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Abstract

This paper explicitly introduces regional factors into a global Dynamic Factor Model. We combine new open economy factor models (emphasising global shocks) with the recent findings of regional importance in the business cycle synchronisation literature. The analysis is applied to a large panel of domestic data for four small open economies. We find that global and regional shocks explain roughly 30 and 20 percent, respectively, of the business cycle variation in all countries. While global shocks have most impact on trade variables, regional shocks explain a relatively large share of the variation in cost variables.

JEL-codes: C32, E32, F41

Keywords: International transmission, Globalisation, Regionalism, Factor model, Business cycle synchronisation

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I Introduction

The most recent decades have been termed an era of globalisation. Total trade as a share of world GDP has increased significantly, while the liberalisation of economic policies and financial markets has boosted financial integration. This has led to rapid economic growth in many regions of the world, beginning with the US and Europe and now extending through much of Asia, parts of Africa and South America.

A long-standing literature has investigated the patterns of globalisation and regionalism and their impacts on business cycle synchronisation, inflation and interest rates.[1] While studies such as Kose et al. (2003) seem to confirm that world factors were indeed sufficient to describe the evolution of domestic business cycles, studies covering more recent periods find support for an increase in the role of regional factors. In particular, Clark and Shin (2000), Stock and Watson (2005), Moneta and Rüffer (2009) and Mumtaz et al. (2011) find that regional factors play a prominent role in explaining the evolution of the business cycle in different countries and regions, especially in North America, Europe and Asia.

It is important for policy institutions in small open economies to understand how international developments affect the domestic economy. The business cycle synchronisation literature referred to above does not study this, as these studies fail to address the issue of identifying the shocks. Moreover, models that analyse the transmission of international shocks to the domestic economy largely ignore the issues of globalisation and regionalism. For instance, small-scale structural vector autoregressions (VARs) of the open economy, such as Eichenbaum and Evans (1995) and Grilli and Roubini (1996), typically use a two-country model to account for foreign influence, while open economy factor models, such as Mumtaz and Surico (2009), Boivin and Giannoni (2007) and Liu et al. (2011), identify shocks to common global factors but do not discriminate between regional and world factors.[2]

[1] See, e.g., Kose et al. (2003), Baxter and Kouparitsas (2005) and Kose et al. (2012) on business cycle synchronisation and Mumtaz and Surico (2012), Monacelli and Sala (2009) and Ciccarelli and Mojon (2010) on the co-movement of inflation rates.

[2] See also Eickmeier (2007) and Eickmeier et al. (2011) on the transmission of US shocks to individual

In this paper, we combine the new open economy factor model studies with the recent findings in the business cycle synchronisation literature and explicitly include both regional and world factors in a Dynamic Factor Model (DFM). More precisely, we extend the global factor model framework proposed by Mumtaz and Surico (2009) to include regional factors. To do so, we estimate a three block DFM model with separate world, regional and domestic blocks. The analysis is applied to four representative small open (advanced) economies: Canada, New Zealand, Norway and the UK. The countries are located across the world, in different geographical regions.

In addition to including regional factors, our DFM set-up differs from Mumtaz and Surico (2009) in two other important respects. First, we allow the dynamics of all the domestic variables to be a linear combination of both foreign (world and regional) and domestic factors. This implies that both domestic and foreign shocks may affect the domestic variables on impact, which we believe is a plausible assumption in an integrated world. In contrast, Mumtaz and Surico (2009) restrict the domestic variables to be a linear combination of domestic factors alone. Therefore, the foreign shocks can only affect the dynamics in the individual domestic variables by first having an impact on common domestic factors. Second, our domestic factors differ, as we assume that they are orthogonal to the foreign factors.

The modeling framework adopted is similar in spirit to the approach taken in Kose et al. (2003) of separating out the effects of the global, regional and country-specific factors.[3] In contrast to the study by Kose et al. (2003), however, our DFM model allows us to identify shocks to foreign inflation and activity factors in addition to shocks to the domestic factors. The shocks are identified using a recursive identification scheme. Finally, compared with the common practice in the business cycle synchronisation literature of focusing on one, two or three variables, our approach utilises a large domestic data set. This allows for a much richer description of the domestic responses to different global, regional and domestic shocks. In particular, while the business cycle synchronisation

countries.

[3] An altogether different approach to analysing foreign impulses to small open economies is the global VAR (GVAR) approach of Dees et al. (2007) and Pesaran et al. (2004).

literature tends to focus on synchronisation of (real) activity variables, we can describe how global factors affect a broad range of domestic variables, such as trade, activity, costs and financial variables.

By employing the above specification, we can address the following questions: How much of the variation in domestic variables can be explained by global factors, and to what extent does the region located close to the country matter? Through which channels and variables do global and regional shocks transmit to small open economies? To our knowledge, this is the first paper to study and separate the effects of global and regional shocks to the domestic economy. Our main contributions and results are as follows:

First, world and regional factors explain a large fraction of the variation in domestic variables. Overidentification tests support the hypothesis that domestic variables are a function of foreign factors. Moreover, shocks to the foreign factors explain a major share of business cycle fluctuations in small open economies. In particular, foreign shocks account for roughly 50 percent of the variation in the domestic variables in all the four countries we examine. The impact is particularly felt in trade and cost variables. Our result contrasts with the findings in Mumtaz and Surico (2009) and Liu et al. (2011) of a weak impact of foreign (activity) shocks to the UK macro economy. There are two key reasons for the differences in the results. First, Mumtaz and Surico (2009) and Liu et al. (2011) do not account for the impact of regional factors. Second, they restrict the domestic variables to be a linear combination of the domestic factors alone. Our results do not support these features, and we show that the latter restriction may undermine the importance of internationally driven shocks.

Second, while shocks that are common to the world are the most important foreign shocks, regional shocks are far from trivial and explain approximately 20 percent of the variance in the domestic variables in all countries studied. Therefore, for the small open economies analysed here, the world is not enough! However, while world shocks transmit to the different economies in a mostly similar way, regional factors and shocks impact the countries differently. For Canada and New Zealand, the impact is felt through trade and activity variables, while for Norway and the UK it is transmitted to a greater extent through variables related to prices and the financial market. Common to all four countries analysed is the relatively large share of the variation in cost variables that is attributable to regional shocks.

We run a number of robustness checks, including the following: augmenting the model with observable factors such as the price of oil, changing the sample period and changing the identification scheme for the shocks. All specifications leave the general conclusions unaltered.

The remainder of the paper is structured as follows: Section II describes the model, the identification scheme and the estimation procedure. The results are reported in Sections III to V. We first describe the estimated factors and report statistical evidence supporting our identification scheme. Then, we provide evidence of the transmission channels of the shocks, by discussing the variance decompositions and impulse responses for different groups of domestic variables. Section VI discusses robustness, while Section VII concludes. An online Appendix provides additional information about the data and the results.

II The model

Our Dynamic Factor Model (DFM) builds on the general set-up in Bernanke et al. (2005) and its extension to the international economy developed by Mumtaz and Surico (2009).[4] The fundamental extension in our analysis is the belief that the dynamics of domestic variables can be captured by some common, unobserved world and regional factors in addition to a set of purely domestic factors. Based on evidence from the international business cycle literature, we have chosen to categorise the world and regional factors into activity and inflation factors.[5]

The factors are unobserved and have to be estimated from the data. Thus, the model can naturally be represented in a state space form. We specify the transition equation as

[4] On a more linguistic note, because the model in Bernanke et al. (2005) and Mumtaz and Surico (2009) also contains an observable domestic factor (the interest rate) in the transition equation, it is referred to as a factor-augmented VAR model (FAVAR).

