RESERVE BANK OF NEW ZEALAND

DP2010/02

All together now: Do international factors explain relative price co-movements?

Özer Karagedikli, Haroon Mumtaz and Misa Tanaka

March 2010

JEL classification: E30, E52

www.rbnz.govt.nz/research/discusspapers/

Discussion Paper Series

ISSN 1177-7567

DP2010/02

All together now: Do international factors explain relative price co-movements?*

Özer Karagedikli, Haroon Mumtaz and Misa Tanaka †

Abstract

Recent research has found evidence of increasing co-movement in CPI inflation rates across industrialised countries. This paper considers whether this increased international co-movement in inflation rates can be attributed to greater global integration of product markets. To examine this question, we use a data set of 28 matched product category price indices for 14 advanced economies for 1998Q1 - 2008Q2, and decompose the inflation rates into a world factor, country-specific factors, and category-specific factors using a Bayesian dynamic factor model with Gibbs sampling. We find that the category-specific factors account for a large part of the co-movement in the prices of goods which are intensive in internationally traded primary commodities; but this is less evident for other traded goods. We also find that both the world factor and the category-specific factors become more significant in explaining the movement in the relative prices in the second half of our sample.

* The Reserve Bank of New Zealand's discussion paper series is externally refereed. The views expressed in this paper are those of the author(s) and do not necessarily reflect the views of the Reserve Bank of New Zealand. This paper is also published as a Bank of England Working Paper, No. 381. We thank Christopher Neely, Simon Price, seminar participants at the Reserve Bank of New Zealand and the Society for Computational Economics Conference for very helpful comments. We also thank Sebestian Walker for excellent research assistance.

† Özer Karagedikli (corresponding author), Reserve Bank of New Zealand, PO Box 600, Wellington, New Zealand. *Email address:* ozer.karagedikli@rbnz.govt.nz, Haroon Mumtaz, Bank of England. *Email address:* haroon.mumtaz@bankofengland.co.uk and Misa Tanaka, Bank of England. *Email address:* misa.tanaka@bankofengland.co.uk.
ISSN 1749-9135 (on-line)

1 Introduction

This paper examines the extent to which the increased co-movement in headline inflation rates across countries found in Ciccarelli and Mojon (2005), Mumtaz and Surico (2006) and Monacelli and Sala (2009) can be attributed to greater global integration of product markets. In a study of OECD countries, Ciccarelli and Mojon (2005) report that a common component or factor explains a large proportion of the variation in national inflation rates. Building on this study, Mumtaz and Surico (2006) have found that the common component explains a greater proportion of quarterly inflation movements in these countries after the mid-1980s relative to the period before that.

The main theme in the findings of all these papers is that (an) international common factor(s) explain some significant amount of variation in headline inflation rates across countries. This is an important finding as it argues that inflation has become more of an international phenomenon. In other words, the international factors (developments) are now affecting the national headline inflation rates in a more systematic way. What causes this 'internationalisation' of national inflation rates is a very important question. Two possible explanations for these finding are as follows. First, the increased co-movement in inflation rates could reflect adoption of similar monetary policy across the industrialised countries. Clarida, Gali and Gertler (1998) argue that the central banks of Japan, Germany and the US have pursued an implicit form of inflation targeting since the beginning of the 1980s; and during the 1990s, inflation targeting has been explicitly adopted in a number of industrialised countries. Second, it could reflect the increased integration of global product and factor markets, which subjects the relative prices of similar products in different countries to common demand and cost shocks. In this paper we test for the second explanation.

One explanation for the relative price co-movements comes from the imported inputs that are used in production of goods. A simple cost-pressure theory of relative prices would suggest that as long as it is not too difficult for new firms to enter a market, prices in a sector should ultimately be a function of the production cost in that sector and some profit margin. The costs fall if productivity increases are greater than wage growth, or if the price of imported inputs falls. So one would expect relatively smaller price increases in sectors that have relatively higher rates of technological progress, or in sectors that import larger proportion of inputs from other countries where prices are falling.

This has important implications: since most technical advances are easily copied, and cheap imports are readily obtained, the relative size of cost pressures should be similar in developed countries (see Coleman (2007)). Therefore, the relative price changes should exhibit some common patterns (or factors) in these countries. We argue if such co-movement is present, it may explain the observed co-movement in headline inflation rates shown in Mumtaz and Surico (2006) and other papers.

We argue that the international common component may not necessarily be the ones that affect every single sector/product in different economies. The international component may also be product/category specific. For example, the international factors affecting rice prices across countries may be different than the international factors affecting the car prices. Therefore, estimating international factors that are common for all categories may underestimate the true nature and the size of the international factors in explaining cross country co-movements in inflation rates. To answer this, we explicitly estimate a model that includes factors that are category/product specific. Our hypothesis is as follows. If it is indeed the adoption of similar monetary policy rather than global integration of product markets that is driving the international co-movement in inflation rates, then we should not find evidence for co-movement in product category inflation rates. For example, if both the US and the UK follow loose monetary policy, we should expect headline inflation to rise in both countries, but inflation rates of each product category– e.g. clothing or household equipment – need not rise in tandem. By contrast, if the international co-movement in inflation rates is mainly driven by integration of global markets, which subjects prices of similar products to global cost and demand shocks, we would expect to see cross-country co-movement in product category inflation rates; and this co-movement should be greater for internationally traded products and products intensive in internationally traded inputs. For instance, if clothes are freely traded across countries, demand or technology shocks that are specific to clothing industry should show up as co-movement in clothing inflation rates. If, on the other hand, clothing markets are not globally integrated, and clothing prices are subject to local demand and technology shocks, we would not necessarily observe co-movement in clothing inflation rates. In fact, we find that when we include the international product/category specific factors, these factors to dominate the "global factor."

To address this issue, we extend Mumtaz and Surico (2006) and Monacelli and Sala (2009) analyses to examine the cross-country co-movement of product category inflation rates which comprise the consumer price index (CPI) of 14 industrialised economies. Our data set consists of quarterly headline CPI and price indices of 28 product categories which are matched across all countries included in the sample, and spans the period of 1998Q1 to 2008Q2. Using a Bayesian dynamic factor analysis, we decompose fluctuations in quarterly inflation rates into a world factor, country-specific factors, and product/category-specific factors. The world factor captures the common pattern in inflation rates across all product categories across all countries. Country-specific factors capture the common pattern in inflation rates across all product categories within the same country. Finally, the category-specific factors capture the common pattern in inflation rates across countries for the same product categories (e.g. clothing). Our data is not as disaggregated as Monacelli and Sala (2009) at the product level. However, our data set has a few other advantages: first, we have a larger number of countries. Second, the product level data we have are balanced and refer to almost same things, which enable us to estimate the product/category level international factors.[1]

There are a number of interesting findings emerging from our analysis. First, product/category factors explain a significant proportion of fluctuations in quarterly inflation rates for products that are intensive in primary commodities; but this is less evident for other traded goods. Second, both the world factor and product category factors have become more significant in explaining the fluctuations in quarterly inflation rates for most product categories. Finally, the sharp pick-up in inflation rates during 2007-8 was captured by our estimated world factor. However, this factor does not show any variation apart from this 2007-2008 period.

