Rapach (2009), since we endogenously group countries based upon the common time series properties of the data.

## 5. Empirical results

### 5.1 Estimated regions

We undertook initial cluster analysis to identify regions by considering three regions, $k$=3, with 400,000 starting random values. The objective function, given by Eq. (7) was reduced approximately by 8% by moving from $k$=3 to $k$=4. Moving from $k$=4 to $k$=5, the objective function was further minimized. We chose $k$=5 as moving from five to six regions further improvements of the objective function were very small. The composition of the five regions and the behaviour of inflation over time in these regions are presented in Figure 3. As K-means clustering aims to group together the observations with the nearest means, it can be observed in Figure 3 that the inflation rates in each region are pretty much synchronized, with the exception of South Korea in region 1 and UK in region 4. In terms of regional membership, region 2 includes two high inflation southern European countries, while regions 3 and 4 generally include low inflation European counties. Regions 1 and 5, on the other hand, are far more diverse geographically.

[FIGURE 3 HERE]

### 5.2 Split sample estimates of dynamic factor model without stochastic volatility

In this subsection we report the estimation results from the dynamic factor model without stochastic volatility for the disturbance terms. We present two types of estimates. First, the restricted split sample estimates, where the factor loading coefficients and the idiosyncratic term's autoregressive coefficient were restricted to be constant over the entire sample period, 1961-1983, but the disturbances variance was allowed to be different over the two subsamples, 1961-1982 and 1983-2008. Second, the unrestricted split sample estimates, produced by estimating the model over the two subsamples.

[TABLE 3 HERE]

Estimates for the restricted split-sample model are reported in Table 3. The factor loadings show the sensitivity of inflation process to global and regional factors. The loadings on the global factor ($\lambda$) are all positive ranging from 0.65 for Spain to 1.36 for Sweden. In addition to Sweden, the set of countries that are highly exposed to the global factor include Switzerland, Luxembourg, Portugal, Belgium, the US and the UK. Regional factor loadings ($\gamma$) are positive in all cases except for South Korea and Switzerland. The idiosyncratic disturbances exhibit considerable persistence, with a median autoregressive coefficient ($\rho$) of 0.92. The estimated standard deviations of the idiosyncratic disturbances over the two subsamples are reported in last two columns of Table 3. With the exception of Germany and New Zealand, the idiosyncratic component of inflation becomes significantly less volatile in the second sub-period. The average idiosyncratic standard deviation across all sample countries declines from 1.2 to 0.6.

[TABLE 4 HERE]

Table 4 reports the restricted split-sample estimates of the factor innovations' standard deviations. Global factor volatility and the volatility associated with regions 3 to 5 fall as we move from the first to the second subsample. The decline is mild in the case of the global factor and the third regional factor and strong in the case of regions 4 and 5.[18] Thus, with the exception of regions 1 and 2, all three types of inflation volatility (global, regional and idiosyncratic) decreased from 1983 onwards, a finding consistent with the 'great moderation' notion.

[18] It appears that the decline in the volatility of the fourth regional factor during the second subsample is mainly due to decline in the variance of UK inflation.

[TABLE 5 HERE]

Table 5 reports the portion of the variance of inflation that can be explained by the global factor, regional factor and the idiosyncratic term over the two subsamples. Each column contains two estimates of the partial $R^2$: the first entry is from the unrestricted split model while the second entry is obtained using the restricted split model. Overall, estimates from unrestricted and restricted split sample models are similar. To economise, further discussion will focus on the restricted split sample estimates. A number of important findings are present in Table 5. First, the relative importance of the global, regional and idiosyncratic components of inflation varies across the OECD economies. For instance, between 1983-2008, around half of the variance of inflation is explained by the global factor in US, Belgium and Switzerland, while the corresponding figure for South Africa and New Zealand is only 4%. During the same subsample, the portion of inflation variability due to the idiosyncratic component varies from 23% in Belgium to more than 90% in Greece, Australia and South Korea. Second, on average, the greatest portion of inflation variability can be attributed to idiosyncratic variation, followed by the global factor and then the regional factor. For example, between 1983-2008, on average 65% of inflation variability is due to idiosyncratic developments, 25% is due to global developments and only 10% is attributable to the regional factor. Third, the global factor becomes relatively more important over time at the expense of the idiosyncratic component, while the influence of the regional component remains fairly small and stable. Specifically, moving from the first to the second subsample, the portion of the variance of inflation that is attributable to the global factor increases by around 10% while the idiosyncratic component's contribution falls by around the same amount.

### 5.3 Estimates of dynamic factor model with stochastic volatility

In this subsection we report the estimation results from the dynamic factor model with stochastic volatility for the factor and idiosyncratic disturbance terms. The DFM-SV model will shed more light on the evolution of inflation dynamics over time. Figure 4 plots the growth rate of the estimated global factor from the DFM-SV model along with two other measures of global developments in inflation: the first principal component of the 22 OECD economies inflation rates, and the change in the cross-country average inflation rate.[19] It is evident from Figure 4 that all three proxies of global developments in inflation move together over time. The characteristics of the G7 countries inflation dynamics that were present in Figure 1 are also apparent here in a global scale. That is, a phase of relative calm during the 1960s, followed by a burst in volatility during the 1970s and the early 1980s, and finally another relative calm phase since the mid-to-late1980s.