[5] To control for the potential influence of regional and domestic monetary policy, we have also run the model including the regional and the domestic interest rate as observable factors. Our results do not qualitatively change when the model is augmented with these factors.

follows:

$$F_t = \beta(L)F_{t-1} + u_t, \quad (1)$$

where $F_t = [F_t^* \quad F_t^{**} \quad F_t^D]'$ is a set of world, regional and domestic factors. $\beta(L)$ is a conformable lag polynomial of order p and u_t is the reduced form disturbances. The structural disturbances follow $u_t = \Omega^{1/2}\varepsilon_t$, with $\varepsilon \sim N(0,1)$ and $\Omega = A_0(A_0)'$.

The observation equation of the system is:

$$X_t = \Lambda F_t + e_t, \quad (2)$$

where X_t is a $N \times 1$ vector of observable variables, and Λ is a $N \times K$ matrix of factor loadings. Finally, e_t is a $N \times 1$ vector of idiosyncratic, zero mean disturbances.

Identifying the factors and shocks

We assume two world factors, $F_t^* = [F_t^{act*} \quad F_t^{pri*}]'$, representing global co-movements in real activity and inflation, respectively, and two regional factors $F_t^{**} = [F_t^{act**} \quad F_t^{pri**}]'$, representing co-movements in real activity and inflation at the regional level, respectively. In addition to the global and regional factors, we assume three domestic factors, $F_t^D = [F_t^{D_1} \quad F_t^{D_2} \quad F_t^{D_3}]'$.[6] Note that in our model, the derived domestic factors, F_t^D, have not been given any economic interpretation. It would have been possible to restrict the domestic factors to rely on specific variables, thereby identifying them as, for example, real activity or inflation factors. However, such additional identifying restrictions would have limited the potential heterogeneous responses of the domestic variables to shocks in the transition equation.

To identify the unobserved factors, the X matrix in the observation equation is partitioned into blocks. Each block consists of world, regional or domestic data. By restricting the different data blocks in X_t, we argue that we can identify the unobserved factors, or

[6] Employing the different information criteria proposed in Bai and Ng (2002) suggests that between five and eight factors are appropriate for our data sets (depending on the country under study). These estimates, however, are based on the reduced form factors and loadings. Thus, to avoid giving the identified international factors an a-priori large weight, we have chosen to include three domestic factors in all model specifications (7 factors in total).

the underlying driving forces of the world, regional and domestic economies. Appendix A describes the estimation and identification procedure in detail. Here, it is sufficient to note that the unobserved factors are essentially estimated by principal components, block by block.

A potential problem when identifying the factors block by block is that the regional and domestic factors may span the same space as the world factors. To further separate the world factors from regional factors, we therefore follow Kose et al. (2003) and impose the restriction that the world activity and regional activity factors are (static) orthogonal.[7] Moreover, a similar restriction is imposed for the world inflation and regional inflation factors. In this way, the regional activity (inflation) factor will capture common co-movements in the regional activity (inflation) variables that cannot be explained by the world activity (inflation) factor. Similarly, we separate the domestic factors from the world and regional factors by assuming that they are orthogonal to both regional and global factors.

Having properly identified the unobserved factors in equation (1), the factors will be related to the domestic variables such that each domestic series is a linear combination of both the domestic factors and the global and regional factors.

To identify the structural shocks, we apply a standard recursive ordering of the factors (Cholesky identification). Here, activity factors are ordered above inflation factors within each block. The global factors are ordered above the regional factors, and the domestic factors are ordered last. Thus, impulse responses and variance decompositions can be computed using standard VAR techniques. Given the identification of the factors, we argue that we can uncover four different structural shocks using the Cholesky ordering, namely world and regional activity and inflation shocks. We will in the following (often) refer to this as our baseline model. Note that the recursive identification scheme implies that the world (regional) activity factor will react with a lag to world (regional) inflation shocks, which is a common assumption in structural VAR analysis. Still, the domestic variables may respond to all shocks on impact, as they are affected by the domestic factors

[7]Note, that although the factors are static orthogonal, we still allow for dynamic spillovers from the regional factors to the world factors.

(ordered last in VAR) and the loading structure we impose.

Data and estimation

To construct the world and regional factors we include variables from 32 different countries in the DFM. The data include variables from the US, the UK, Switzerland, the Netherlands, Japan, Italy, France, Finland, Denmark, Sweden, Norway, Spain, Germany, Belgium, Luxembourg, Canada, Chile, Peru, South Africa, Brazil, Argentina, Mexico, Korea, China, Malaysia, India, Taiwan, Hong Kong, Thailand, Singapore, Australia and New Zealand. We primarily employ real activity and price series from the G20 countries to construct the global activity and inflation factors, respectively.

As is common in the business cycle literature, see, e.g., Kose et al. (2003), the regional activity and inflation factors are constructed using activity and price variables from the respective geographical regions. The region is chosen a-priori. For Norway and the UK, the regional block consists of data from European countries, while for Canada and New Zealand, the regional block consists of data from North America and Asia, respectively.

Apart from proximity due to geographical location, the primary reason for using these regional definitions comes from the observation that the geographical region is also the most important trading partner for each of the countries. This is documented in Table B.1 in Appendix B. The US is by far the most important trading partner for Canada, accounting for approximately 75 percent of all exports and over 50 percent of all imports. The European Union as a whole is the most important trading partner for both Norway and the UK, accounting for 80 and 55 percent of the countries' exports and 66 and 53 percent of the countries' imports, respectively. For New Zealand, the picture is somewhat more diverse. However, Asia together with Australia account for over 50 percent of both exports from and imports to New Zealand.

The variables entering into the domestic block of the model are collected from a much wider pool of series than the global and regional data. This enables us to give a rich description of how foreign factors affect a large panel of domestic variables. In total, we include roughly 90 data series for each of the countries we analyse: Canada, New Zealand, Norway and the UK. The domestic data sets cover a broad range of aggregated and disaggregated macroeconomic variables. The online Appendix provides a more detailed description of the variables included in the model.

Four models are estimated, one for each of the countries we analyse in detail. The models are estimated on quarterly observations from 1992:Q2 to 2009:Q4. Some monthly series are included in the model; these series are aggregated to quarterly series by taking the mean. Variables that are assumed to be non-stationary are in quarterly growth rates, while variables affected by seasonality are seasonally adjusted using the X12 ARIMA procedure. To make the estimation of the factors invariant to scale, all variables are normalised to have zero mean and unit variance prior to estimation.

Finally, we estimate the system in equations (1) and (2) using a two-step procedure: The unobserved factors are first estimated by principal components, block by block. Then, after the factors are identified and estimated, these are used as observable variables when estimating equation (1) by ordinary least squares. To construct distributions for the impulse response functions and accurately account for the problem of generated regressors in the second estimation step, we employ a residual bootstrap procedure for the entire system with 5000 replications. Appendix A provides a detailed description of the two-step estimation procedure.

III The identified factors

In the following, we first present the identified world and regional factors. As shown in Figure 1, the world activity factor captures the most important features of the world business cycle over the past 20 years. It closely resembles the factor identified in Mumtaz and Surico (2009), although our sample covers more years at the end, including the period of the financial crisis. Several periods stand out. The Asian-led crisis at the end of the 1990s, which induced a brief downturn in the world business cycle, is particularly noteworthy. The world activity factor also captures the global effect of the 2001 slowdown following the burst of the dot-com bubble. Finally, the recession following the financial crisis is by far the deepest recession in our sample period. The size and timing of this downturn implies that the global activity factor may also pick up developments in financial markets, and especially developments taking place in US financial markets prior to the recession.[8] Still, the impact of the recession was short-lived, and the results presented below suggest that the global factor is more related to the real economy than the financial market.

The North American factor captures the downturn in the US in 2001 following the burst of the dot-com bubble. The recession that began in 2007 is also clearly visible. Interestingly, this recession preceded the world recession, and was hence a genuinely North American recession, which is not observed in the world factor. The dates correspond well with the dates used by the NBER when dating the recession.