The remainder of the paper is organised as follows. Section 2 describes

[1] Another strand of the literature attempts to tackle this issue by looking at the relationship between inflation rates in individual countries and some estimates of the global output gap; but evidence from this literature is mixed. For instance, Borio and Filardo (2007) argues that a global output gap measure helps explain the behaviour of inflation for a range of advanced countries. Ihrig et al. (2007), however, argues that Borio and Filardo's results are not robust to plausible alternative inflation equation specifications. Calza (2008) finds little evidence that global output gap measures have predictive power for consumer price inflation in the euro area. Thus, the evidence on the link between domestic inflation and global economic slack remains, at best, inconclusive, and there are a number of conceptual and empirical reasons why global influences on domestic costs and prices may not be captured by a measure of the global output gap. These findings, however, do not necessarily imply that increased trade integration has had no impact on domestic inflation dynamics. Thus, our paper seeks to shed light on the impact of globalisation on inflation dynamics using an alternative empirical strategy. A very similar research in terms of the methodological approach has emerged on the effects of globalisation on business cycle synchronisation. Kose, Otrok and Whiteman (2003), for example, decompose the fluctuations on key macro variables into a global, country specific and region specific factors. Cruccini, Kose and Otrok (2008) examined the G-7 business cycles in a similar fashion.

our data set. Section 3 explains the factor model approach used in our analysis. Section 4 presents the results. Section 5 discusses the implications and limitations of our analysis. Section 6 concludes.

2 Data

Our data set consists of the headline consumer price indices (CPI) for 14 advanced economies and the price indices for 28 product categories which comprise each country's CPI index. The 14 advanced economies included in our sample are the US, UK, Norway, Canada, and 10 euro area countries (Germany, Belgium, Spain, Finland, France, Greece, Ireland, Italy, Netherlands, and Austria). The data are quarterly averages of the monthly series that run from 1998Q1 to 2008Q2. The raw CPI headline and product category indices are seasonally adjusted (using Census X12), and transformed into quarterly log differences. They are then normalised to have zero mean and unit variance before the factor analysis.

In order to examine the extent to which global integration of product markets affect the co-movement of inflation rates, we created a data set of product category price indices that are matched across countries. This data set allows us to estimate the world factor, the country factors and the product category factors separately. In some countries, a certain product category is included in calculation of the headline CPI but not in others: such product categories were excluded from our sample. In other cases, a synthetic product category price index was created by using a weighted sum of several product category price indices from the raw data in order to create a match with other countries' data. Furthermore, some product categories were dropped from our sample because their prices are regulated in some countries and hence are changed only infrequently: examples of such product categories include water and electricity. Having gone through this procedure, we end up with the price indices of 28 matched product categories, which are listed in Table 1 in the Annex. Thus, our data set includes a total of 406 price series, consisting of 29 matched price series (headline CPI and 28 product categories) for the 14 countries.

By construction, each of the matched product categories should contain a *similar* set of goods and services in each country in our sample, such that they can reasonably be expected to be subject to similar product-specific demand and cost shocks if their product markets are globally integrated.

But clearly, the products included in each category would not be exactly the *same* across countries: for instance, 'fish' included in the UK CPI basket are different from 'fish' included in the US CPI basket. The total weights of these product categories account for about 45 percent of the headline consumer price index on average for countries included in our sample (Table 2 in the Annex).

3 Methodology

Consider a panel of international inflation series $\pi_{i,j,t}$ where the subscript i indexes the country, j indexes the product category, and t denotes the time dimension: so $\pi_{i,j,t}$ is the inflation rate of product category j in country i at time t. We assume that each inflation series $\pi_{i,j,t}$ can be described by the following dynamic factor model:

$$\pi_{i,j,t} = \beta_i^c F_{i,t}^c + \beta_j^g F_{j,t}^g + \beta_{i,j}^w F_t^w + \nu_{i,j,t} \tag{1}$$

where F^c denotes the country-specific factor which captures the common movement in inflation series of different products within the same country; F^g denotes the product category-specific factor which captures the common movement in inflation series of the same product across countries; and F^w denotes the common 'worldwide' movement across inflation series of all products in all countries. The country, product and world factor loadings are denoted by β^c, β^g, and β^w, respectively, while $\nu_{i,j,t}$ is the error term. Neely and Rapach (2008) and Mumtaz and Surico (2006) allow time-variation in factor loadings. We do not go down that route for two reasons as the time series dimension of our sample, which matters for time variation in factor loadings. In addition, this would have increased the computational burden immensely.[2]

The three unobserved factors F^c, F^g, and F^w are assumed to follow an autoregressive process of order P (4 in our case):

$$F_t^k = c^k + \sum_{l=1}^{P} \rho_t^k F_{t-l}^k + e_t^k \tag{2}$$

[2] Our full sample estimation takes just under six days in the fixed factor loading version that we present in this paper.

where $k = \{c, g, w\}$. Finally the error term $\nu_{i,j,t}$ follows an autoregressive process too, $AR(4)$.

$$\nu_{i,j,t} = \sum_{i=1}^{P} \rho_{i,j} \nu_{i,t-i} + e_{i,j,t} \tag{3}$$

The model described in equations (1) - (3) can be estimated by the Bayesian methods with Gibbs sampling. Gibbs sampling is a Markov chain Monte Carlo (MCMC) method for approximating joint and marginal distributions by sampling from conditional distributions. We describe the conditional prior and posterior distributions in detail in the appendix. However, in summary our algorithm contains the following steps:

1. Conditional on a draw for F^c, F^g and F^w, we simulate the AR coefficients and the variance of the shocks to equations 2 and 3.
2. Conditional on a draw of F^c, F^g and F^w, we draw the factor loadings β^c, β^g and β^w.
3. Simulate F^c, F^g and F^w conditional on all other parameters above.
4. Go to step 1.

We use 30000 Gibbs sampling replications and discard the first 26000 as burn-in. So the results are from the remaining 4000 iterations. The moments of model parameters vary little over the retained draws suggesting convergence.[3]

4 Results

This section presents the results from our analysis. First, the estimated world, country and product category factors are presented. Second, results from the variance decomposition are discussed to examine the extent to which the three factors explain the variance of the headline inflation rates and changes in product prices in the full sample, first sub-sample (1998Q1–2003Q1) and the second sub-sample (2003Q2–2008Q2). Finally, we consider the relative importance of the country, category and world factors in driving the *level* of price changes for different goods by constructing indicators.

[3] These results are available on request.

4.1 Description of factors

Figures 1, 2, and 3 in the Annex show the estimated world, country and product category factors for quarter-on-quarter inflation rates, respectively. The black lines show the median of the last 4000 replications from the Gibbs sampling. The red lines show the upper and lower quartiles of these replications. The world factor captures the common movement across price indices of all product categories (and the headline CPI) in all countries in the sample. The country factors capture the common movement across price indices of all product categories and the headline CPI within each country. The product category factors capture the common movement of the same product category prices across all countries in the sample.

Our methodology does not allow us to distinguish between the structural shocks driving these factors. However, economic theory suggests a number of possible interpretations of these factors. For instance, the world factor could be capturing global demand and supply shocks; and cross-country similarities in monetary policy. The country factors could be capturing country-specific demand and supply shocks; changes in taxes; idiosyncratic monetary policy shocks; and exchange rate movements. The product category factors could be capturing product-specific demand and supply shocks. Thus, a strong role played by the world factor in explaining price movements would be consistent with the hypothesis that similar monetary policy is behind the increased co-movement in inflation rates across countries. Conversely, strong product category factors would be consistent with the hypothesis that globalisation of product markets is driving greater co-movement in inflation rates.