[FIGURE 4 HERE]

Figure 5 shows the estimated instantaneous standard deviation of the global and regional factor innovations. The stochastic volatility of the global factor exhibits boom-bust behaviour, reaching a peak at mid 1970s and a trough at the mid 1990s, while recently it is again on the rise. Out of the regional factors, the first and the fifth are the most volatile, with the former's variability reaching a maximum at the late 1980s, around a decade after the latter's variability peaked. The remaining three regional factors are considerably less volatile. The variability of regional factors 3 and 4 generally declines over time, while that of factor 2 appears to mildly fall since the mid 1990s.

[FIGURE 5 HERE]

Figure 6 plots the instantaneous estimates of the standard deviation of innovations to the idiosyncratic disturbance and the partial $R^2$ attributable to the global factor, regional factors and the idiosyncratic disturbance. The volatility of the idiosyncratic innovations

[19] The first principal component measures the global factor in a single-factor model (Stock and Watson, 2002) under the assumption that the average population factor loading for the global factor is nonzero (Forni and Reichlin, 1998).

peak during the 1970s and then follows a downward trend. The partial $R^2$ DFM-SV results in Figure 5 are consistent with those from split sample analysis in Table 5. The importance of the global factor and the idiosyncratic component has fluctuated over time, while that of the regional factor has remained fairly stable. In line with the globalisation hypothesis, country-specific developments become less significant over time, while global developments are gaining importance. It should be pointed out that the aforementioned trends are not strictly monotonic over time and temporary setbacks do take place. For instance, we can see that, having reached a temporary high-point (low-point) during the late 1980s, the importance of global (country-specific) developments decreased (increased) until the mid-1990s and only then the positive (negative) trend resumed.

Overall however, the magnitude of the shift in the relative importance of national versus global influences is striking. Focusing on the median (50th percentile), between 1961-2008 the portion of the variability of national inflation that is explained by the global factor has increased from around 5% to 40%, while that due to idiosyncratic disturbances has decreased by around 40% from a high-point of more than 80% during the 1960s. If the trends that are present in Figure 6 are sustained, the global factor may soon replace idiosyncratic developments as the main driver of inflation volatility.

[FIGURE 6 HERE]

## 6. Conclusions

In this paper, we examine empirically the extent of inflation co-movement among 22 OECD countries over the period 1961-2008. We use dynamic factor modelling to decompose inflation rates into a common global factor, several endogenously determined regional factors and the idiosyncratic disturbances. As a first step to take into account shifts in inflation volatility over the sample period we using unrestricted and restricted split sample estimation. Furthermore, we utilise the stochastic volatility model of Stock and Watson (2008). Our main findings can be summarised as follows.

First, there is significant cross-country heterogeneity in the exposure of national inflation rates to global, regional and country-specific developments. This is consistent with the findings of previous studies (see e.g. Monacelli and Sala, 2009). Second, on average, the country-specific component dominates international (regional and global) influences as an explanatory factor for inflation variability. For example, between 1983-2008, with restricted split sample estimation, on average, 65% of inflation variation can be attributed to idiosyncratic developments, while 25% is due to global developments and only 10% is attributable to the regional factor. Thus, at a first glance, our results are not as positive for the role of a global factor as those reported by Cicarelli and Mojon (forthcoming). However, the story is rather different once we focus upon how the relative importance of the global and idiosyncratic components changes over time, which brings us to the third main finding of our study. More specifically, we find that the global factor becomes relatively more important over time at the expense of the idiosyncratic component, while regional component exerts a fairly weak but nonetheless stable effect. The DFM-SV estimation results suggest that if the strengthening of the role of the global factor and the corresponding weakening of that of country-specific developments persist it will not be long before the global factor takes over as the principal determinant of inflation volatility. Nevertheless, the considerable cross-country heterogeneity and the fact that short-term setbacks may hinder again the transition process towards more globalised inflation imply that the invitation by Ciccarelli and Mojon (forthcoming), *"central bankers of all countries: unite!"* may not yet be accepted.

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**Table 1: Summary Statistics for National Inflation**

| Country | Mean | Standard deviation | |
|---|---|---|---|
| | | 1961-1982 | 1983-2008 |
| Austria | 3.55 | 0.93 | 0.50 |
| Australia | 5.18 | 1.06 | 0.88 |
| Belgium | 3.83 | 0.83 | 0.56 |
| Canada | 4.16 | 0.69 | 0.68 |
| Switzerland | 2.97 | 0.79 | 0.52 |
| Germany | 2.90 | 0.51 | 0.47 |
| Spain | 7.39 | 1.64 | 0.64 |
| Finland | 5.21 | 1.29 | 0.49 |
| France | 4.68 | 0.77 | 0.40 |
| U.K. | 5.58 | 1.53 | 0.58 |
| Greece | 9.32 | 2.10 | 1.02 |
| Italy | 6.58 | 1.37 | 0.45 |
| Japan | 3.51 | 1.58 | 0.52 |
| South Korea | 8.66 | 4.03 | 0.98 |
| Luxembourg | 3.63 | 0.71 | 0.61 |
| Netherlands | 3.66 | 1.06 | 0.44 |
| Norway | 4.93 | 1.31 | 0.79 |
| New Zealand | 6.17 | 0.99 | 1.42 |
| Portugal | 9.36 | 3.31 | 1.16 |
| Sweden | 4.96 | 1.20 | 0.85 |
| South Africa | 8.46 | 1.41 | 1.31 |
| U.S. | 4.15 | 0.76 | 0.54 |