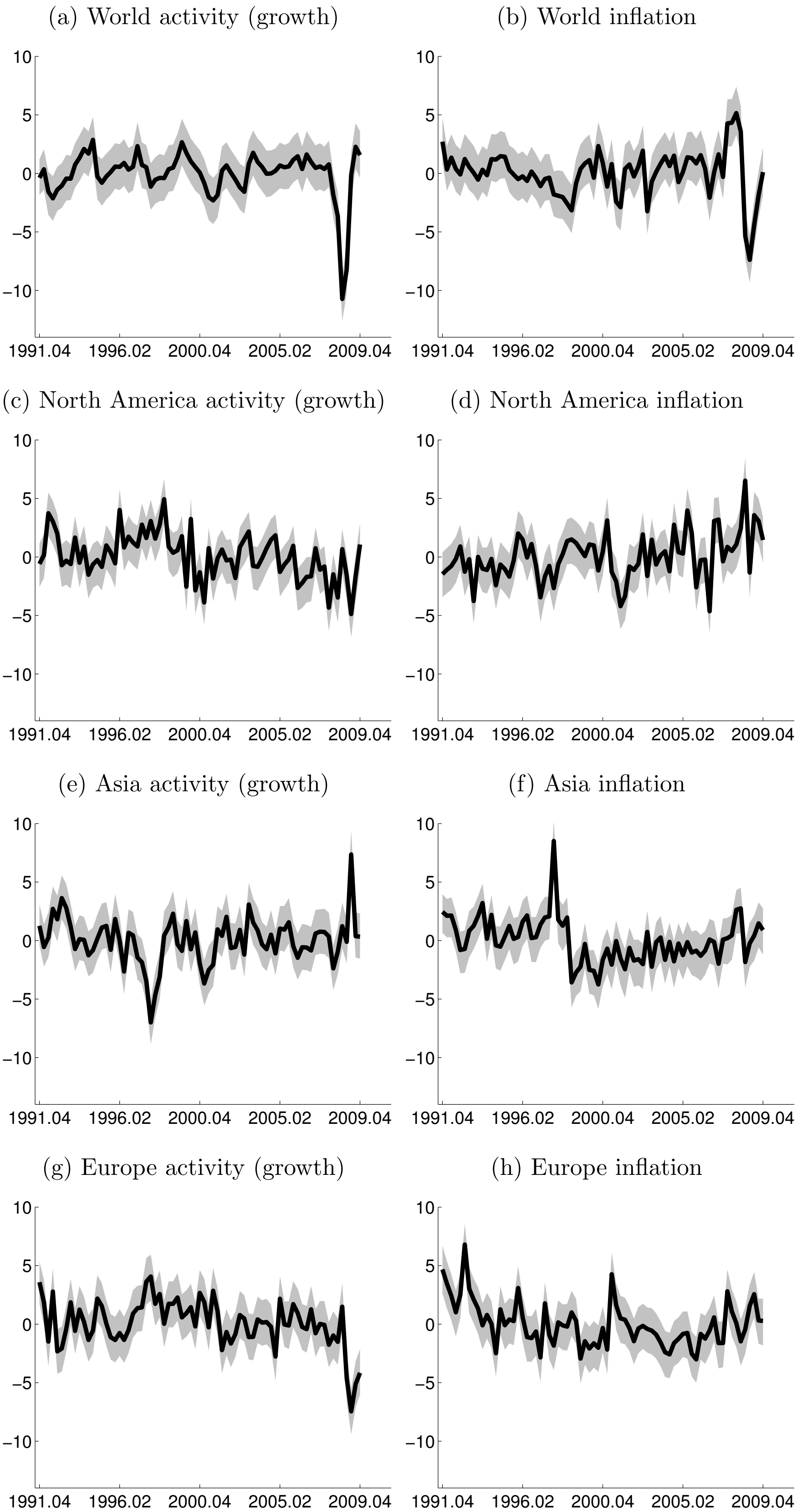
The Asian activity factor captures in particular the Asian crisis in the latter part of the 1990s, which appears to have been more severe than the ensuing downturn in the world activity factor. Furthermore, after the substantial decline in economic activity following the global financial crisis, the Asian activity factor recovered much better than the world activity factor, which at the end of 2009 is still barely above zero.

The European factor shows a boom in the late 1990s corresponding to the period when a common monetary policy was introduced under the authority of the ECB. There was also a European-led recession in 2001/2002 and again in the latter part of the sample. The most recent recession began a few periods into the global financial crisis, but was much more severe than the recession experienced in the other regions. By the end of the period (2009), the European recession had not yet ended.

The world price factor reflects the global co-movement in inflation rates across the world found in prior studies, such as Mumtaz and Surico (2009) and Ciccarelli and Mojon (2010). Particularly striking is the significant upturn at the end of the sample, likely representing a hike in commodity prices. We note that the regional factors exhibit a declining pattern when most countries went through a period of disinflation, in particular in Europe and in Asia in the late 1990s.

[8]Under the assumption that financial market shocks spread fast throughout the economy and across borders, this can easily be picked up by the global factors in our (quarterly) model.

Figure 1: Identified factors



Note: The factors are estimated using data from 1991:Q4 to 2009:04. The black solid lines are point estimates. The grey shaded areas are 90 percent confidence bands.

Table 1: Correlations

Variable	Country	Factors			
		World	**North America**	**Asia**	**Europe**
GDP growth	North America	0.73	0.59	-0.08	0.15
	Asia	0.49	-0.05	0.35	-0.17
	Europe	0.71	0.02	-0.13	0.25
CPI inflation	North America	0.67	0.67	-0.15	-0.08
	Asia	0.51	-0.06	0.22	-0.01
	Europe	0.69	-0.04	-0.03	0.16

Note: The table reports the average correlation between GDP growth (inflation) in countries within a region and the different activity (inflation) factors.

Correlations

To interpret the factors somewhat further, we compute simple pairwise correlations between GDP growth (inflation) among countries in a specific region and all the estimated activity (inflation) factors. Table 1 reports the average correlation coefficient across countries within a region. The world activity and inflation factors are positively correlated with output growth and inflation, respectively, in all regions. Thus, the world activity and inflation factors seem to be common across the world. The average correlation between the individual countries in North America and Europe and the world factors is somewhat higher than between the Asian countries and the world factors. This likely reflects the fact that we have used the G20 countries to construct the world factors, see Section II.

For regional activity and inflation factors, the correlation patterns are more dispersed. Still, one pattern is very clear. The correlation between the variables in a geographical region and its relevant regional factor is always (much) higher than for the other regional factors. For example, GDP growth in North American countries has on average a correlation coefficient of 0.59 with the North American activity factor, while the average correlation with the Asian and European activity factors are -0.08 and 0.15, respectively. For inflation the relevant numbers are 0.67, -0.15 and -0.08.

IV The world is not enough

We extend the current literature in two directions. First, we include regional factors in the model. Second, we assume that the domestic variables are a linear combination of both world, regional and domestic factors. Below we show that all these features are supported by the data, and that not taking this into account leads to a very different description of how foreign business cycles transmit into small open economies.

R^2's and overidentification tests

Table 2 reports, for each country, key statistics associated with the observation equation of the model. In particular, the table reports average R^2 and partial R^2 across all domestic variables in the data set, the fraction of significant factor loadings, and lastly the fraction of (Wald) null hypothesis rejected. In the three cases, $H(0)$ is respectively: no loading on the world factors (G), no loading on the regional factors (R), and no loading on the world and regional factors (GR).

The table emphasises that the average variance explained by all of the factors for each country (R^2) is approximately 50 percent. This is consistent with other FAVAR studies (see, e.g., Bernanke et al. (2005)). The partial R^2 numbers suggest that including global and regional factors in the model increases the proportion of explained variance in all four domestic data sets.[9] Note, however, that the results reported in Table 2 also suggest that the partial R^2 and the percentage of significant factor loadings are smaller for the regional factors than for the global factors. This follows almost by construction from the way we identified the factors, i.e. the orthogonality restrictions. Yet, the numbers illustrate that the regional factors are far from trivial and they are significant for between 34 percent (regional inflation in Canada) and 60 percent (regional activity in the UK) of the variables in the domestic data sets.

