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Modelling Global Trade Flows: Results from a GVAR Model*

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Abstract

This paper uses a Global Vector Auto-Regression (GVAR) model featuring 21 emerging market and advanced economies to investigate the factors behind the dynamics of global trade flows, with a particular view on the issue of global trade imbalances and on the conditions of their unwinding. The GVAR approach enables us to make two key contributions: first, to model international linkages among a large number of countries, which is a key asset given the diversity of countries and regions involved in global imbalances, and second, to model exports and imports jointly. The latter proves to be very important due to the internationalization of production chains. The model can be used to gauge the effect on trade flows of various scenarios, such as an output shock in the United States, a shock to the US real effective exchange rate and shocks to foreign (e.g., German and Chinese) variables. Results indicate that changes in domestic and foreign demand have a much stronger effect on trade flows than changes in relative trade prices. In addition, we show how the model can be used to monitor trade developments, with an application to the Great Trade Collapse.

JEL codes: F10, F17, F32, C33

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1 Introduction

The question of what drives exports and imports at the country level has a very long history in the field of international economics. Already a quarter of a century ago, Goldstein and Kahn (1985) could write "Few areas in all of economics, and probably none within international economics itself, have been subject to as much empirical investigation over the past thirty five years as the behavior of foreign trade flows". More recently, the reasons behind the emergence of global trade imbalances in the early 2000s, as well as the conditions of their unwinding in the wake of the 2008 financial crisis, have attracted a lot of attention among academics and policy-makers, triggering in particular renewed interest in the role of the exchange rate and of relative demand terms in the adjustment of international trade flows. Studies on the issue have focused in particular on the magnitude of the dollar depreciation that would accompany a reduction in the US trade deficit (Obstfeld and Rogoff, 2005, 2006, Blanchard, Giavazzi and Sá, 2005). Similarly, the debate on what caused the sharp contraction in world trade towards the end of 2008 has been very intense (see Baldwin, 2009, for an early review) and underlines the importance of carefully modeling trade flows and their explanatory factors.[1]

One specific aspect of the above questions that calls for particular attention - and largely motivates the approach that we follow in this paper - is the multilateral nature of international trade and of global imbalances. Indeed, the notion of global trade imbalances cannot be subsumed to one country, or even to one country pair; rather, it involves a large number of countries. Unfortunately, the multi-country dimension of the problem at stake is generally overlooked, as existing papers focus on a small subset of countries. In papers using panel regressions, such as Chinn and Prasad (2003) and the subsequent literature using this framework, the countries that compose the panel are often treated as independent units and dynamic cross-country spillovers are ignored. Similarly, recent studies aiming to understand trade flows and their reaction to demand shocks typically model each country individually, not allowing for the complex cross-country interlinkages that characterize the global economy.

The present paper aims to fill this gap by using a Global Vector Auto-Regression model (GVAR). This approach enables us to model cross-country spillovers and allows us to answer questions such as, for instance, what are the effects of a slow-down in domestic demand in the United States on the global economy, i.e., not only the direct impact of lower US demand on US imports, but also the indirect effect on demand from foreign countries and, in turn, on US exports. To our knowledge there is only one paper – Greenwood-Nimmo, Nguyen and Shin (2010) – that has applied this

[1] These two issues (global imbalances and the dynamics of trade flows in the aftermath of demand shocks) are of course very closely related, given that “the gap between exports and imports ineluctably falls at the same pace as the underlying export and import flows” (Baldwin and Taglioni, 2009).

technique to the issue of trade flows and global imbalances. This paper differs from theirs in many respects; first, on the estimation and model design, we are the only one to identify which long-run macroeconomic equilibrium relations, among a battery of theory-funded ones, hold among the variables of our framework and, after careful testing, to impose them in our GVAR model. Second, on the applications of the model, while they focus only on the forecasting performance, we look mainly at the effects of (generalized) US and foreign shocks on selected variables with the aim of assessing, among other things, the effects of changes in domestic and foreign demand and in relative prices on trade flows. This way we can therefore contribute also to the debate on trade elasticities.