**Table 2: Unit Root Tests of National Inflation**

| Country | 95% confidence interval for largest AR root | | DF-GLS test statistic | Ng Perron MZa test statistic |
|---|---|---|---|---|
| | Lower | Upper | | |
| Austria | 0.93 | 1.02 | -1.75 | -6.01 |
| Australia | 0.92 | 1.02 | -2.04* | -7.74 |
| Belgium | 0.92 | 1.02 | -1.31 | -3.55 |
| Canada | 0.94 | 1.02 | -1.20 | -2.86 |
| Switzerland | 0.90 | 1.01 | -2.14* | -8.92* |
| Germany | 0.91 | 1.01 | -2.01* | -8.64* |
| Spain | 0.95 | 1.02 | -0.91 | -1.76 |
| Finland | 0.93 | 1.02 | -1.52 | -4.91 |
| France | 0.97 | 1.02 | -1.11 | -2.37 |
| U.K. | 0.94 | 1.02 | -1.46 | -4.45 |
| Greece | 0.95 | 1.02 | -1.22 | -3.08 |
| Italy | 0.97 | 1.02 | -0.89 | -1.64 |
| Japan | 0.92 | 1.02 | -2.04* | -8.20* |
| South Korea | 0.89 | 1.01 | -2.57** | -13.19* |
| Luxembourg | 0.92 | 1.02 | -1.49 | -4.77 |
| Netherlands | 0.94 | 1.02 | -0.93 | -1.82 |
| Norway | 0.93 | 1.02 | -1.17 | -2.58 |
| New Zealand | 0.95 | 1.02 | -1.17 | -2.85 |
| Portugal | 0.95 | 1.02 | -1.06 | -2.343 |
| Sweden | 0.93 | 1.02 | -1.41 | -4.17 |
| South Africa | 0.94 | 1.02 | -0.84 | -1.72 |
| U.S. | 0.89 | 1.10 | -1.62 | -6.22 |

Notes: The 95% confidence interval for the largest autoregressive root is computed by inverting the ADF$\mu$ *t* statistic, computed using 4 lags. The lag selection criterion used in the calculation of the Elliott-Rothenberg-Stock DF-GLS and Ng and Perron unit root test statistics is the Modified Akaike Information Criterion proposed by Ng and Perron (2001). **, * indicate rejection of the unit root null hypothesis at the 5%, 1% significance level, respectively.

**Table 3: Maximum Likelihood Estimates, Restricted Split Sample**

| Country | Region | $\lambda$ | $\gamma$ | $\rho$ | $\sigma_\varepsilon$(61-82) | $\sigma_\varepsilon$ (83-08) |
|---|---|---|---|---|---|---|
| U.S. | 1 | 1.32 | 0.24 | 0.95 | 0.61 | 0.37 |
| Canada | 1 | 1.03 | 0.88 | 0.90 | 0.61 | 0.45 |
| New Zealand | 1 | 0.88 | 1.75 | 0.89 | 0.91 | 1.20 |
| Norway | 1 | 0.74 | 1.26 | 0.78 | 1.21 | 0.57 |
| Sweden | 1 | 1.36 | 0.49 | 0.87 | 1.06 | 0.73 |
| South Africa | 1 | 0.86 | 1.12 | 0.94 | 1.32 | 1.20 |
| South Korea | 1 | 0.86 | -0.11 | 0.87 | 3.99 | 1.01 |
| Finland | 2 | 0.86 | 0.39 | 0.93 | 1.25 | 0.40 |
| Portugal | 2 | 1.20 | 1.67 | 0.93 | 3.21 | 0.85 |
| Greece | 2 | 0.88 | 0.27 | 0.97 | 2.04 | 1.02 |
| Belgium | 3 | 1.32 | 1.37 | 0.78 | 0.55 | 0.29 |
| Luxembourg | 3 | 1.20 | 1.40 | 0.85 | 0.45 | 0.38 |
| Netherlands | 3 | 0.78 | 0.27 | 0.92 | 1.00 | 0.37 |
| Switzerland | 3 | 1.18 | -0.31 | 0.92 | 0.66 | 0.38 |
| Germany | 4 | 0.88 | 0.58 | 0.92 | 0.31 | 0.37 |
| Austria | 4 | 0.90 | 0.53 | 0.75 | 0.78 | 0.41 |
| U.K. | 4 | 1.26 | 1.54 | 0.94 | 1.23 | 0.51 |
| Japan | 5 | 0.78 | 1.59 | 0.84 | 1.03 | 0.47 |
| Italy | 5 | 0.77 | 1.28 | 0.97 | 1.02 | 0.39 |
| Spain | 5 | 0.65 | 0.72 | 0.95 | 1.60 | 0.58 |
| France | 5 | 0.98 | 0.51 | 0.95 | 0.53 | 0.35 |
| Australia | 5 | 0.82 | 0.26 | 0.95 | 0.98 | 0.85 |

Notes: Estimates are restricted split-sample MLEs of the dynamic factor model with innovation variances ($\sigma_\varepsilon$) that are constant over each sample (i.e. 1961-1982 and 1983-2008) but differ between samples. $\lambda$ is the factor loading on global factor, $\gamma$ is factor loading on regional factor and $\rho$ is autoregressive coefficient of disturbance term. Region indicates the regional grouping of each country.