The hypothesis tested in columns 7-9 of the table has two important messages. First,

[9] The partial R^2 measures the mutual relationship between two variables, y and x, when other variables (z, u, v...) are held constant with respect to the two variables involved, y and x. As such, it allows us to directly estimate the proportion of unexplained variation in the domestic variables that is explained by the addition of the regional factors.

Table 2: Factor statistics

Country	R^2	World		Region		Wald		
		F^{act*}	F^{inf*}	F^{act**}	F^{inf**}	**G**	**R**	**GR**
Canada	0.53	0.14 (0.62)	0.19 (0.59)	0.16 (0.44)	0.11 (0.34)	0.82	0.49	0.80
New Zealand	0.51	0.11 (0.59)	0.17 (0.63)	0.09 (0.52)	0.10 (0.47)	0.77	0.56	0.74
Norway	0.41	0.08 (0.49)	0.08 (0.46)	0.08 (0.43)	0.10 (0.45)	0.67	0.54	0.74
UK	0.52	0.17 (0.66)	0.11 (0.49)	0.15 (0.60)	0.14 (0.49)	0.80	0.67	0.85

Note: The R^2 column reports the average R^2 across all variables in the domestic data sets. Likewise, columns 3-6 report the partial R^2 attributed to each factor and the fraction of significant factor loadings (in parenthesis). The significance level employed is 10 percent. For brevity, the results for the domestic factors have been left out. Columns 7-9 report overidentification tests. That is, the fraction of (Wald) null hypothesis rejected, where $H(0)$ is: no loading on the world factors (G), no loading on the regional factors (R), and no loading on the world and regional factors (GR), respectively.

for between 67-82 percent of the variables, depending on the country, we can reject the null hypothesis that the factor loadings associated with the world factors are zero. Likewise, the same conclusion holds for between 49-67 percent of the factor loadings associated with the regional factors. Testing the hypothesis that all factor loadings associated with the international factors (world and region) should be zero is rejected for a large majority of the domestic variables.

In sum, the results presented in Table 2 show that restricting the domestic variables to be functions of the domestic factors only is (generally) invalid. The results presented also suggest that regional factors are important and add explanatory power to the model. That is not to say that non-geographical regions are unimportant for any of the countries. However, the correlations presented in Table 1 suggest that non-geographical regions are less important than the relevant geographical region.

Variance decompositions

The results presented so far have all been in terms of the static relationship between the observable variables and the estimated factors. Now we turn to the dynamic relationship, i.e. we examine how different structural shocks affect the observable variables in our system over time. Clearly, the dynamic relationship will be a function of the static relationship through the estimated factor loadings, see equations (1) and (2). Yet, the dynamics between the world and regional factors can also potentially alter over time. We quantify this by investigating the contribution of the various world and regional shocks for the domestic variables over time (variance decompositions).

Continuing with our baseline model, Table 3 reports the contribution from world, regional and domestic shocks, measured as the average variance decomposition across all variables in the domestic data sets. The contribution from the world activity and inflation shocks, and the regional activity and inflation shocks, and the three domestic shocks, are aggregated into three groups: world, region and domestic.

Table 3 emphasises the large contribution from the foreign shocks in small open economies. Taking the world and the regional factors together, roughly 50 percent of the variation in the variables is explained by the foreign shocks in the short run (horizon 1) and in all countries.

Of these, shocks that are common to the world explain the largest proportion of the variance in the domestic variables, thus extending the results commonly found in previous business cycle studies, e.g., Kose et al. (2003) to a more recent period, new countries and additional variables. In particular, 30-38 percent of the variation in domestic variables is explained by shocks to the world factors on impact. After two years the contribution attributed to world shocks generally increases further. The contribution is particularly large for the UK and Canada, where 49 and 42 percent of the variation in domestic variables, respectively, is explained by shocks to the world factors. This can in part be explained by the large contribution of the US to the world factor and the fact that the UK in particular has trading partners spread across the world, see Table B.1 in Appendix B.

The regional factors are also non-trivial, explaining on average approximately 20 percent of the variance in domestic variables on impact. Thus in all countries, the world is not enough! In contrast to the shocks to the world factors, however, the contribution

Table 3: Variance decompositions: Average across all domestic variables

		Horizon: 1			Horizon: 8		
Country	**Group**	**World**	**Region**	**Domestic**	**World**	**Region**	**Domestic**
Canada	All	0.33	0.16	0.51	0.42	0.16	0.40
New Zealand	All	0.30	0.21	0.49	0.22	0.15	0.63
Norway	All	0.34	0.19	0.47	0.33	0.16	0.51
UK	All	0.38	0.18	0.44	0.49	0.11	0.40

Note: The variance decompositions for the activity and inflation shocks are aggregated into world and regional groups. Likewise, the three domestic shocks are aggregated into one domestic group.

from the regional shocks does not increase substantially over time, but falls slightly.[10]

To load or not to load

Why do we find such large contributions from the world and the regional factors? Mumtaz and Surico (2009) and Liu et al. (2011) specify a FAVAR model with world activity and price factors for the UK, but find only a weak impact of foreign shocks on the macroeconomy. In fact, Liu et al. (2011), using a time-varying VAR, find a weaker impact of foreign shocks on the UK economy after the 1990s.

There are two main discrepancies between our model and theirs. First, in contrast to our study, Mumtaz and Surico (2009) and Liu et al. (2011) restrict the domestic variables to be a linear combination of domestic factors alone. This implies that the foreign factors can only affect the common dynamics in the domestic variables through their impact on the domestic factors in the transition equation. However, since the domestic factors are ordered below the foreign factors in the VAR part of the model, foreign shocks can still have an immediate effect on domestic variables (through the impact on the domestic factors). A second discrepancy between our model and much of the earlier literature is that we include regional factors in addition to world factors.

To show the implications of our modelling assumptions, we conduct two experiments. We estimate a DFM including only three domestic factors and the two world factors, and

[10] Note that the countries we analyse were selected because they are somewhat peripheral to their respective geographical regions. This is important, as one can then disentangle the purely domestic factors from the regional factors. Therefore, our results can likely be interpreted as a lower bound on the importance of regional factors and shocks.