This paper is related to two main strands of the literature: the econometric literature on GVAR models and the empirical literature on trade and open economy macroeconomics, which aims to estimate trade elasticities. Starting with the former, the present paper builds on previous contributions to the GVAR literature, in particular Pesaran, Schuermann and Weiner (2004), Pesaran and Smith (2006), as well as Dées et al. (2007a, 2007b).[2] The GVAR framework was applied in the past to a variety of questions. This includes an analysis of the international linkages of the euro area (Dées et al., 2007a), a credit risk analysis (Pesaran et al., 2006), and the construction of a theoretically coherent measure of steady-state of the global economy (Dées et al., 2009). To our knowledge this paper presents, together with the paper of Greenwood-Nimmo et al. (2010), the only application of the GVAR methodology to the issue of international trade and global imbalances.

Turning to the trade literature, if one abstracts from the foreign variables featured in the GVAR model, the equations we estimate for individual countries are similar to the models used in other policy institutions for forecasting and simulation purposes, such as the New OECD International Trade Model (Pain et al., 2005), the ECB's Area Wide Model (Fagan, Henry and Mestre, 2001), the models presented in the IMF World Economic Outlook (IMF, 2007 and 2010)[3], the forecasting model developed at the World Trade Organization (Keck and Raubold, 2006), the Fed's FRB Global and USIT models (see e.g., Bertaut, Kamin and Thomas, 2008), research work on trade elasticities at the Federal Reserve Board (Hooper, Johnson and Marquez, 1998, 2000, Levin, Rogers and Tryon, 1997) and at the Federal Reserve Bank of Chicago (Crane, Crowley and Quayyum, 2007), etc. This family of models itself follows the contribution of Goldstein and Kahn (1985) and the literature reviewed within.

Compared to existing trade models, the present paper makes two main contributions. The first one is to link individual country trade models together through the foreign variables in a GVAR framework. This allows us to specifically model cross-country spillovers and to perform a significant

[2] A textbook treatment of GVAR approach can be found in Garratt et al. (2006).

[3] The IMF world Economic Outlook (2010) presents an empirical exercise aiming to understand the dynamics of real exports and imports in the wake of financial crises. Panel regression results are presented, in which each country is treated as an independent unit. The modeling strategy of the present paper is similar to the regressions presented in IMF (2010) and the literature reviewed therein, in that the main variables used to model trade flows are demand and relative import prices. The main innovation we introduce is to model exports and imports jointly and link countries together using for this the flexibility of the GVAR framework.

number of simulations. One feature of the model that is particularly appealing is that the restrictions under which the GVAR modeling strategy works are well known and easily interpretable as small open economy assumptions (see Chudik and Pesaran, 2011). Therefore, a fundamental difference with other existing global models of trade is that we are being explicit about the conditions under which our modeling framework is justified in a large system of endogenously determined variables. The second main contribution is that we estimate export and import equations jointly, in contrast to most of the existing literature, which typically estimates them separately. This proves to be very important given the substantial comovements between exports and imports observed in the data. Such comovements may come in particular from the vertical integration of production chains, also known as the fragmentation of production across borders (Hummels, Ishii and Yi, 2001), e.g., exporting firms typically import components, inducing comovements between exports and imports. The high import content of exports also clearly emerges from the analysis of OECD input-output tables and by considering the high correlation of imports and exports among OECD countries (e.g., see Bussière et al., 2011).

We use the results from our GVAR model to carry out two main exercises. In the first exercise, the model is used to simulate the effects of various shocks. Specifically, we look at two main scenarios: shocks to US variables (namely, a shock to the US real effective exchange rate and a shock to US domestic output) and shocks to foreign - from a US perspective - variables (for this latter case, we chose Germany and China, two countries that are systemically important and belong to two separate regions, which provides a sense of regional and global dynamics). We find that the average response of world exports to the US output shock is around 0.5%, against 0.17% for the shock to the US real effective exchange rate. Overall, the fact that world exports react substantially more to a (generalized) output shock in the United States than to a depreciation of the US dollar helps assess which variables are typically associated with trade adjustments: changes in domestic and foreign demand have a much stronger effect on trade flows than changes in relative trade prices. This result is in line with the fact that the adjustment in global imbalances observed in the wake of the 2008 financial crisis was not associated with a sharp depreciation of the dollar (contrary to what many observers had expected). It also underlines the importance of policy measures aiming to rebalance the world economy by stimulating demand in surplus countries, as outlined by G20 Leaders in the "Framework for Strong, Balanced and Sustainable Growth" and in the 2011 Cannes Action Plan for Growth and Jobs.[4] The large effect of a US output shock on exports from other countries may also indirectly illustrate the importance of the trade channel in the transmission of shocks across countries. Finally, we find that shocks to foreign variables (focusing on Germany and China) have the expected effects on the rest of the world (namely, shocks to Germany affect primarily European countries and shocks to China the Asian region). For each of these shocks, the paper provides a

[4] http://www.minfin.ru/common/img/uploaded/library/2011/11/Cannes_Action_plan_4_November_2011.pdf.

ranking of the countries, from most to least affected.