**Table 4: Restricted Split Estimates of Factor Shocks Volatility**

| | 1961-1982 | 1983-2008 |
|---|---|---|
| Global Factor | 0.34 | 0.30 |
| Region 1 | 0.18 | 0.35 |
| Region 2 | 0.01 | 0.46 |
| Region 3 | 0.26 | 0.21 |
| Region 4 | 0.41 | 0.02 |
| Region 5 | 0.66 | 0.01 |

Notes: This table reports the standard deviations of the factor shocks for global and regional factors.

## Table 5: Variance Decomposition of Inflation into Global, Regional and Idiosyncratic: Unrestricted/Restricted Split Sample Estimation

| | | 1961-1982 | | | 1983-2008 | | |
|---|---|---|---|---|---|---|---|
| | **Region** | $R^2$-*F* | $R^2$-*R* | $R^2$-*e* | $R^2$-*F* | $R^2$-*R* | $R^2$-*e* |
| South Africa | 1 | 0.27 0.05 | 0.01 0.02 | 0.72 0.93 | 0.01 0.04 | 0.19 0.10 | 0.80 0.86 |
| New Zealand | 1 | 0.19 0.10 | 0.06 0.11 | 0.75 0.79 | 0.01 0.04 | 0.22 0.22 | 0.77 0.74 |
| U.S. | 1 | 0.38 0.36 | 0.35 0.00 | 0.27 0.63 | 0.53 0.53 | 0.09 0.03 | 0.38 0.45 |
| South Korea | 1 | 0.05 0.01 | 0.15 0.00 | 0.80 0.99 | 0.03 0.07 | 0.00 0.00 | 0.96 0.93 |
| Norway | 1 | 0.06 0.05 | 0.00 0.04 | 0.94 0.91 | 0.05 0.09 | 0.44 0.40 | 0.51 0.50 |
| Sweden | 1 | 0.13 0.18 | 0.00 0.01 | 0.87 0.82 | 0.24 0.25 | 0.03 0.05 | 0.73 0.70 |
| Canada | 1 | 0.15 0.25 | 0.15 0.05 | 0.70 0.69 | 0.25 0.25 | 0.30 0.26 | 0.46 0.49 |
| Finland | 2 | 0.07 0.06 | 0.00 0.00 | 0.93 0.94 | 0.21 0.27 | 0.09 0.13 | 0.70 0.60 |
| Portugal | 2 | 0.09 0.02 | 0.00 0.00 | 0.91 0.98 | 0.10 0.09 | 0.30 0.43 | 0.61 0.48 |
| Greece | 2 | 0.22 0.02 | 0.00 0.00 | 0.78 0.98 | 0.01 0.06 | 0.01 0.01 | 0.98 0.92 |
| Belgium | 3 | 0.31 0.35 | 0.67 0.22 | 0.02 0.43 | 0.61 0.50 | 0.09 0.27 | 0.30 0.23 |
| Luxumbourgh | 3 | 0.23 0.35 | 0.12 0.28 | 0.65 0.36 | 0.62 0.38 | 0.08 0.26 | 0.30 0.36 |
| Netherlands | 3 | 0.06 0.07 | 0.21 0.00 | 0.72 0.92 | 0.26 0.29 | 0.06 0.02 | 0.68 0.69 |
| Switzerland | 3 | 0.24 0.29 | 0.01 0.01 | 0.75 0.70 | 0.61 0.47 | 0.35 0.02 | 0.04 0.51 |
| Germany | 4 | 0.30 0.38 | 0.36 0.25 | 0.34 0.37 | 0.46 0.36 | 0.00 0.00 | 0.54 0.64 |
| Austria | 4 | 0.15 0.15 | 0.18 0.08 | 0.67 0.77 | 0.27 0.36 | 0.00 0.00 | 0.73 0.64 |
| U.K. | 4 | 0.22 0.09 | 0.18 0.20 | 0.60 0.70 | 0.25 0.37 | 0.00 0.00 | 0.75 0.63 |
| Japan | 5 | 0.28 0.03 | 0.16 0.54 | 0.56 0.43 | 0.09 0.22 | 0.00 0.00 | 0.91 0.78 |
| Italy | 5 | 0.20 0.04 | 0.55 0.40 | 0.25 0.56 | 0.43 0.27 | 0.05 0.00 | 052 0.73 |
| Spain | 5 | 0.03 0.02 | 0.15 0.08 | 0.82 0.90 | 0.08 0.11 | 0.06 0.00 | 0.85 0.89 |
| France | 5 | 0.33 0.23 | 0.08 0.23 | 0.59 0.54 | 0.47 0.42 | 0.02 0.00 | 0.51 0.58 |
| Australia | 5 | 0.21 0.08 | 0.03 0.03 | 0.77 0.89 | 0.02 0.08 | 0.95 0.00 | 0.02 0.92 |
| | | | | | | | |
| Mean | | 0.19 0.14 | 0.16 0.12 | 0.66 0.74 | 0.26 0.25 | 0.15 0.10 | 0.59 0.65 |
| | | | | | | | |
| Percentiles | | | | | | | |
| 0.10 | | 0.06 0.02 | 0.00 0.00 | 0.27 0.43 | 0.01 0.06 | 0.00 0.00 | 0.30 0.45 |
| 0.25 | | 0.09 0.04 | 0.01 0.00 | 0.59 0.56 | 0.05 0.09 | 0.01 0.00 | 0.46 0.50 |
| 0.50 | | 0.20 0.08 | 0.12 0.04 | 0.72 0.77 | 0.24 0.25 | 0.06 0.02 | 0.61 0.64 |
| 0.75 | | 0.27 0.25 | 0.18 0.22 | 0.80 0.92 | 0.46 0.37 | 0.22 0.22 | 0.77 0.78 |
| 0.90 | | 0.31 0.35 | 0.36 0.28 | 0.91 0.98 | 0.61 0.47 | 0.35 0.27 | 0.91 0.92 |