Figure 1, which plots the world factor, shows very clearly that the pick-up in inflation during 2007–8 was indeed a global phenomenon affecting several countries and several product categories in our sample. However, figure 2 shows that in a number of countries in our sample – e.g. Belgium, Canada, Finland, France, Italy, the UK, and the US – country-specific factors were also pushing up inflation rates during this period. figure 3 show that certain food items – such as bread, dairy, oil & fats, and sugar – saw price increases in many countries in our sample: this is consistent with the fact that food and energy contributed strongly to the rise in inflation rates in advanced economies during 2007-8.

As figure 1 shows, the world factor is fairly precisely estimated. The precision with which country-factors are estimated varies from country to country (see figure 2). For instance, country factors of Belgium, Canada, Greece and Ireland are not as precisely estimated as in other countries. Although one would expect the country-specific factor to matter less in small, highly open economies compared to large, relatively closed economies, the significance of country-specific factors is not entirely explained by countries' openness to trade: for instance, the country-specific factor for Netherlands, which is small and highly open to trade, is quite precisely estimated. It is also worth noting that country-specific factors are significant in most euro area countries, suggesting that common monetary policy in the euro area interacts with heterogeneous country-specific conditions to give rise to inflation dynamics in each of the member countries.

Figure 3 shows that the precision with which product category factors are estimated differs from category to category. However, it displays some interesting patterns. Confirming our prior, the products which are intensive in globally-traded primary commodities – such as most food items (bread, meat, fish, dairy, oil & fats, fruit, vegetables, sugar, and coffee), vehicle fuels and jewelery – display strong product-specific factors. This suggests that developments in commodity markets – which are globally integrated – indeed play a significant role in causing common short-run movements in inflation rates across countries. However, some of the heavily traded manufactured goods – such as clothing, footwear, furniture, utensils, computer and vehicles – do not display strong product factors, although audio visuals has a strong product factor. As expected, less traded items such as accommodation and personal care do not display significant product factor, although the strong product factor found for laundry is rather puzzling.

4.2 Variance decomposition

This section summarises the results from the variance decomposition analysis. With orthogonal factors, the variance of $\pi_{i,j,t}$ can be written as:

$$var(\pi_{i,j,t}) = (\beta_i^c)^2 \, var\left(F_{i,t}^c\right) + \left(\beta_j^g\right)^2 var\left(F_{j,t}^g\right) + \left(\beta_{i,j}^w\right)^2 var\left(F_t^w\right) + var\left(\nu_{i,j,t}\right) \quad (4)$$

So we can decompose the variance of each inflation series $\pi_{i,j,t}$ into the proportion explained by each of the three factors. Specifically, we compute the fraction of total variance explained by the country, product category, and world factors as $\frac{(\beta_i^c)^2 var(F^c)}{var(\pi_{i,j,t})}$, $\frac{(\beta_j^g)^2 var(F^g)}{var(\pi_{i,j,t})}$, and $\frac{(\beta_{i,j}^w)^2 var(F^w)}{var(\pi_{i,j,t})}$, respectively. Using these formula, we calculate the median variances explained by each factors for each sub-category in each country (for 406 series). We do this for two sub-samples (1998Q1 – 2003Q1 and 2003Q2 – 2008Q2) and the full sample.

Table 3 in the Annex shows the cross-country average proportion of variances explained by each factor for each product category inflation. The columns 'first, second and full' refer to the first and second sub-samples, and the full sample respectively. For example, the first row of Table 3 shows the average proportion of variance in bread inflation explained by each factors in 14 countries in our sample. [4] There are a few important patterns to note. First, the product category factors (which can be regarded as category-specific international factors) are found to be very important (and the most important factor) in explaining the variations in most product category inflation rates across countries. Second, the world factor seems to explain very little of the variation in product-category inflation rates. These two findings suggest the importance of the category-specific factors at relative price level. Third, the country-specific factors are still important in most cases, though not as important as the product category factors. Finally, as one would have expected, the product-category factors explain a greater proportion of variances for those goods that are more traded than the others. Most of the food-related items (such as meat and dairy), audio-visual prices and vehicle fuel are examples of this.

Focusing on specific products, it is noteworthy that product category factors explain a very high proportion of the variances in inflation for products intensive in primary products – such as food, vehicle fuels and jewelery. Other highly-traded goods, such as audio visuals, also displays a strong product-category factor. Thus, there is some evidence that the relative prices of certain internationally traded goods – and goods that are intensive in internationally traded inputs – do co-move across countries. On the other hand, there are also a number of highly traded goods (e.g. clothing, footwear, and computer) for which the product category factor explains very little of the inflation variation.

Table 4 in the Annex shows the average proportion of inflation variances explained by each factor for each country in our sample. For example, columns two, three and four of the table show the average variance explained by the country factor in the first sub-sample, second sub-sample and the full sample, respectively. The first row of the table shows that the average variation in German sub-category inflation series explained by the country factor is 22 percent in the first sub-sample; but this falls to 13 percent in the second sub-sample and is 14 per ent in the full sample. As this table shows, the product category factors explain the largest share of variation in almost all countries. Moreover, the variation explained by this factor increases in the

[4] Results for individual country are available upon request.

second sub-sample in most countries. The country factors remain important for most countries, although they have declined noticeably in importance in the second sub-sample for some countries, e.g. Germany, Belgium, Canada and Norway. Finally, the world factor explains very little of the variation in inflation rates on average.

4.3 Indicators

In this section we consider the relative importance of the country, category and world factors in driving the *level* of inflation for different goods. We conduct this exercise by constructing the following indicators for each inflation series in our panel. These indicators are calculated as:

$$\begin{aligned}
\hat{Y}_{i,t}^{C} &= \hat{\Phi}_i F_t^C \\
\hat{Y}_{i,t}^{GC} &= \hat{\Phi}_i F_t^C + \hat{\Upsilon}_j F_{j,t}^G \\
\hat{Y}_{i,t}^{GCW} &= \hat{\Phi}_i F_t^C + \hat{\Upsilon}_j F_{j,t}^G + \hat{\lambda}_k F_t^W
\end{aligned}$$

where $\hat{\Phi}_i$ represents estimated factor loadings on the country factors F_t^C, $\hat{\Upsilon}_j$ are the estimated factor loadings on the category factors $F_{j,t}^G$ and $\hat{\lambda}_k$ are the estimated factor loadings on the world factor F_t^W. In the charts below the black lines represent actual data, $\hat{Y}_{i,t}^{C}$ is shown as the red lines. The light blue lines represent $\hat{Y}_{i,t}^{GC}$ while the dark blue lines depict $\hat{Y}_{i,t}^{GCW}$. A comparison of the data and $\hat{Y}_{i,t}^{C}$ provides information about the role played by the country factor in driving the *level* of inflation. A comparison of $\hat{Y}_{i,t}^{C}$ and $\hat{Y}_{i,t}^{GC}$ provides information on the importance of the category factor – a large gap between the red and the light blue lines would suggest that the category factor plays an important part in driving inflation fluctuations. Similarly, a comparison of $\hat{Y}_{i,t}^{GC}$ and $\hat{Y}_{i,t}^{GCW}$ provides information on the relative importance of the world factor – a large difference between the dark and the light blue lines would suggest that the world factor plays an important role in determining the level of inflation.