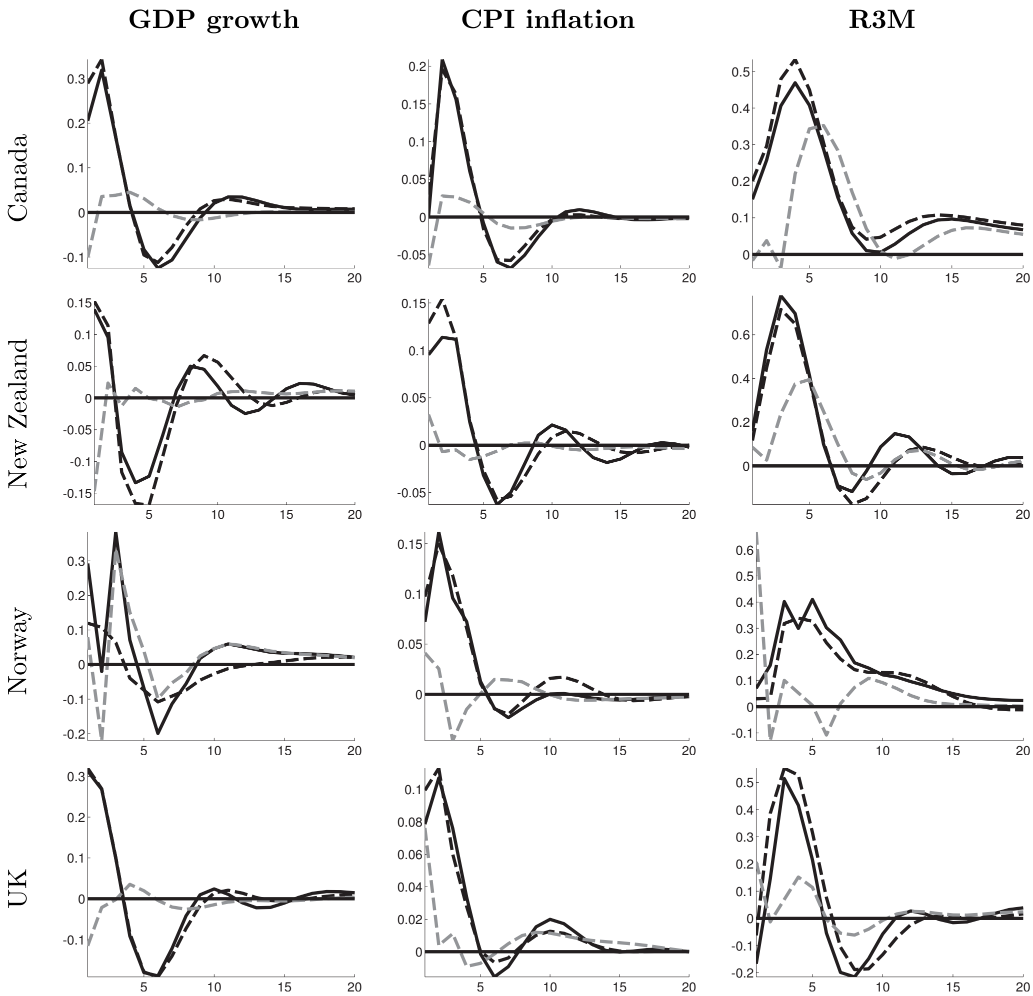
we estimate a DFM similar to our baseline model but enforce zero restrictions on the domestic factor loadings associated with the world and regional factors. The results of these experiments are summarised in Figures 2 and 3.[11] The figures show the impulse responses of three key macroeconomic variables as implied by the two alternative models just described, and as implied by our baseline model. The three variables are GDP growth, CPI inflation ($ln(P_t/P_{t-1})$) and the 3-month interest rate (R3M). Data is quarterly and two shocks are considered: world activity and inflation shocks.

First, the model that enforces the overidentifying zero restrictions (broken grey line) produces much more muted responses than the two other alternatives. In some cases, the direction of impact and the shape of the responses also change. These are important discrepancies. The results from the overidentified model imply that foreign shocks do not cause any substantial response in either domestic GDP growth or inflation. In addition, the response in the interest rate is in most cases substantially delayed. The results provided in Table 2 have already illustrated that the overidentification restrictions are generally not supported by our data. Thus, inference based on the overidentified model can be misleading. A related argument, highlighted by Reichlin (2010), is that observed domestic variables in an open economy will be the result of a general equilibrium process that reflects changes in both domestic and foreign forces. Domestic dynamics, therefore, incorporate the effect of foreign forces. The only way to disentangle domestic and foreign forces is to identify domestic and foreign shocks separately. Once these shocks are identified, the dynamics of the domestic variables will be a linear combination of both domestic and foreign forces.

Second, the impulse responses associated with our baseline model (solid black line), which includes regional factors, and the DFM model that excludes these factors (broken black line) are very similar. That is, excluding the regional factors from the model does not alter the identification of the world shocks. Still, the results presented in Tables 2 and 3 are mostly supportive of this extension, as are newer business cycle synchronisation

[11] Note that a direct comparison of our restricted model estimates and the one in, e.g., Mumtaz and Surico (2009) is not feasible. They estimate their model using different identification schemes, sample and data sets. In particular, we include a larger share of variables from emerging and developed Asian economies.

Figure 2: Impulse responses: Baseline, global and restricted model. World activity growth shock

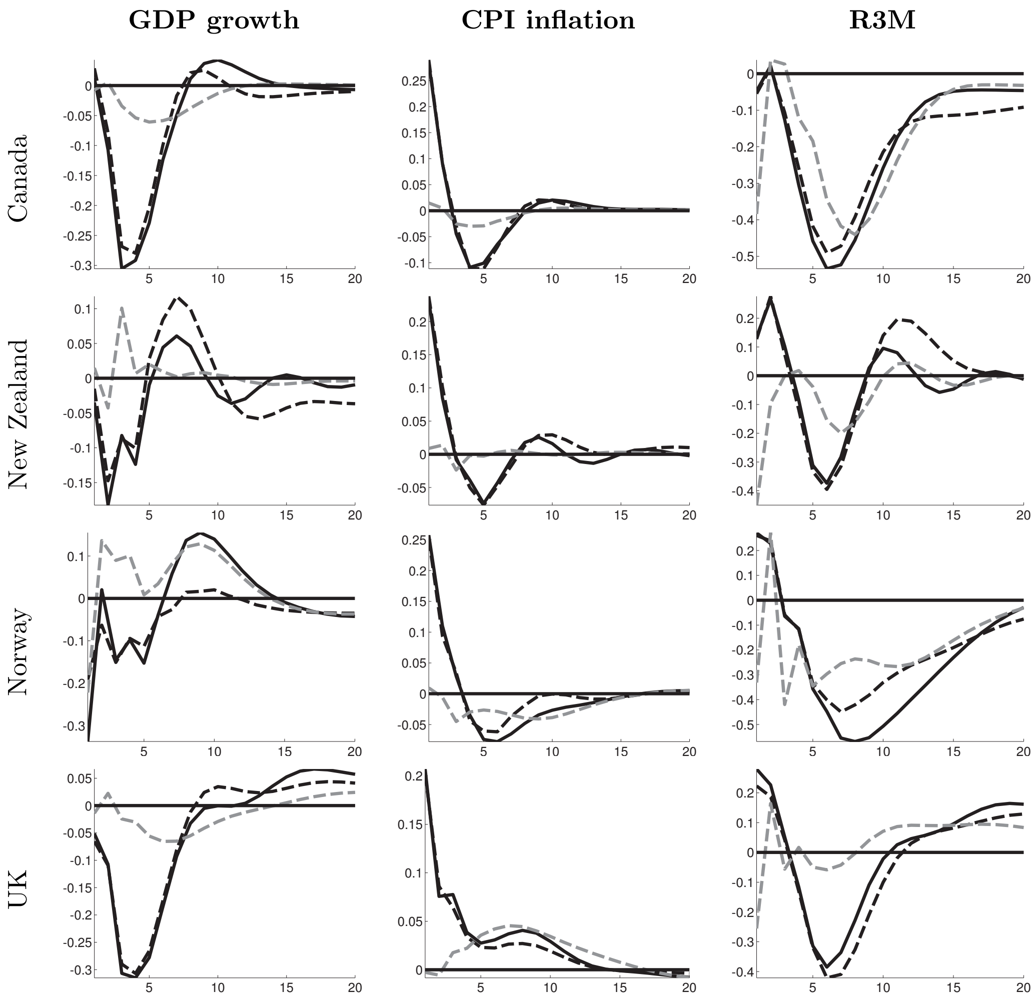


Note: The plots report the impulse responses from three different models: the baseline model (solid black line), global only model (broken black line), and restricted baseline model (broken grey line), i.e. no international loading for the domestic variables. The shock is normalised to increase world activity by one percent.

studies, see e.g, Stock and Watson (2005) and Mumtaz et al. (2011), which look at the co-movement in aggregate activity and inflation measures.

Third, focusing on the impulse responses associated with the baseline model, we see that the world activity and inflation shocks have a typical demand and supply shock interpretation. That is, after a positive shock to global activity, GDP growth, inflation and the interest rate increase in all four countries considered. Both in size and persistence, the responses are surprisingly similar across countries. After a positive shock to global inflation, domestic inflation increases in all countries, while GDP growth falls. The sys-

Figure 3: Impulse responses: Baseline, global and restricted model. World inflation shock



Note: The plots report the impulse responses from three different models: the baseline model (solid black line), global only model (broken black line), and restricted baseline model (broken grey line), i.e. no international loading for the domestic variables. The shock is normalised to increase world inflation by one percent.

tematic interest rate responses differ slightly in the initial response. However, after 3 to 4 quarters the interest rate falls in all countries. Therefore, in all countries, a positive shock to world activity has the characteristics of an aggregate demand shock, increasing activity and prices, while a positive world inflation shock can be interpreted as an adverse aggregate supply shock.