Notes: This Table decomposes inflation into global, regional and idiosyncratic proportions. Each cell of results has two entries; the first entry in each cell is computed using the unrestricted split sample estimates of the dynamic factor model; the second entry is computed using restricted split sample estimates for which the factor loadings and idiosyncratic autoregressive coefficients are restricted to equal their full sample values. The first numeric column is the region of the country. The next block of the columns contains the fraction of the variance attributed to global factor F, the regional factor R, and the idiosyncratic disturbance e, during the period 1961 to 1982. The second block of columns contains the same statistics for 1983 to 2008.

**Figure 1: G7 Inflation Rates**

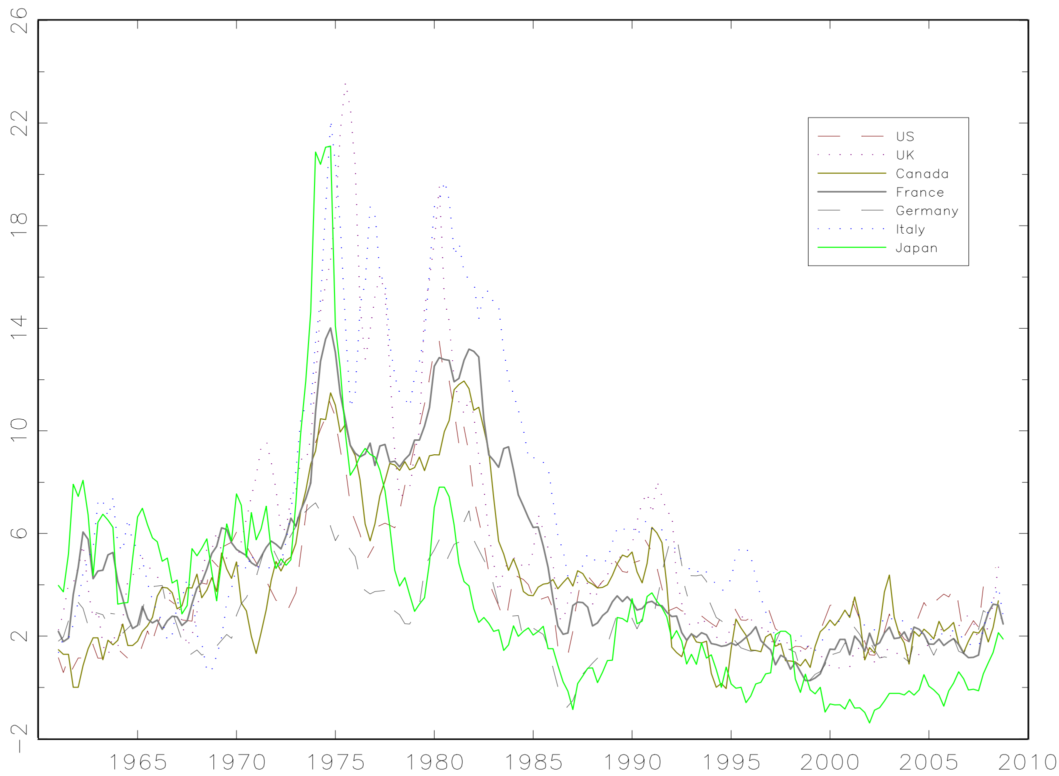
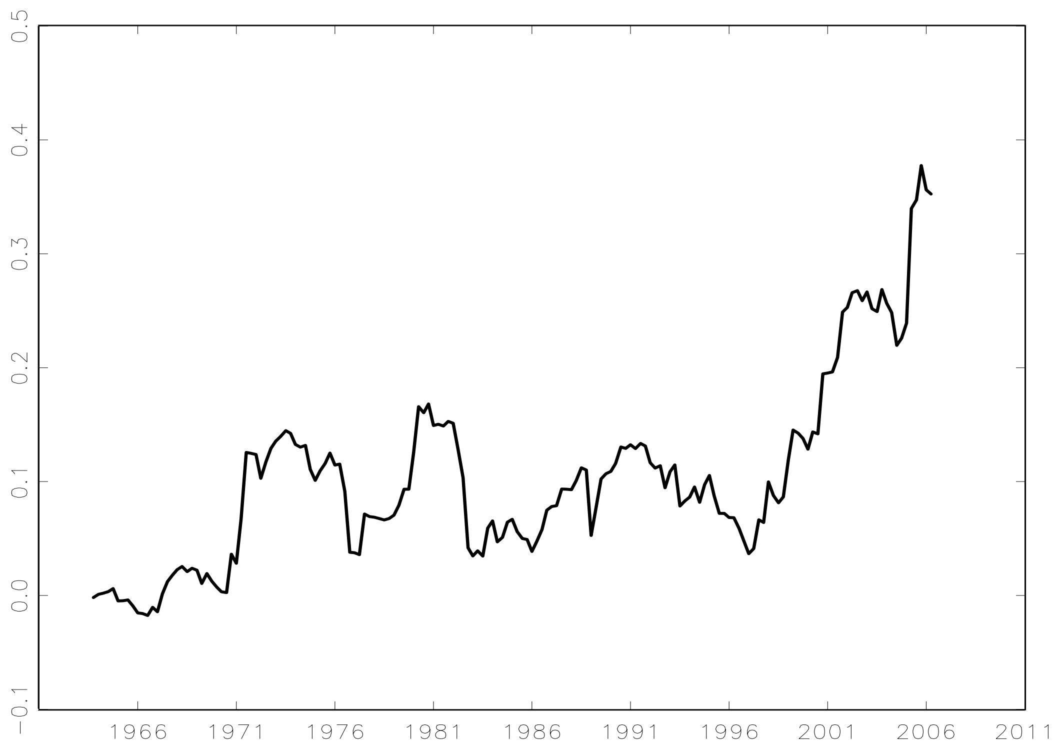