Charts 4, 5, 6 and 7 plot the estimated indicators for a selected set of food items–i.e. bread, dairy products, meat and sugar. Note that, in general, there is a sharp increase in inflation for these categories towards the end of the sample period and then a fall in the last quarter. Consider chart 4. The country factor plays a limited role with the red line flat for almost all countries. The increase in bread prices in 2001–2002 is largely explained by the bread-specific category factor with little difference between the light and the dark blue lines over this period. Both the category and the world factors appear to be important in explaining the sharp increase in bread prices towards the end of the sample, with the world factor particularly important in countries such as Germany, Canada, Finland and France. Prices for dairy products show a similar pattern with the increase in 2008 driven by the dairy category factor. The largest movement in meat prices occurred during the years 2000–2002 for a number of countries. The sharp increase over this period appears to be largely driven by the meat category factor. In contrast the increase in meat prices seen in 2008 in Finland, Ireland, Austria and the UK was driven to a large extent by the world factor. Sugar price inflation also rose in 2008 and chart 7 shows that this was driven primarily by the world factor. chart 8 plots the estimated indicators for vehicle fuel. For all countries recent fluctuations in vehicle fuel inflation have been driven almost entirely by the category-specific factor. In particular, the increase in fuel prices in 2007 and their subsequent fall is explained almost entirely by the fuel specific factor.

These results are consistent with the findings in Ciccarelli and Mojon (2005), Mumtaz and Surico (2006) and Monacelli and Sala (2009) which suggest an increasingly important role for co-movement in national inflation rates. Our estimates show that this pattern is also reflected at the disaggregated level with cross-country and good-specific co-movement important over the last decade.

5 Discussion

So what does our analysis say about the drivers of increased inflation co-movement found by previous research? First, there is some evidence supporting the 'correlated monetary policy' hypothesis. In particular, the world factor is fairly precisely estimated and suggests that the sharp rise in inflation during 2007–8 was a global phenomenon affecting a large number of price series included in our sample. We note, however, that the world factor may be overstating the cross-product, cross-country inflation co-movement, because of the way our data set is constructed. In particular, we have dropped product categories which account for more than half of the CPI weight from our sample in order to construct a matched data set. One consequence of this is the overrepresentation of food items in our sample. Since food prices tend to be strongly correlated across countries and across food product categories, this sample selection may have led to the overstatement of the role of the world factor.

Second, the evidence supporting the globalisation hypothesis appears to be mixed. On the one hand, product category factors account for a significant share of variations in price movements for commodity-intensive products, such as food and vehicle fuels; and the importance of product factors appear to have increased in the second sub-sample relative to the first. On the other hand, product category factors do not appear to account for a large share of variations in price movements for heavily-traded manufactured goods.

One interpretation of our results is that the only markets which appear to be globally integrated are the global commodity markets, and developments in these do exert strong influence on inflation dynamics in advanced economies. Outside these markets, global integration of product and factor markets – and hence product-specific demand and cost shocks – play a limited role in influencing inflation dynamics in advanced economies, despite the increase in international trade over the last decade. This could, for example, reflect the 'pricing to the market' behaviour of wholesalers and retailers who adjust their margins according to the local market conditions, at least in the short-run.

Equally, however, there are a number of reasons why the estimated product factors may not be fully capturing the impact of product- and factor-market integration on inflation dynamics. First, exchange rate movements could be reducing the estimated co-movement of product price indices across countries. For instance, it is possible that the product category factor becomes insignificant even if the product markets are perfectly integrated such that the law of one price holds across countries. This can happen if exchange rates are volatile relative to the product-specific demand and cost shocks. As mentioned previously, exchange rate movements are likely to be captured by country-specific factors. Second, the relative unimportance of product factors for heavily traded manufactured goods could simply reflect data limitations. As discussed in section 2, product categories are matched in order to ensure that they contain similar basket of goods and services. However, the differences in goods and services contained in each product category, and the weights assigned to each items within the basket, could be quite significant. If the items contained in each category are quite heterogeneous, then they may not be subject to similar product-specific shocks. Thus, the estimated product category factor may be insignificant even if product markets are actually integrated.

6 Conclusions

In this paper we estimated a dynamic factor model for a balanced panel of disaggregated inflation series for 28 different components of the CPI from 14 different countries. In particular, we estimated a world factor, country specific factors and product/category specific factors. Our results highlight the role of co-movement at category/product level, which is the main contribution of to the previous literature. Inflation series of the goods across countries are significantly driven by the good specific factor. This is further evidence to the role of international factors not only at the headline CPI level but also at goods level.

Our results provide evidence at disaggregated level for the increasing role of co-movement of national inflation rates, which was highlighted in Ciccarelli and Mojon (2005), Mumtaz and Surico (2006) and Monacelli and Sala (2009). Our results indicate that the co-movement across the headline CPI numbers in industrialised economies are probably a function of globalisation and integration at product/category level. To the extent this integration continues one should expect further co-movement in inflation rates.

References

Bernanke, B S, J Boivin, J, and P Eliasz (2005), "Measuring the effects of monetary policy: A factor augmented vector autoregression (FAVAR) approach", *Quarterly Journal of Economics,* Vol 120(1), 387-422.

Borio, C E V, and A Filardo (2007), "Globalisation and inflation: new cross-country evidence on the global determinants of domestic inflation", *BIS Working Paper*, No 227.

Calza, A (2008), "Globalisation, domestic inflation and global output gaps: Evidence from the euro area", *ECB Working Paper* No. 890.

Ciccarelli, M, and B Mojon (2005) "Global Inflation", *European Central Bank Working Paper*, No. 537.

Clarida, R, J Gali, and M Gertler (1998), "Monetary Policy Rules in Practice: Some International Evidence", *European Economic Review*, Vol. 42(6), 1033-1067.

Coleman, A (2007), "Tradables and non-tradables inflation in Australia and New Zealand", *Reserve Bank of New Zealand Bulletin*, Vol. 70, March, 45-52.

Cruccini, M, M A Kose, and C Otrok (2008), "What are the driving forces of international business cycles?", *National Bureau of Economic Research*, Working Paper 14380.

Ihrig, J, S Kamin, D Lindner, and J Marquez (2007), "Some Simple Tests of the Globalization and Inflation Hypothesis", Board of Governors of the Federal Reserve System, *International Finance Discussion Papers* 891.

Kim, C-J, and C Nelson (1998), State-Space Models with Regime-Switching: Classical and Gibbs-Sampling Approaches with Applications, MIT Press.

Kose, M A, C Otrok, and C H Whiteman (2003), "International business cycles: world, region, and country specific factors", *American Economic Review*, 93(4), 1216-1239.

Monacelli, T, and L Sala (2009), "The International Dimension of Inflation: Evidence from Disaggregated Price Data", *Journal of Money, Credit and Banking*, Vol. 41(1), 101-120.

Mumtaz, H, and P Surico (2006), "Evolving international inflation dynamics: evidence from a time-varying dynamic factor model", *Bank of England Working Paper* No. 341.

Neely, C J, and D E Rapach (2008), "Is inflation an international phenomenon?", *Federal Reserve Bank of St. Louis, Working Paper* No. 2008-025.