Our GVAR model is estimated on a sample going from the first quarter of 1980 to the last quarter of 2007. We intentionally decided to exclude the 2008-09 global crisis from the estimation of the model since the collapse in global trade that occurred at the end of 2008 and beginning of 2009, the so-called Great Trade Collapse (GTC), represents likely a structural break in the dataset that may affect the estimation results. However, since in the past few years the GTC has stimulated a wealth of theoretical and empirical analysis,[5] we also set out to use the model in a monitoring/conditional forecasting exercise, focusing on this unprecedented trade development. In this second application of the model, we aim to compare the growth rates of exports and imports of the 21 countries in the sample during the GTC with the model's prediction, conditioning on the observed values of real output and real exchange rates. The objective of this exercise is to assess whether the collapse in world trade that took place at the end of 2008 and beginning of 2009 can be rationalized by our model, i.e., whether the explanatory variables we use to model trade successfully account for this recent evolution. What makes this second exercise particularly interesting is that the collapse in world trade was particularly sharp, sudden (world exports contracted by more than 6% and 10% in the last quarter of 2008 and in the first quarter of 2009, respectively) and synchronized across regions. This trade development should hence be, in principle, better rationalized by a multi-country model, such as the GVAR, which is able to take cross-country spillovers into account. We find indeed that model performance is satisfying, particularly for advanced countries and most emerging market economies (for a few emerging market economies the performance of the model towards the end of 2008 and the beginning of 2009 is not as good, suggesting perhaps that other factors may have played a role). Although our forecasting exercise differs from that of Greenwood-Nimmo et al. (2010)[6], we share the same conclusion that the GVAR approach is satisfactory in monitoring and forecasting trade development and may prove highly useful for policy analyses.

The rest of the paper is organized as follows. Section 2 outlines the main features of the GVAR model. Section 3 reports the estimation results; it also motivates the modeling strategy regarding the choice of the long-run cointegrating relationships. Section 4 presents the results of the different

[5] The literature on the Great Trade Collapse is already too vast to be exhaustively reviewed here. The fact that world trade has fallen by so much more than world output constitutes a puzzle that many authors have aimed to solve. The composition of trade flows, richer in intermediate goods and in durable goods than output, has attracted a lot of attention (see in particular Levchenko, Lewis, and Tesar, 2010, Bems, Johnson, and Yi, 2010, and Eaton, Kortum, Neiman, and Romalis, 2011). Bussière et al. (2011) focus on the composition of demand based on input-output tables and review the literature. In addition, the role of trade credit and trade finance has also attracted a lot of attention (in particular Amiti, and Weinstein, 2011, Ahn, Amiti, and Weinstein, 2011, Feenstra, Li, and Yu, 2011 and Chor and Manova, 2011). Although trade credit probably played a role during the Great Trade Collapse, incorporating such factors in a systematic way in a GVAR model for so many countries does not appear to be a feasible extension of the model given current data availability.

[6] The main difference between the two forecasting exercises is that they compute *out-of-sample* forecasts of the core variables of their model by performing a probabilistic forecasting exercise, while we compute *conditional* forecasts for real exports and imports (conditionally on the demand variables and relative prices) by means of bootstrapping. Moreover, a comparison of the results is difficult since different information sets are used and they do not report central forecasts for exports and imports separately but only for the real trade balance of four economic areas.

model's applications, focusing on specific adjustment scenarios, on trade developments during the GTC, and on US long-run trade elasticities. Section 5 concludes.

2 The GVAR Approach to Global Macroeconomic Modelling

One recurrent problem in the global macroeconometric literature is the heavy parametrisation of the empirical models. This issue, which is sometimes referred to as the "curse of dimensionality"[7], arises when the number of variables is relatively large compared to the available time dimensions, making it impossible to estimate an unrestricted global VAR even when as few as two or three macroeconomic variables per economy are included. The restrictions that have been imposed in the literature to overcome this problem can be broadly divided into two categories: (*i*) data shrinkage (as, for instance, in factor models) and (*ii*) shrinkage of parameter space (e.g., spatial models or Bayesian shrinkage). An alternative way to overcome the dimensionality problem is the GVAR modeling approach originally proposed by Pesaran, Schuermann and Weiner (2004).