V Transmission channels

The previous sections have established that foreign factors are important. Now we investigate how they are important. The model we employ offers a parsimonious representation of the data. We explicitly assume that the co-movement of international and domestic data is driven by a few latent business cycle factors and shocks. Due to our large panel of domestic data, we can trace out how these shocks transmit to different types of variables in the domestic economy. This is an important extension of the traditional business cycle literature, which focuses on synchronisation of output and price variables, but does not investigate the channels behind the synchronisation. It is also an extension to the theoretical business cycle literature, employing Dynamic Stochastic General Equilibrium (DSGE) models. Here, the transmission channels are investigated, but the models are generally unable to replicate the common finding from the empirical literature that business cycles are highly synchronised across countries, see Justiniano and Preston (2010).[12] As such, the question of how global factors (or shocks) are important is left unanswered.

To be concrete, we analyse four types of shocks: world activity and inflation shocks, and regional activity and inflation shocks.[13] To communicate the broader picture, we cluster the variables in the domestic data set into four different variable groups: *Trade*, *activity*, *cost* and *financial*. The *trade* group contains export and import volumes. The *activity* group contains GDP, consumption, investment, labour market variables and activity indicators. The *cost* group contains consumer and producer prices, wages and labour costs, as well as export, import and house prices. Finally, the *financial* group contains the stock market, credit and money indicators, interest rates and exchange rates.[14]

The results are presented in Figures 4 and 5, which display the distribution of impulse responses across variable groups within a country. The figures are meant to summarise the main tendencies. For exposition purposes, the individual responses are standardised. To facilitate the interpretation of the shocks, a list of individual country responses, across

[12] Notable exceptions are Eyquen and Kamber (2010) and Bergholt and Sveen (2013).

[13] We do not identify the three domestic shocks related to the unobservable domestic factors.

[14] The exchange rate responses within the *financial* group are normalised so that an increase in the exchange rate refers to an appreciation.

a large number of key indicators, is included in the online Appendix. There we also report the uncertainty bands associated with the individual impulse responses.

World shocks and domestic responses

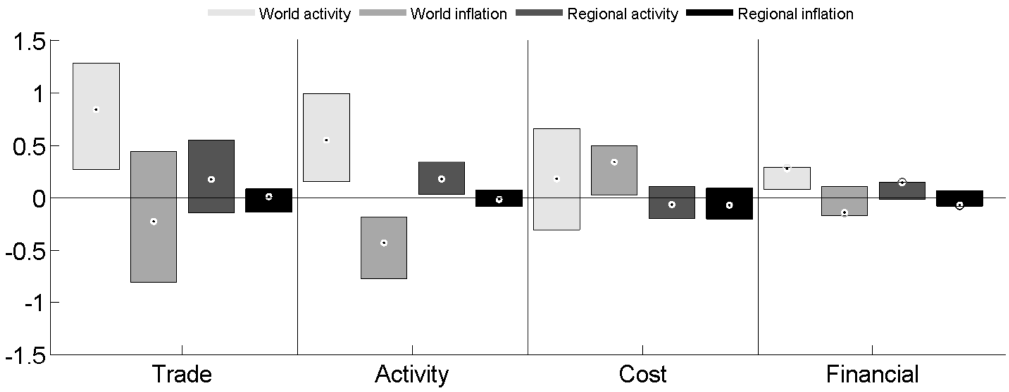
The results presented in Figures 2 and 3 have already established that, for our baseline model, the world activity and inflation shocks can be interpreted as aggregate demand and adverse supply shocks, respectively. This finding is confirmed by the results presented for the different variable groups in Figures 4 and 5. After a positive world activity shock, the level of trade, activity and cost variables increases for nearly all countries. The effect on the *trade* group seems particularly strong, as the whole group increases above zero for all countries. Variance decompositions in Table 4 also confirm that the world activity shocks explain a major share of the variation in the trade variables. With the exception of New Zealand, the *financial* group also increases after this shock. For Canada and the UK, the effect is also highly significant, suggesting financial markets are important for the transmission of international shocks. Yet, only about 10 percent of the variation in the financial variables are driven by this shock, see Table 4, suggesting that global shocks have their main effect on the real economy through trade.

Turning to the world inflation shock, we find that the median responses in the *cost* group increase, while the responses in the *trade*, *activity* and *financial* groups are negative after a world inflation shock. The variance decompositions reported in Table 4 also suggest that world inflation shocks primarily work via trade and cost, at least in the short run. Hence, this is an imported global cost push shock.

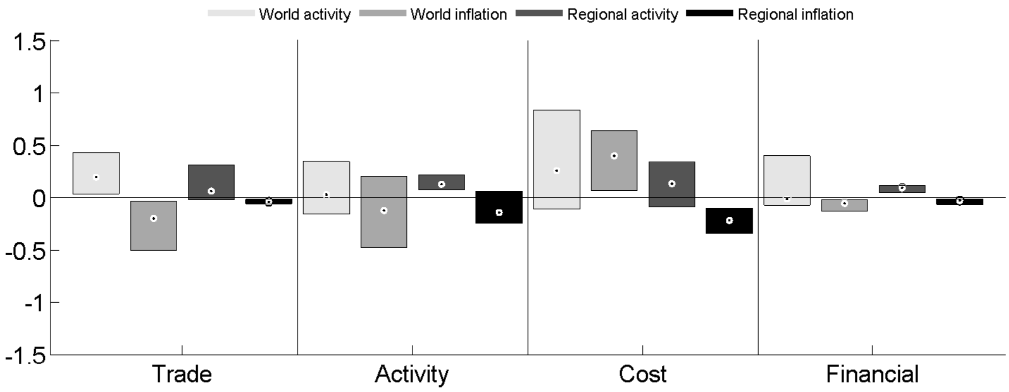
Looking at country details, it is interesting to note that for Norway a large share of the variance in the financial variables is also explained by the world inflation shock, and that the terms of trade increase temporarily in all four countries, see Figure D.2 in the online Appendix. In Canada and Norway, the exchange rate also appreciates significantly. This could be because Canada and Norway are net oil and gas exporters. That is, if the inflation factor captures important oil market dynamics and the world inflation shock has the characteristics of an adverse oil price shock that increases oil prices and subsequently

Figure 4: Response distributions: Baseline model, Canada and New Zealand

(a) Canada



(b) New Zealand



Note: Note: For each country the figures report a box plot of the impulse responses for a particular variable group and shock. The individual responses (that is summarised within a variable group) correspond to the level (in percent) of the variables at the one year horizon. Within a variable group, the distributions of the responses are ordered from left to right following shocks to: World activity, World inflation, Regional activity and Regional inflation. All shocks are normalised to 1. On each box, the central mark is the median and the edges of the box are the 25th and 75th percentiles.

costs, the response in these two countries may be exchange rate appreciation. In Section VI we control for this by augmenting the model to include oil prices.

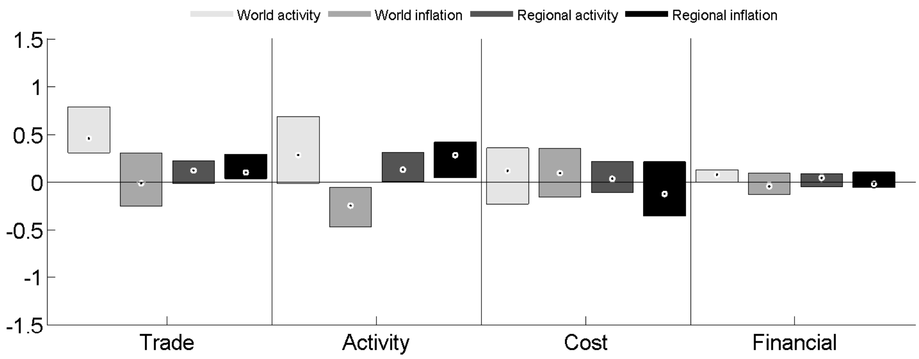
Still, the large degree of homogeneity across responses and countries after the world shocks is consistent with the interpretation that the shocks are truly common and global.