**Figure 2: Rolling Average Spatial Correlation**



# Figure 3: Regional Inflation Groups

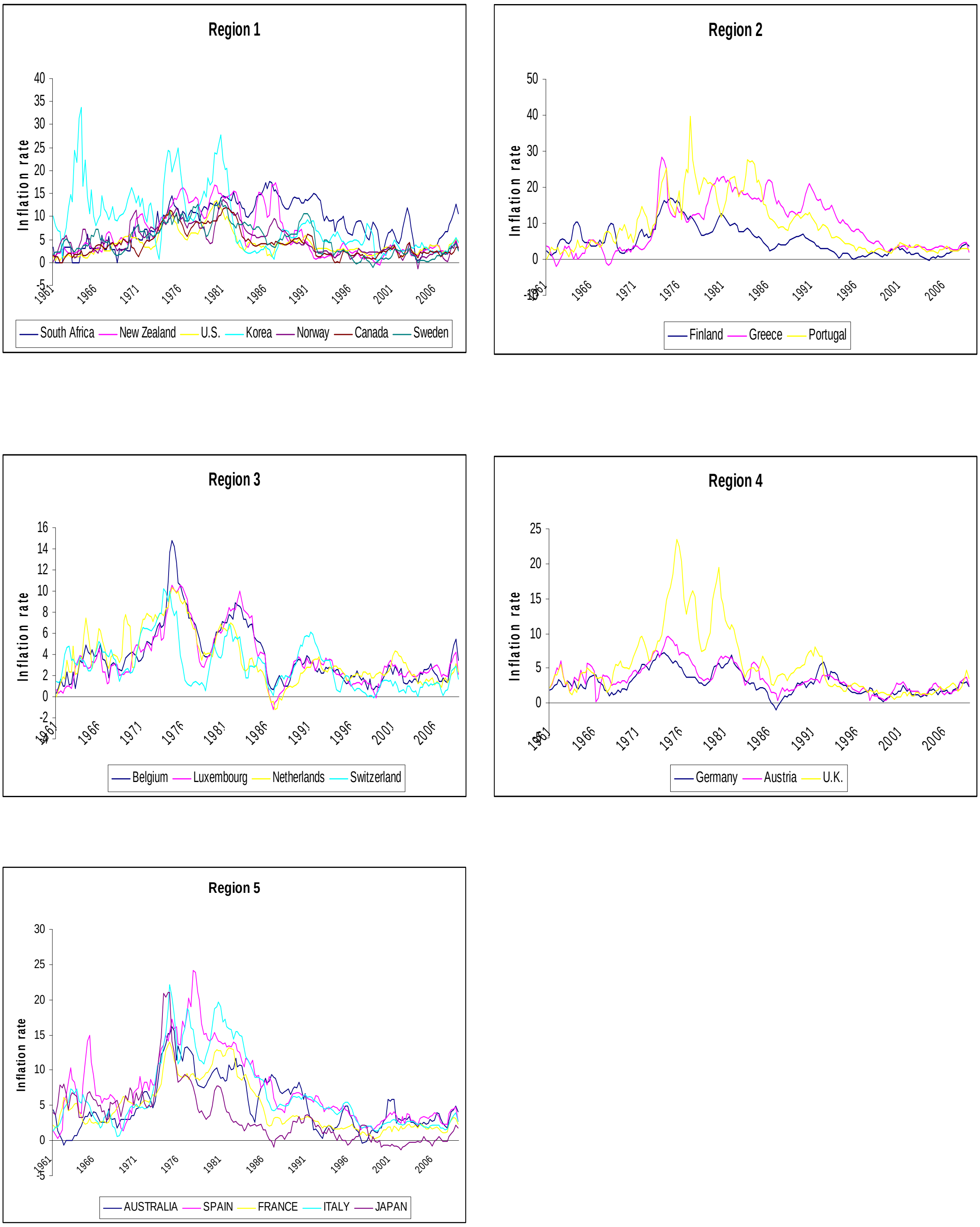
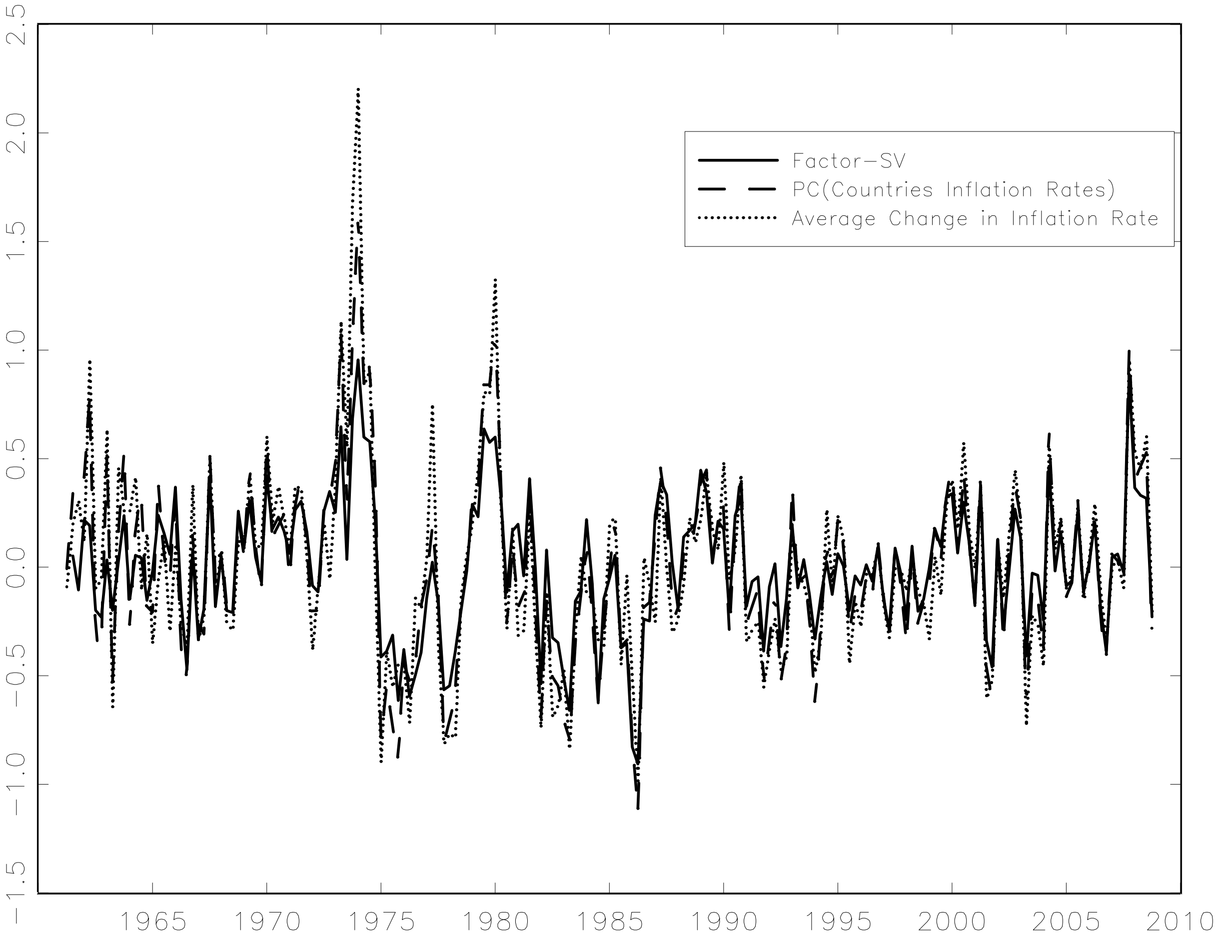
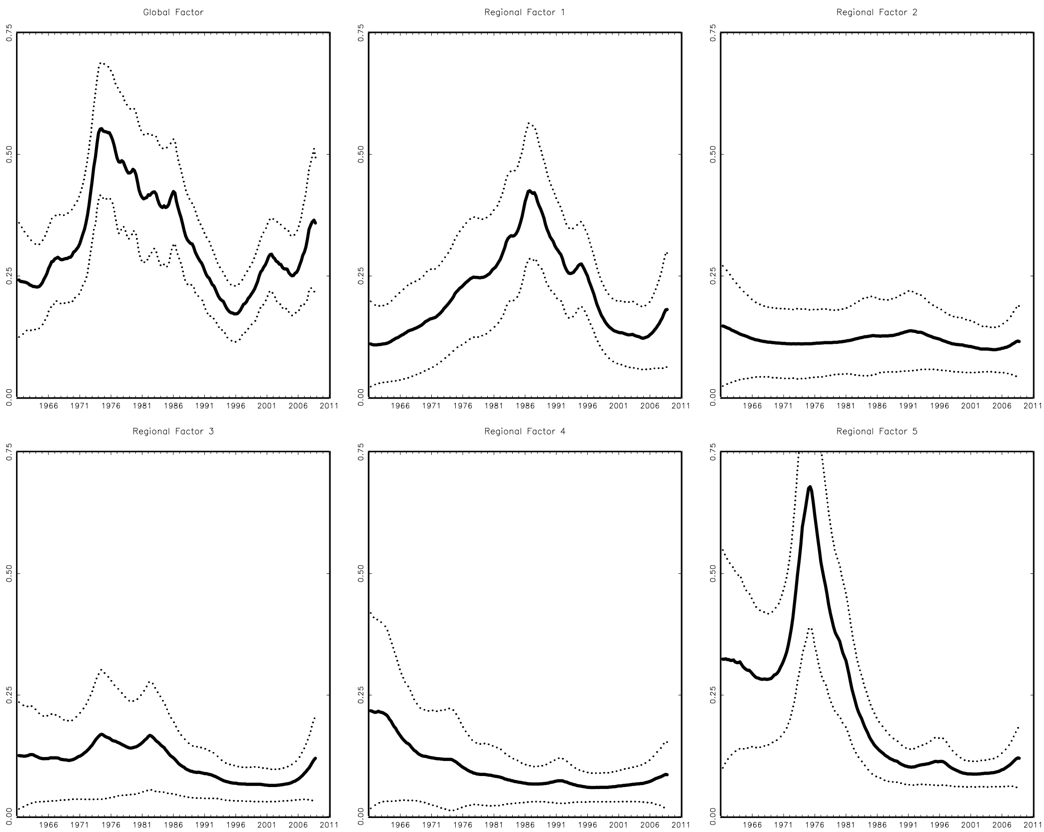