The GVAR approach can be briefly described in two steps. In the first step, country-specific small-dimensional models are estimated, which include domestic variables and cross section averages of foreign variables. In the second step, the estimated coefficients from the country-specific models are stacked and solved in one big system (global VAR), which can be used for different purposes, such as the analysis of the transmission of shocks across countries, the forecast of variables, etc.

The use of a GVAR framework can be motivated in several different ways: Dées et al. (2007a), for instance, derive the GVAR approach as an approximation to a global common factor model, while Chudik and Pesaran (2011) obtain the GVAR approach as an approximation to a large system, where *all* variables are *endogenously* determined. We follow the latter approach in motivating our analysis below.

Let $\mathbf{x}_{it}$ denote a $k_i \times 1$ vector of macroeconomic variables belonging to country $i \in \{1, 2, .., N\}$ where N denotes the number of countries. Collect all variables in the $k \times 1$ vector $\mathbf{x}_t = (\mathbf{x}'_{1t}, \mathbf{x}'_{2t}, ..., \mathbf{x}'_{Nt})'$ with $k = \sum_{i=1}^{N} k_i$ denoting the total number of variables. Our starting point is to assume that all macroeconomic variables in the global economy are endogenously determined. Few would dispute this rather general assumption: there are complex trade and financial linkages among economies and agents are forward looking. In the case of trade flow variables, such as aggregate exports and imports in country $i \in \{1, 2, .., N\}$, endogeneity is implicit in their construction since the exports from country i to country j are the imports from country j to country i and vice versa. Suppose that the vector of all collected macroeconomic variables in the world economy is generated from the following factor augmented VAR model,

$$\boldsymbol{\Phi}(L, p)(\mathbf{x}_t - \boldsymbol{\delta}_0 - \boldsymbol{\delta}_1 t - \boldsymbol{\Gamma}\mathbf{f}_t) = \mathbf{u}_t, \tag{1}$$

[7] This expression was coined by Richard Bellman.

where $\mathbf{\Phi}(L,p) = \mathbf{I}_k - \sum_{\ell=1}^{p} \mathbf{\Phi}_\ell L^\ell$, $\mathbf{\Phi}_\ell$ for $\ell = 1,..,p$ are $k \times k$ matrices of unknown coefficients, $\boldsymbol{\delta}_s$ for $s = 0,1$ are $k \times 1$ vectors capturing the deterministic trends, $\mathbf{f}_t$ is an $m \times 1$ vector of unobserved common factors, $\mathbf{\Gamma}$ is a $k \times m$ matrix of factor loadings and $\mathbf{u}_t$ is a $k \times 1$ vector of cross sectionally weakly dependent error terms.[8] The number of parameters to be estimated grows at quadratic rate with the number of variables and it is therefore not feasible to consistently estimate the unrestricted VAR model (1) if k and T are of the same order of magnitude.

To cope with the "curse of dimensionality" problem of such a big model, Chudik and Pesaran (2011) proposed a shrinkage of parameter space approach, which shrinks the parameter space only in the limit as $N \to \infty$. Assuming that the coefficients corresponding to the foreign variables in the matrix polynomial $\mathbf{\Phi}(L,p)$ are small (of order N^{-1}), it can be shown that, under few additional assumptions as stated in Chudik and Pesaran (2011) for stationary variables and in Chudik (2008) for variables integrated of order 1,

$$\mathbf{\Phi}_{ii}(L)(\mathbf{x}_{it} - \boldsymbol{\delta}_{0,i} - \boldsymbol{\delta}_{1,i}t - \mathbf{\Gamma}_i \mathbf{f}_t) - \mathbf{u}_{it} \overset{q.m.}{\to} \mathbf{0}_{k_i}, \tag{2}$$

as well as

$$\mathbf{f}_t - \left(\mathbf{\Gamma}_i^{*\prime}\mathbf{\Gamma}_i^*\right)^{-1}\mathbf{\Gamma}_i^{*\prime}(\mathbf{x}_{it}^* - \boldsymbol{\delta}_{0i}^* - \boldsymbol{\delta}_{1i}^* t) \overset{q.m.}{\to} \mathbf{0}, \tag{3}$$

uniformly in $t \in \{1,2,...,T\}$ as $N,T \overset{j}{\to} \infty$, such that $T/N \to 0$;[9] where the "star" variables are the following cross section averages

$$\mathbf{x}_{it}^* = \mathbf{W}_i'\mathbf{x}_t,\ \mathbf{\Gamma}_i^* = \mathbf{W}_i'\mathbf{\Gamma},\ \boldsymbol{\delta}_{si} = \mathbf{W}_i'\boldsymbol{\delta}_s \text{ for } s = 0,1,$$