Appendix: Gibbs Sampling algorithm for a dynamic factor model

Consider the estimation of the following dynamic factor model

$$\pi_{i,j,t} = \beta_i^c F_{i,t}^c + \beta_j^g F_{j,t}^g + \beta_{i,j}^w F_t^w + \nu_{i,j,t} \tag{5}$$

$$F_t^k = c^k + \sum_{l=1}^{P} \rho_t^k F_{t-l}^k + e_t^k \tag{6}$$

where $k = \{c, g, w\}$.

$$\nu_{i,j,t} = \sum_{i=1}^{P} \rho_{i,j}\nu_{i,t-i} + e_{i,j,t} \tag{7}$$

where

$$\begin{aligned} var\left(e_t^k\right) &= Q_k \\ var(e_{i,j,t}) &= R \end{aligned}$$

Prior distributions and starting values

Factors and factor loadings

Following Bernanke, Boivin and Eliasz (2005), we center our prior on the factors (and obtain starting values) by using a Principal Component (PC). The covariance of the states ($P_{0/0}$) is set equal $I_{0.1}$ where I_n denotes a diagonal matrix with n on the main diagonal.

Starting values for the factor loadings are also obtained from the PC estimator. We assume a flat prior for the factor loadings.

AR coefficients

The prior for the AR coefficients is Normal and is defined as

$$\rho_0 \sim N(\bar{\rho}, \bar{V})$$

where $\bar{\rho}$ is a 4×1 vector of zeros and $\bar{V} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0.75 & 0 & 0 \\ 0 & 0 & 0.5 & 0 \\ 0 & 0 & 0 & 0.25 \end{pmatrix}$. This reflects a stronger belief that the coefficients on higher lags are equal to zero. The prior mean for the constant is zero while the prior variance is set equal to 1.

Hyperparameters

We assume a flat prior for Q and R.

Simulating the posterior distributions

Factors

The conditional distribution of the factors F_t is linear and Gaussian:

$$F_T \backslash X_{i,t}, R, Q \sim N\left(F_{T\backslash T}, P_{T\backslash T}\right)$$
$$F_t \backslash F_{t+1}, X_{i,t}, R, Q \sim N\left(F_{t\backslash t+1,F_{t+1}}, P_{t\backslash t+1,F_{t+1}}\right)$$

where $t = T-1, ..1$, X denotes the inflation data transformed to account for serial correlation in $\nu_{i,j,t}$.

$$\begin{aligned} F_{T\backslash T} &= E\left(F_T \backslash X_{i,t}, R_t, Q\right) \\ P_{T\backslash T} &= Cov\left(F_T \backslash X_{i,t}, R_t, Q\right) \\ F_{t\backslash t+1,F_{t+1}} &= E\left(F_t \backslash X_{i,t}, R_t, Q, F_{t+1}\right) \\ P_{t\backslash t+1,F_{t+1}} &= Cov\left(F_t \backslash X_{i,t}, R_t, Q, F_{t+1}\right) \end{aligned}$$

As shown by Carter and Kohn (2004), the simulation proceeds as follows. First we use the Kalman filter to draw $F_{T\backslash T}$ and $P_{T\backslash T}$ and then proceed backwards in time using:

$$F_{t|t+1} = F_{t|t} + P_{t|t}P^{-1}_{t+1|t}\left(F_{t+1} - F_t\right)$$

$$P_{t|t+1} = P_{t|t} - P_{t|t}P^{-1}_{t+1|t}P_{t|t}$$

Because of the AR form for $\nu_{i,j,t}$ the state space has to be 'augmented' such that the factors are transformed to account for serial correlation. For details see Kim and Nelson (2000).

Elements of R

Conditional on a draw for the factors and the factor loadings and the autoregressive coefficients, the diagonal elements R_{ii} are drawn from the following inverse gamma distribution:

$$R_{ii} \sim IG\left(\bar{R}_{ii}, T\right)$$

where

$$\bar{R}_{ii} = \hat{e}'_{i,j,t}\hat{e}_{i,j,t}$$

Elements of β

Conditional on the factors, the autoregressive coefficients The factor loadings are sampled from

$$\beta_i \sim N\left(\bar{\beta}_i, \bar{M}_i\right)$$

where $\bar{\beta}_i$ and $\bar{M}_i$ represents an OLS estimate of the factor loading and its variance.

$$\bar{\beta}_i = \left(F_t^{*\prime} F_t^*\right)^{-1} \left(F_t^{*\prime} X_{i,t}\right)$$

$$\bar{R}_{ii} \left(X_{i,t}' X_{i,t}\right)^{-1}$$

where F_t^* and $X_{i,t}$ represent factors and inflation data (respectively) transformed to account for serial correlation.

AR coefficients

Given an estimate for the factors, factor loadings, R and Q, the model reduces to a series of simple autoregressive regressions. The conditional posterior for these is normal and described in detail in Kim and Nelson (2000) chapter 7.

Elements of Q_k

Conditional on factors, and the autoregressive parameters, the innovations to equation 6 are observable and elements of Q are drawn from the Inverse Gamma distribution.

Identification

The factor model in equations 5, 6 and 7 suffers from rotational indeterminacy. That is, the sign and the scale of the factors and factor loadings is not identified separately. In order to identify the scale we fix the magnitude of Q_k. Following Kose, Otrok, Whiteman (2003) we restrict the signs of some factor loadings to identify the signs. For example, the world factor is restricted to load positively on the U.S. headline CPI. The goods factor is restricted to load positively on prices of the U.S goods. Finally, the country factor is restricted to load positively on headline CPI in each country.

Appendix: Tables and Charts

Table 1
Products/Categories

Bread
Meat
Fish
Dairy
Oil
Fruit
Vegetables
Sugar
Coffee
Juice
Alcohol
Clothing
Laundry
Footwear
Furniture
Utensils
Tools
Domestic non-durables
Vehicles
Vehicle spare parts
Vehicle fuel
Vehicle maintenance
Audio visuals
Computer
Books
Personal Care
Accommodation
Jewellery

Table 2
Total CPI weights by country (percent)

Country	Total CPI weight
UK	41.00
Belgium	48.54
Germany	40.24
Ireland	42.21
France	47.99
Italy	54.40
Netherlands	42.82
Spain	52.33
Austria	44.64
Finland	45.61
Greece	45.65
Norway	49.48
Canada	38.76
US	35.00

Table 3
Variance decomposition by product

	Country			Product			World		
	S1	S2	FS	S1	S2	FS	S1	S2	FS
Bread	19	20	19	11	37	35	1	4	4
Meat	11	13	12	46	42	40	1	2	2
Fish	16	14	14	4	9	9	1	1	1
Dairy	12	13	13	29	40	37	1	5	4
Oil	13	14	13	6	25	28	1	3	3
Fruit	10	7	7	19	21	20	1	2	2
Vegetables	5	4	4	40	34	33	1	1	1
Sugar	15	21	20	23	15	15	1	3	3
Coffee	16	14	13	32	43	43	1	1	1
Juice	19	23	23	8	14	14	1	3	3
Alcohol	8	18	18	7	5	5	1	3	2
Clothing	19	16	15	8	3	3	1	1	1
Laundry	10	10	10	13	10	9	1	1	1
Footwear	20	18	18	5	6	5	1	1	1
Furniture	20	15	15	5	6	6	1	1	1
Utensils	18	13	13	6	4	5	1	1	1
Tools	14	9	8	6	3	3	1	2	2
Domestic non-durables	11	16	15	12	12	11	1	2	2
Vehicles	14	6	6	5	5	5	1	3	3
Vehicle spareparts	11	10	10	11	18	17	2	2	2
Vehicle fuel	3	1	1	63	78	67	1	1	1
Vehicle maintanance	12	11	10	7	9	10	1	2	2
Audio visuals	10	4	4	17	41	33	1	2	2
Computer	9	3	3	6	8	8	1	1	1
Books	10	6	6	4	3	4	1	10	9
Personal Care	22	28	26	5	3	4	1	1	1
Accommodation	9	7	7	8	4	4	1	1	1
Jewellery	12	4	4	9	44	43	1	2	2
Headline	12	14	14	28	31	28	1	2	2