Regional shocks and domestic responses

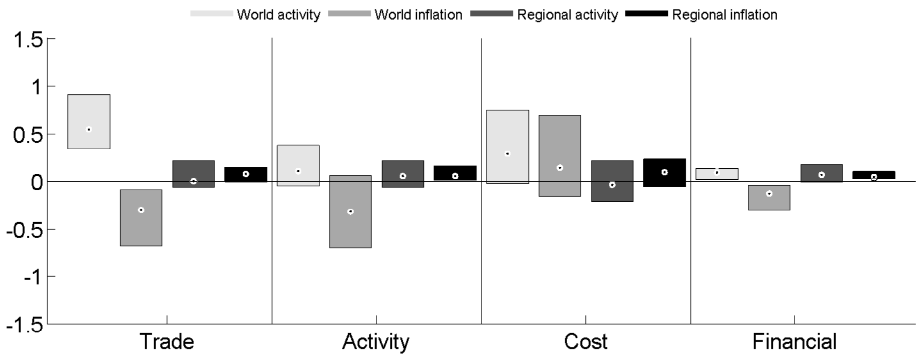
For the regional shocks, we observe a larger degree of heterogeneity in how the shocks transmit to the different economies. The dynamic relationship between the domestic

Figure 5: Response distributions: Baseline model, Norway and the UK

(a) Norway



(b) UK



Note: See Figure 4

variables in a given country and the regional shocks is a complex function of how all the world, regional and domestic factors interact after regional shocks. As the four countries considered differ both in terms of structure and geographical location, there is a-priori no reason to believe that they respond similarly to regional shocks.

The regional activity shock is the most important regional shock, see Table 4. It shares some of the same characteristics as a world activity shock, increasing the level of the variables in the *trade*, *activity* and *financial* groups for all countries. As seen in Figures 4 and 5, the positive responses in Canada and New Zealand are particularly clear. For these two countries, the variance decompositions also show that an important transmission channel likely goes through trade. Detailed impulse responses reported in the online Appendix also confirm that there is a substantial and positive effect on exports from a regional activity shock in at least Canada. In New Zealand the response is positive, but not significant. In Norway and the UK in particular, the regional activity shock does not have a major effect on exports, and the subsequent effects on the activity variables are smaller. Instead the regional activity shock works its way through *cost* over time (see Table 4).

That exports respond very little to the European activity shocks in Norway and the UK may seem at odds with the fact that the European Union as a whole is the most important trading partner for both Norway and the UK, see Table B.1 in Appendix B. Two points should be noted here. First, the UK's and, particularly, Norway's exports of goods to the EU are concentrated in primary products, of which a large share is the supply of energy, which is not particularly price- or income-elastic. Second, the share of traditional goods exports (excluding energy) in both Norway and the UK is much smaller than in Canada and New Zealand, making their economies less influenced by trade overall.

A regional inflation shock is generally the least important shock in the model. Some significant responses are found in the two smallest economies in the sample: New Zealand and Norway. In Norway the regional inflation shock leads to an increase in *trade* and *activity*, and a fall in *costs* (on average). The tendency for the *cost* variables to fall is somewhat surprising, given that the initial impulse increases European inflation. A similar pattern of falling *costs* can also be found in New Zealand. Here however, *trade* and *activity* tend to fall as well.

As noted above, common to both of the regional shocks is that they generally explain a relative large share of the variation in the *cost* variables. In fact, together, regional activity and inflation shocks explain more of the variation in *costs* than in any of the other groups. For example, between 22 and 24 percent of the variation in the *cost* variables for the four countries is explained by regional activity and inflation shocks on impact. The same numbers for the *activity* group vary between 15 and 19 percent (for Canada and Norway, respectively).

In sum, and focusing on the similarities across countries, the two world shocks seem to be particularly important for trade variables, while the two regional shocks together are relatively more important for explaining the variation in the cost variables. However, as

Table 4: Variance decompositions: By variable group

Country	Group	Horizon: 1					Horizon: 8				
		World		Region		Domestic	World		Region		Domestic
		Act.	Inf.	Act.	Inf.		Act.	Inf.	Act.	Inf.	
CAD	All	0.16	0.17	0.10	0.06	0.51	0.18	0.24	0.10	0.06	0.43
	Trade	0.21	0.21	0.13	0.07	0.39	0.22	0.27	0.11	0.06	0.34
	Activity	0.26	0.10	0.10	0.05	0.49	0.17	0.29	0.09	0.04	0.40
	Cost	0.11	0.29	0.12	0.10	0.39	0.20	0.17	0.09	0.09	0.45
	Financial	0.08	0.08	0.04	0.03	0.77	0.12	0.22	0.09	0.05	0.52
NZ	All	0.13	0.17	0.11	0.10	0.49	0.09	0.13	0.09	0.06	0.63
	Trade	0.26	0.18	0.21	0.03	0.32	0.06	0.23	0.13	0.03	0.55
	Activity	0.08	0.11	0.05	0.13	0.63	0.07	0.07	0.07	0.08	0.72
	Cost	0.11	0.30	0.11	0.13	0.35	0.11	0.15	0.09	0.09	0.56
	Financial	0.08	0.08	0.09	0.10	0.65	0.12	0.08	0.07	0.05	0.68
NOR	All	0.11	0.23	0.10	0.09	0.47	0.13	0.20	0.07	0.09	0.51
	Trade	0.12	0.36	0.15	0.07	0.31	0.17	0.24	0.05	0.05	0.50
	Activity	0.14	0.12	0.07	0.12	0.54	0.11	0.16	0.05	0.15	0.52
	Cost	0.06	0.19	0.11	0.11	0.53	0.12	0.14	0.08	0.10	0.56
	Financial	0.10	0.27	0.08	0.06	0.49	0.12	0.28	0.09	0.06	0.45
UK	All	0.21	0.17	0.10	0.08	0.44	0.13	0.36	0.08	0.03	0.40
	Trade	0.36	0.20	0.06	0.08	0.31	0.15	0.45	0.06	0.02	0.32
	Activity	0.20	0.13	0.10	0.05	0.53	0.11	0.39	0.07	0.02	0.40
	Cost	0.17	0.27	0.12	0.11	0.33	0.15	0.33	0.09	0.04	0.39
	Financial	0.12	0.09	0.14	0.07	0.59	0.11	0.26	0.10	0.04	0.49

Note: The three domestic shocks are aggregated into one domestic group. See Figure D.5 in the online Appendix for a graphical representation of the relative importance of the shocks across countries and variable groups.

documented in Figures 4 and 5, Table 4, and in the online Appendix, the exact country-specific responses and contributions vary.

For policy makers in small open economies that need to understand how international developments affect the domestic economy so as to respond accordingly, our results yield important information. In many policy institutions, DSGE models play an important role in policy decisions. Our results showing a strong transmission of both global and regional shocks to small open economies are in sharp contrast to evidence from recently developed small open economy DSGE models that incorporate foreign economies more explicitly, such as Galí and Monacelli (2005), Justiniano and Preston (2010) and Christiano et al. (2010). One concern in some of these models is that they assume that the shocks are not correlated across countries. For instance, the model-implied cross-correlations between Canada and the US are essentially zero in Justiniano and Preston (2010). This is at odds with the data and our findings here. A specification that assumes correlated cross-country shocks partially resolves this discrepancy, but still falls well short of matching our findings. On the other hand, our findings of a strong trade and cost channel should be suggestive of further theoretical work within the DSGE literature on how to incorporate international shocks and transmission channels.

VI Robustness

We have run a number of different model specifications to ensure that our main findings are robust. The details and additional results are presented in the online Appendix. The main results are summarised here.