$\mathbf{\Phi}_{ii}(L) = \mathbf{I}_{k_i} - \sum_{\ell=1}^{p} \mathbf{\Phi}_{\ell,ii} L^\ell$, $[\mathbf{\Phi}_{\ell,ij}]$ constitutes a conformable partitioning of the $k \times k$ matrix $\mathbf{\Phi}$ into $k_i \times k_j$ submatrices and matrix $\mathbf{W}_i$ is a $k \times k_i^*$ dimensional matrix of weights that defines k_i^* country-specific cross section averages of foreign variables. Matrix $\mathbf{W}_i$ can be any arbitrary non-random (or pre-determined) matrix of weights as long as it is granular, namely the following conditions are satisfied.

$$\|\mathbf{W}_i\| = O\left(N^{-\frac{1}{2}}\right), \tag{4}$$

and

$$\frac{\|\mathbf{W}_{ij}\|}{\|\mathbf{W}_i\|} = O\left(N^{-\frac{1}{2}}\right), \tag{5}$$

where $[\mathbf{W}_{ij}]$ represents a conformable partitioning of $k \times k_i^*$ matrix $\mathbf{W}_i$ into $k_j \times k_i^*$ dimensional submatrices $\mathbf{W}_{ij}$.

Equation (3) implies that the unobserved common factors can be approximated by cross section

[8] See Chudik et al. (2011), Pesaran and Tosetti (2011) and Bailey et al. (2012) for a definition and a discussion of strong and weak cross section dependence.

[9] $T/N \to 0$ is required in the case of variables integrated of order one(see Chudik, 2008), while $T/N \to \kappa$, where $0 \leq \kappa < \infty$, is sufficient in the case of stationary variables (see Chudik and Pesaran, 2011).

averages of endogenous variables, an idea originally proposed by Pesaran (2006).[10] Together with equation (2), we obtain the following country-specific VARX* (p_i, q_i) models

$$\mathbf{\Phi}_{ii}(L, p_i)\,\mathbf{x}_{it} \approx \mathbf{a}_{i0} + \mathbf{a}_{i1}t + \mathbf{\Lambda}_i(L, q_i)\,\mathbf{x}_{it}^* + \mathbf{u}_{it}, \tag{6}$$

where the cross section averages $\mathbf{x}_{it}^*$ are asymptotically uncorrelated with the errors $\mathbf{u}_{it}$, and $p_i = q_i = p$. Lags for domestic and foreign variables would no longer be the same if the unobserved common factors were introduced directly in the residuals in the infinite dimensional VAR model (1).[11] We introduce the notation p_i and q_i because we allow for different lags across countries as well as different lags for domestic and foreign variables in the empirical application below.

Once estimated on a country by country basis, individual VARX* models (6) for $i = 1, 2, .., N$, can be stacked together and solved as one system by explicitly taking into account that $\mathbf{x}_{it}^* = \mathbf{W}_i'\mathbf{x}_t$. In particular, we can write models (6) as

$$\mathbf{B}_i(L, p_i, q_i)\,\mathbf{x}_t = \mathbf{a}_{i0} + \mathbf{a}_{i1}t + \mathbf{u}_{it}, \tag{7}$$

where

$$\mathbf{B}_i(L, p_i, q_i) = \left[\mathbf{\Phi}_i(L, p_i)\,\mathbf{E}_i', \mathbf{\Lambda}_i(L, q_i)\,\mathbf{W}_i'\right],$$

and $\mathbf{E}_i$ is $k \times k_i$ is a selection matrix that selects vector $\mathbf{x}_{it}$, namely $\mathbf{x}_{it} = \mathbf{E}_i'\mathbf{x}_t$. Let $p = \max_i\{p_i, q_i\}$ and construct $\mathbf{B}_i(L, p)$ from $\mathbf{B}_i(L, p_i, q_i)$ by augmenting $p - p_i$ or $p - q_i$ additional terms in powers of L by zeros. Stacking equations (7) for $i = 1, 2, .., N$ yields the following GVAR model