Table 4
Variance decomposition by country

	Country			Product			World		
	S1	S2	FS	S1	S2	FS	S1	S2	FS
Germany	22	13	14	21	27	26	1	3	3
Belgium	14	3	3	13	26	25	1	1	1
Canada	13	9	8	10	10	10	1	3	2
Spain	12	10	10	16	28	26	1	2	2
Finland	8	9	9	17	14	13	1	3	3
France	9	12	10	25	27	26	1	3	3
Greece	5	6	5	10	14	12	1	1	1
Ireland	10	17	17	12	17	16	1	2	1
Italy	13	17	18	13	19	18	1	1	1
Netherlands	23	26	24	15	25	24	1	3	2
Norway	29	23	21	11	11	10	1	4	4
Austria	9	7	6	21	25	25	1	2	2
UK	7	9	9	16	18	17	1	3	3
US	10	8	8	9	10	10	1	1	1

Figure 1
World factor

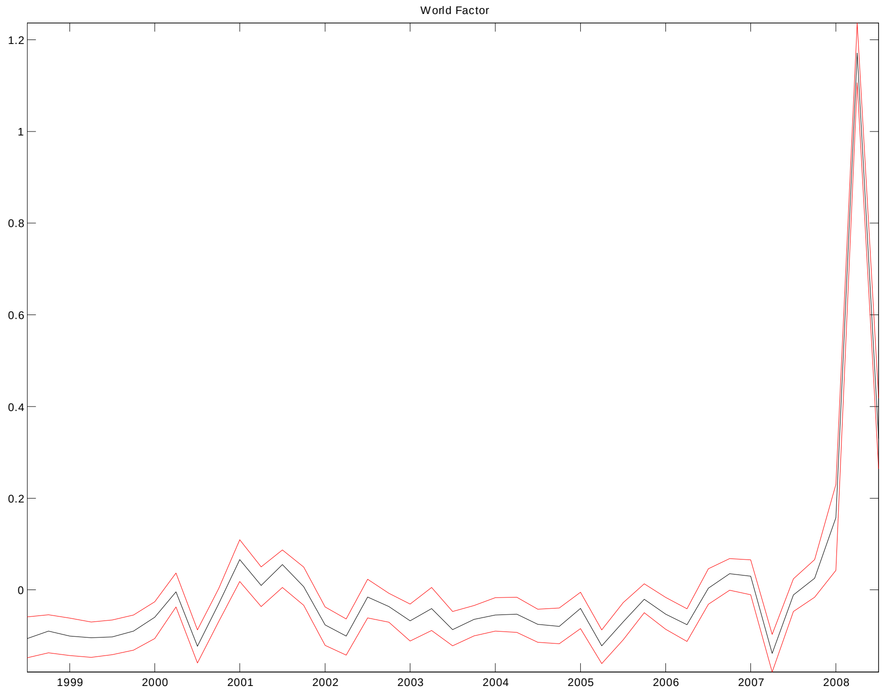

Figure 2
Country factors

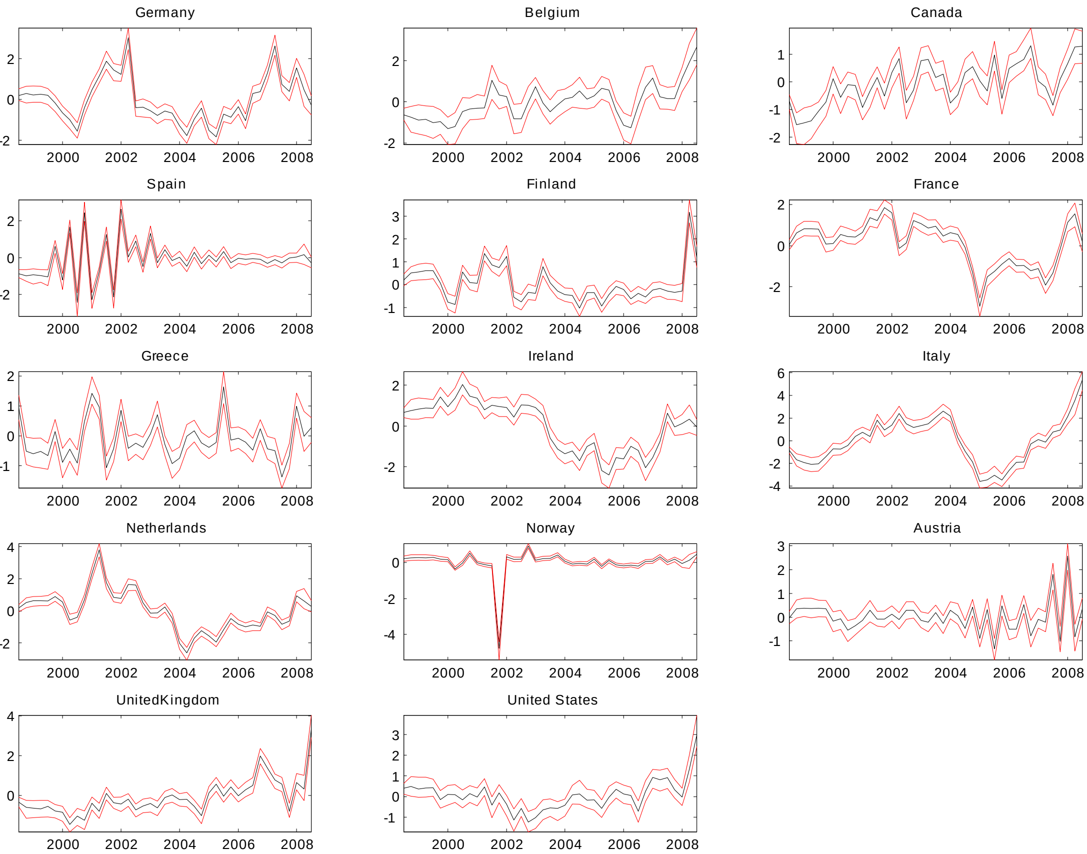

Figure 3
Product factors