We extend the DFM by including the real price of oil (ordered first in the system). This extension serves three purposes: First, it ensures that the world price factor is not simply a stand-in for typical common shocks, such as changes in oil prices. Second, Canada and Norway (and previously the UK) are net oil exporters, and third, the small open economies we analyse are all very oil-dependent, not only as oil exporters but also in their oil use relative to the size of GDP (especially Canada and New Zealand). The results show that the oil price shock is important and explains roughly 10-20 percent of the variation in the domestic variables (on average). Importantly, the contribution from the world inflation shock decreases almost proportionally with the increased contribution from the oil price shock, while the regional and domestic shock contributions remain very similar to the baseline case.

To ensure that the financial crisis starting at the end of 2007 does not drive our results, we have also run the model on a shorter estimation sample, setting 2007:Q4 as the end-of-sample date. Doing so, we find that the main results do not change; if anything, the importance of regional shocks is even stronger for the UK.

We have also run the model using different exogeneity restrictions imposed on the transition equation of the system. Restricting the domestic factors to be exogenous, contemporaneously and at all lags, to the world and regional factors does not alter our main conclusion of a strong regional importance, nor does restricting the domestic factors to be exogenous to the world factors only.

We have also employed a combination of zero and sign restrictions to identify the shocks to the world and regional factors, making them interpretable as demand and supply shocks.[15] In our implementation, we assume the same ordering of the variables as in the recursive identification scheme, but with additional sign restrictions on the structural disturbances such that world and regional demand and supply shocks can be identified. With minor modifications, the sign restrictions are implemented following the procedure outlined in Rubio-Ramirez et al. (2009) and Mumtaz and Surico (2009). Our results show that regional shocks still explain a considerable share of the total variance in domestic variables. Due to the inherent indeterminacy associated with sign restrictions, we prefer our baseline model, which yields unique identification of the shocks.

VII Conclusions

We estimate a three block Dynamic Factor Model (DFM) with separate world, regional and domestic blocks for four small open economies: Canada, New Zealand, Norway and the UK. In so doing, we combine the emphasis on transmission mechanisms in small-scale structural models of the open economy with the recent findings in the business cycle synchronisation literature, documenting regional importance.

We find that foreign shocks explain a substantial share of the business cycle variation in small open economies. Of these shocks, those that are common to the world explain the largest proportion of the variance in the domestic variables, thus extending the results commonly found in previous business cycle studies to a more recent period, new countries and additional variables. However, regional factors are also non-trivial, explaining approximately 20 percent of the variance in the domestic variables. Thus, for all countries, the world is not enough. While the trade channel stands out as a particularly important

[15]Sign restrictions have become a popular method of identifying shocks of interest in structural VARs, see, e.g., Faust and Rogers (2003) and Uhlig (2005).

channel for transmitting global shocks, regional shocks explain a relatively large share of the variation in cost variables.

Our results contrast with the findings in other recent open economy factor model studies of a weak impact of foreign (activity) shocks. We document that there are (at least) two key reasons for this discrepancy. First, we include regional factors. Second, we let the domestic variables be a linear combination of both foreign and domestic factors. In our model, both of these features are supported by the data.

In many policy institutions, DSGE models play an important role in policy decisions. Our findings of a strong transmission of both global and regional shocks to small open economies are in sharp contrast to evidence from recently developed small open economy DSGE models that incorporate foreign factors. As such, our analysis should be a stepping stone to investigate further, and in greater depth, how and why the transmission of international shocks is so strong.

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Appendices

Appendix A Estimation and identification

We estimate the system in equations (1) and (2) using a two-step procedure:

Step 1: Estimating the factors. The unobserved factors are first estimated by principal components.[16] The world activity factor is extracted based on the world activity data, the world inflation factor is extracted based on the world price data, etc. The factors are identified according to the following procedure:

(i) World activity and inflation factors are estimated as the first principal component from the G20 activity and inflation series. To identify the sign of the world activity (inflation) factor, we restrict the world activity (inflation) factor to have a positive loading on US activity (inflation).

(ii) To obtain the regional activity (inflation) factor, we first regress all regional activity (inflation) series on the global activity (inflation) factor. We then obtain a set of activity (inflation) residuals. We estimate the regional activity (inflation) factor as the first principal component of the activity (inflation) residuals. This will guarantee that the regional activity (inflation) factor is orthogonal to the world activity (inflation) factor. For the European regional factors, we restrict the activity (inflation) factor to load positively on German activity (inflation). The Asian activity (inflation) factor is restricted to have a positive loading on Japanese activity (inflation), and finally, for North America, the regional activity (inflation) factor loads positively on US activity (inflation).

(iii) To obtain the domestic factors, we regress all of the domestic series on the world and regional factors and obtain a set of residuals. The three domestic factors are estimated as the first three principal components of these residuals. This will guarantee that the domestic factors are orthogonal to the global and regional factors. Finally, the identified factors are used to estimate the restricted factor loading matrix in equation (2).

Step 2: Estimating the VAR. The estimated factors are used as observable variables

[16] To avoid the rotational indeterminacy problem associated with principal component analysis, we use the standard normalisation implicit in the literature and restrict $C'C/T = I$, where $C(\cdot)$ represents the common space occupied by the factors of X in each block of data.

in a standard VAR framework. In our baseline model, we restrict the number of lags to 2. Given our relatively short estimation sample, we have also estimated the VAR in equation (1) using Bayesian techniques. Our results are essentially unaltered irrespective of the estimation procedure we employ.[17]

After estimation, the structural shocks are identified based on the covariance, Ω, of the reduced form residuals. The structural disturbances follow $u_t = \Omega^{1/2}\varepsilon_t$, with $\varepsilon \sim N(0,1)$ and $\Omega = A_0(A_0)'$.

Uncertainty To account for estimation uncertainty in the parameters and factors and to construct confidence bands around the impulse response functions, we implement a residual-based bootstrap procedure of the whole system, following, e.g., Goncalves and Perron (2013) and Yamamoto (2012).

We first do Step 1 and Step 2 described above, yielding estimates of β^0, u^0, Λ^0, F^0 and $e^0 = X - F^0\Lambda^0$, then, for $i = 1, ..., 5000$:

1. Simulate $\tilde{F}_t = \beta^0\tilde{F}_{t-1} + u_t^*$, where u_t^* is re-sampled from u^0.

2. Simulate $\tilde{X}_t = \Lambda^0\tilde{F}_t + e_t^*$, where e_t^* is re-sampled from e^0.

3. Use $\tilde{X}_t$, and follow Step 1 and Step 2 described above to estimate and identify: Λ^i, F^i β^i and u^i, which are saved.

4. Return to 1.

[17]For the Bayesian estimation, we apply an independent normal-Wishart prior for the VAR and use the Gibbs sampler to derive the posterior distributions of the parameters. To further avoid the problem of over-fitting, we adopt a Minnesota-type prior on the coefficients.

Appendix B Trading partners

Table B.1: Main trading Partners: Export and import shares

	Country	Exports	Country	Imports
Canada	United States	75.0	United States	51.2
	European Union	8.3	European Union	12.4
	China	3.1	China	10.9
	Japan	2.3	Mexico	4.5
	Mexico	1.3	Japan	3.4
New Zealand	Australia	23.0	Australia	18.4
	European Union	13.0	European Union	17.3
	United States	10.0	China	15.1
	China	9.1	United States	10.8
	Japan	9.1	Japan	7.4
Norway	European Union	80.4	European Union	66.3
	United States	4.8	China	7.8
	Canada	2.1	United States	6.2
	China	2.0	Japan	2.5
	Korea	1.9	Canada	2.2
UK	European Union	54.9	European Union	53.0
	United States	14.9	United States	9.6
	China	2.3	China	9.0
	Switzerland	1.7	Norway	4.8
	Canada	1.9	Japan	2.2

Note: 5 most important trading partners. Based on export and import values in 2009. Source: WTO.

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