$$\mathbf{G}(L, p)\,\mathbf{x}_t = \mathbf{a}_0 + \mathbf{a}_1 t + \mathbf{u}_t, \tag{8}$$

where $\mathbf{u}_t = (\mathbf{u}_{1t}', ..., \mathbf{u}_{Nt}')'$, $\mathbf{a}_\ell = (\mathbf{a}_{\ell 1}', ..., \mathbf{a}_{\ell N}')'$ for $\ell = 0, 1$, and

$$\mathbf{G}(L, p) = \begin{pmatrix} \mathbf{B}_1(L, p) \\ \vdots \\ \mathbf{B}_N(L, p) \end{pmatrix}.$$

GVAR model (8) can be used for impulse response or persistence profile analysis in the usual manner.

3 The GVAR Trade Model

3.1 The Choice of the Variables

There are many modeling choices involved in the construction of a GVAR model. The first one relates to the selection of the variables to include in the model. In this paper, since we want to model global trade, we include real exports and imports, which are our main variables of interest.

[10] The minimum number of country-specific cross section averages, $\min_{i\in\{1,..,N\}} k_i^*$, has to be at least as large as the number of unobserved common factors for the consistent inference of the country-specific models (2).

[11] See Chudik and Pesaran (2012).

Next, we include real output and the real effective exchange rate, which play the role of demand and relative price terms. Finally, to account for possible common factors influencing global trade imbalances, we include the price of oil and cross section averages of the endogenous variables, the latter capturing possible *unobserved* common factors.[12]

3.2 Data

A second modeling choice involves the appropriate time and country coverage. In our case, we want to maximize data availability, in order to cope with the "curse of dimensionality" problem, conditional, however, on the reliability of the available time series. These considerations lead us to exclude countries for which the time series are too short or too volatile. Hence, our country sample comprises 21 countries, including 14 advanced countries and 7 emerging market economies.[13] We use quarterly data starting in 1980 and ending in 2007. We decided to exclude the years of the global crisis and subsequent recovery from the estimation since the Great Trade Collapse occurred at the end of 2008 and beginning of 2009 represents most likely a structural break in the dataset that may affect significantly the estimation results of our global trade model. Unlike Dées et al. (2007a), we do not consider the euro area as a whole, including, instead, the five largest euro area countries: Germany, France, Italy, Spain and the Netherlands. There are several reasons behind this choice. First, available time series are much longer for the individual countries than for the aggregate (as the euro was introduced in 1999). Second, although some trade series are computed backwards (for example, the IMF WEO provides current account data for the euro area starting in 1997), it is questionable to treat the euro area as a single entity before the euro was actually created, especially when it comes to assessing the impact of exchange rate changes on trade.[14] The different choice made by Dées et al. (2007a) can be easily reconciled with the specific focus of their paper on the euro area. Finally, by adding five countries (at the cost of removing the aggregate euro area), we simply increase the N dimension of the panel, which enables us to reach a better understanding of the determinants of trade across countries.

Our country-specific VARX* models include 9 variables.[15] In addition to the 5 key series (exports, imports, GDP, real exchange rate and the price of oil, all in real terms and in logs)[16], we construct four country-specific foreign series corresponding to cross section averages of exports, imports, output

[12] We refer to the earlier working paper version of this article (see pp.11-13 in Bussière, Chudik and Sestieri, 2009) for a discussion of the choice of the best measure of relative prices and foreign and domestic demand, and of the issue of the comovements between exports and imports.

[13] Due to the difficulty of finding reliable time series on real exports and imports for some countries for the whole period 1980Q1-2007Q4, our country coverage is slightly smaller than that of Dées et al. (2007a). The full list of countries is presented in Table 1.

[14] Nominal exchange rate fluctuations of the legacy currencies vis-à-vis each other were substantial in the years preceding 1999, especially if one goes back to 1980.

[15] Table 1 reviews the data sources in details.