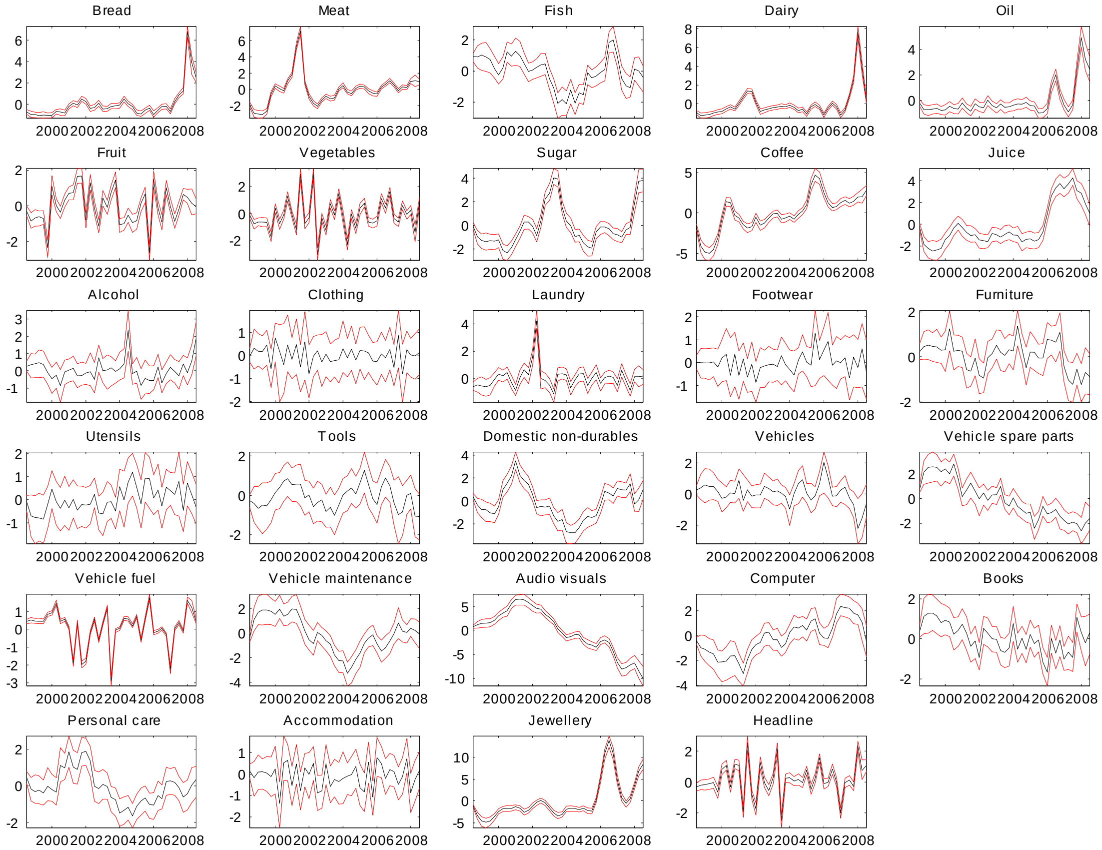

Figure 4
Indicators - Bread

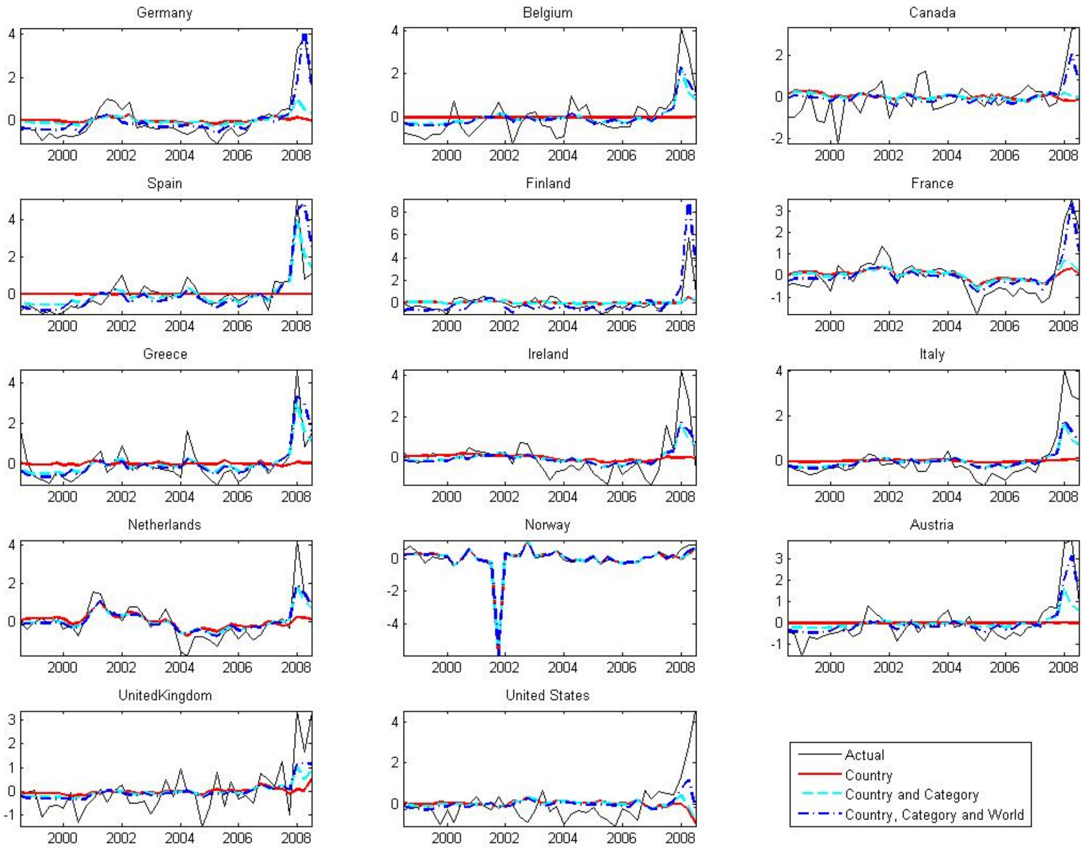

Figure 5
Indicators - Meat

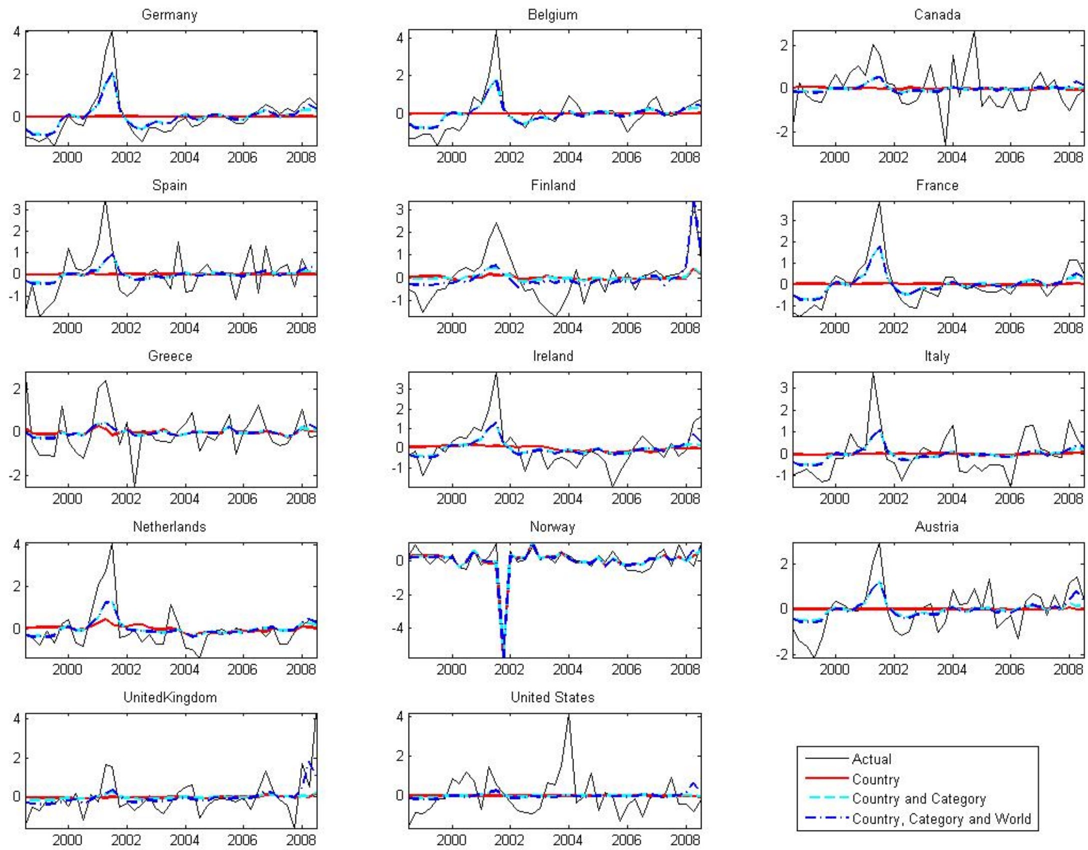

Figure 6
Indicators - Dairy

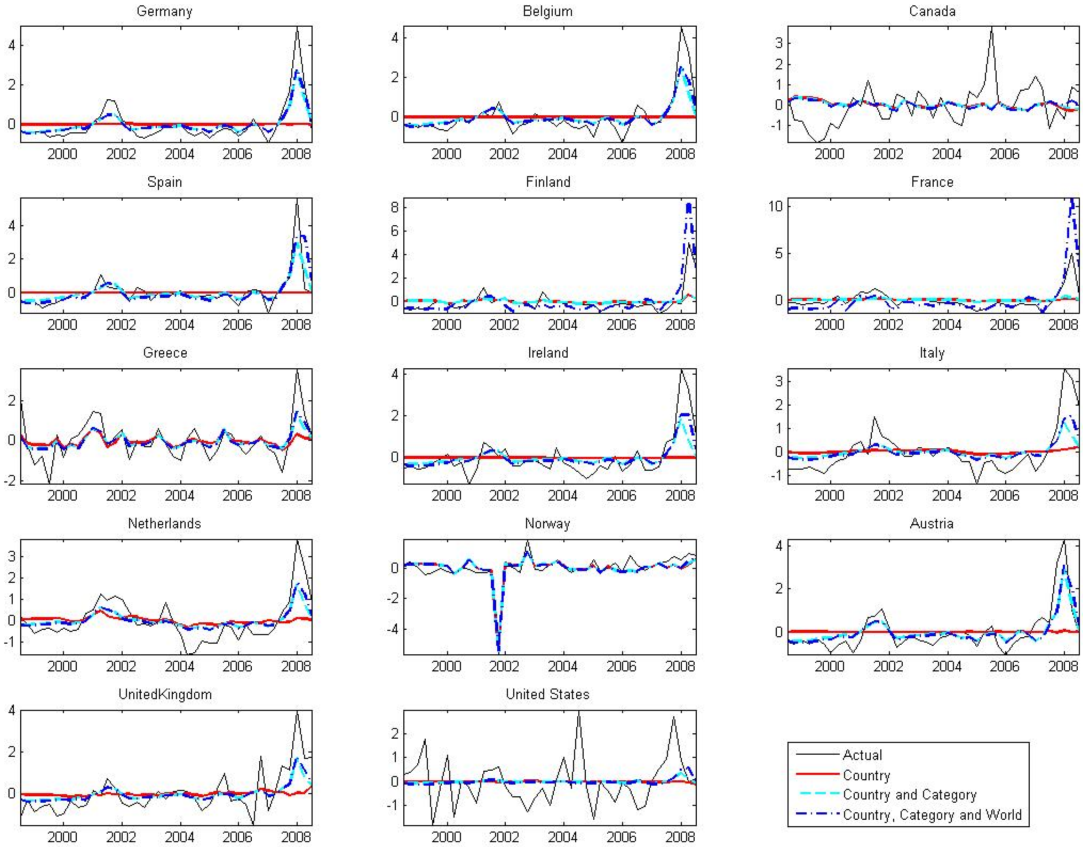

Figure 7
Indicators - Sugar

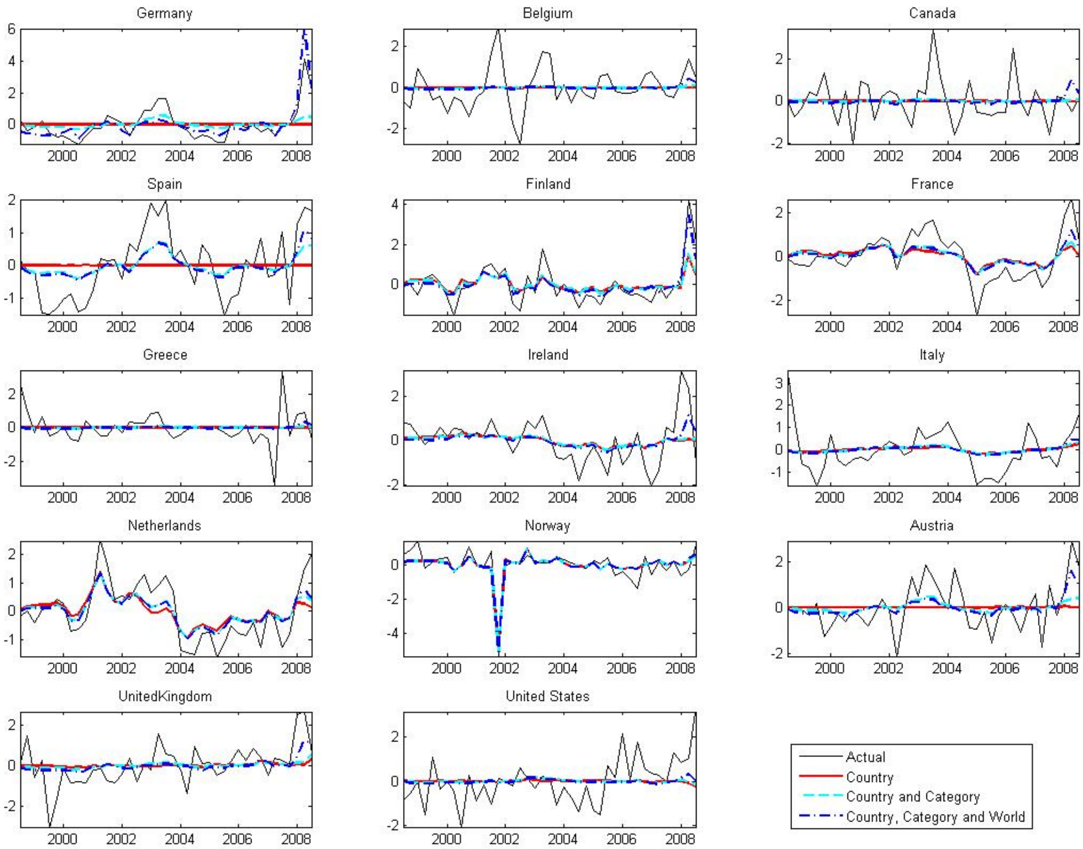

Figure 8
Indicators - Vehicle fuel