**Figure 4: Comparison of Global Factor-SV, First Principal Component and Average Change in Inflation Rate**



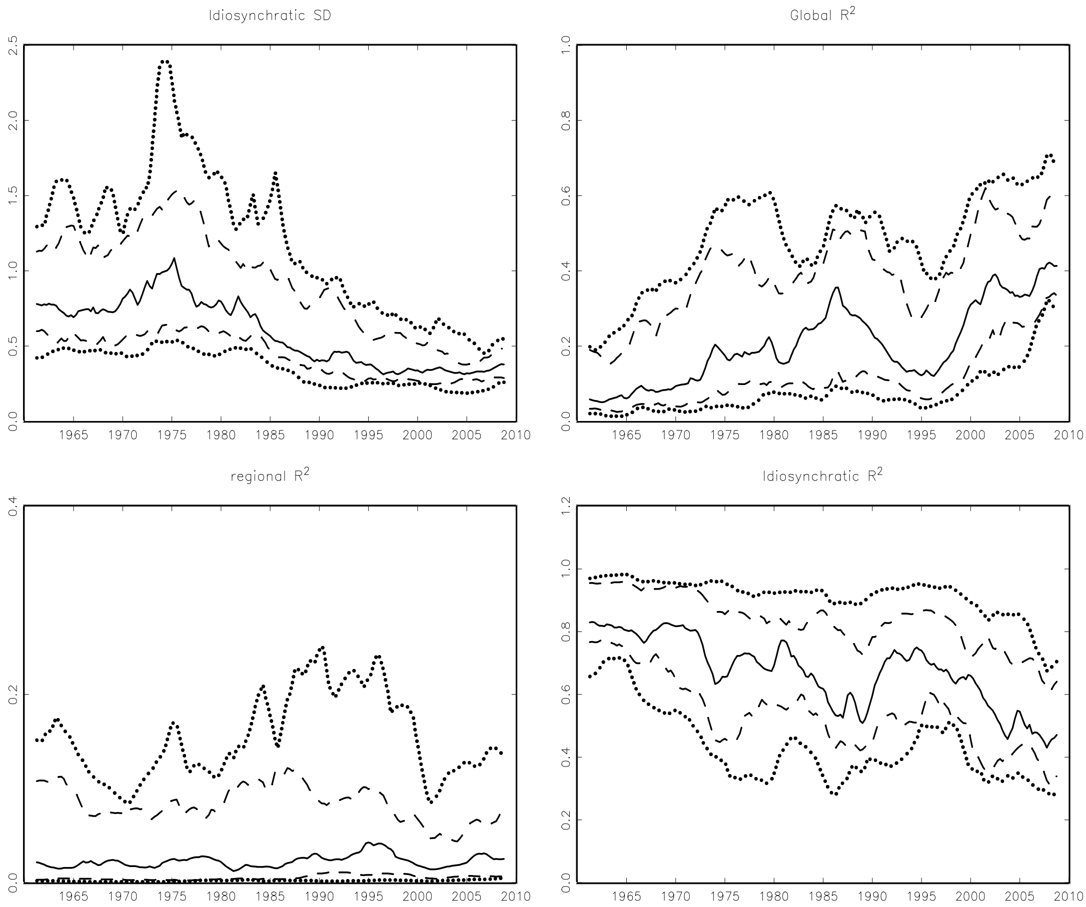

Notes: Comparison of DFM_SV filtered estimate of the global factor (solid line) to the first Principal component of the 22 countries inflation series, and average change in inflation rate (dotted-line).

**Figure 5: Standard Deviation of Factor Innovations**




Notes: FM-SV estimates of the instantaneous standard deviation of the innovations to the global and regional factors, with ± standard deviation bands (dotted lines).

**Figure 6: Standard Deviation of Idiosyncratic Innovations and Variance Decomposition**




Notes: DFM-SV estimates of the evolution of the country-level factor model: the standard deviation of idiosyncratic innovation and the partial $R^2$ from the global factor, the regional factor, and the idiosyncratic term. Shown are the 10%, 25%, 50%, 75% and 90% percentiles across countries, evaluated quarter by quarter.