[16] We used seasonally adjusted data. When the original series downloaded from the IMF and the other sources were not seasonally adjusted, we seasonally adjusted them ourselves. See the working paper version of this article (Bussière, Chudik and Sestieri, 2009) for details.

and real exchange rate in foreign countries. Thus, the country specific vector of domestic variables is

$$\mathbf{x}_{it} = (ex_{it}, im_{it}, y_{it}, rer_{it})' \text{ for } i \in \{1, .., N-1\},$$

while for the US model (country $i = N$) we follow Dées et al. (2007a) and include the (logarithm of) real price of oil as endogenous variable,

$$\mathbf{x}_{Nt} = \left(ex_{Nt}, im_{Nt}, y_{Nt}, rer_{Nt}, p_t^{oil}\right)'.$$

The corresponding vector of country-specific foreign variables is

$$\mathbf{x}_{it}^* = \left(ex_{it}^*, im_{it}^*, y_{it}^*, rer_{it}^*, p_t^{oil}\right)' \text{ for } i \in \{1, .., N-1\},$$

and for the US,

$$\mathbf{x}_{Nt}^* = (ex_{Nt}^*, im_{Nt}^*, y_{Nt}^*, rer_{Nt}^*)'.$$

Our set of real exchange rates does not constitute a closed system and therefore we treat this variable as any other endogenous variable.[17]

To construct the foreign variables we use trade weights that correspond, for each country in the sample, to the trade shares of foreign countries in total exports and imports over the period 2000-2002.[18] The choice of the weights one should employ in constructing relative variables is still an open question in the empirical literature. The preferred option in open economy macroeconomic modeling typically consists in using trade weights. Another option is to use GDP weights (i.e., shares of individual countries on the world output). It has been shown however that weights are likely to be of secondary importance if certain conditions are satisfied, namely when the so-called small open economy or "granularity" conditions apply (see Chudik and Pesaran, 2011).

In the estimation of the VARX* models, we also include dummy variables to take into account various episodes of currency and balance of payments crises.[19]

3.3 Individual Country Models

Following the GVAR literature, we estimate country-specific VARX* models (6) , which can be written in the following error-correction representation:

$$\Delta\mathbf{x}_{it} = \mathbf{c}_{i0} - \boldsymbol{\alpha}_i\boldsymbol{\beta}_i' \left[\mathbf{z}_{i,t-1} - \boldsymbol{\gamma}_i (t-1)\right] + \boldsymbol{\Lambda}_{i0}\Delta\mathbf{x}_{it}^* + \boldsymbol{\Psi}_i (L) \Delta\mathbf{z}_{i,t-1} + \mathbf{u}_{it}, \quad (9)$$

where $\mathbf{z}_{it} = (\mathbf{x}_{it}', \mathbf{x}_{it}^{*\prime})'$, $\boldsymbol{\alpha}_i$ is a $k \times r_i$ matrix of rank r_i and $\boldsymbol{\beta}_i$ is a $(k_i + k_i^*) \times r_i$ matrix of rank r_i. It is clear from (9) that this formulation allows for possible cointegration within domestic variables as

[17] In Dées et al. (2007a, 2007b, and 2008) real exchange rates are constructed as a closed system where the N-th effective real exchange rate can be derived as a function of the remaining $N-1$ exchange rates. Our real effective exchange rates come from IMF IFS and BIS databases and therefore they cannot be considered as a closed system.

[18] The trade weights are reported in Table 2 of the working paper (see Bussière, Chudik and Sestieri, 2009).

[19] The dummy list is not provided in the paper but it remains available upon request.

well as between domestic and foreign variables.

To estimate (9), several choices must be made about the unit root properties of the data, the number of cointegrating vectors and the way foreign variables should be treated. We address the two latter issues in details in the following subsections.[20]

3.4 Long-run Relations

In the economic literature, there is a reasonable degree of consensus about the long-run properties of a macroeconomic model, no matter the chosen econometric framework. On the contrary, the identification of the short-run dynamics of such models is still controversial, as identification schemes often lack support from economic theory or are rejected by the data.[21] While theories of the short-run relations generally focus on the optimisation behavior of agents in a particular moment of time, theories of the long-run relations look at equilibrium conditions between the observed variables that hold over a certain (longer) period of time. In the data, we generally observe deviations from such equilibria, in the form of linear combinations of the variables under consideration (the term $\boldsymbol{\beta}_i' \left[\mathbf{z}_{i,t-1} - \boldsymbol{\gamma}_i \left(t-1\right)\right]$ in (9) represents these deviations, while $\boldsymbol{\beta}_i$ is the matrix containing the parameters that describe such equilibrating relations).

The identification of such relations, however, is not straightforward since there are many candidate long-run relations borrowed from economic theory, which might or might not hold in our framework and need to be tested.

Among our variables, namely $\{y_{it}, ex_{it}, im_{it}, rer_{it}\}$ (plus the oil price and the corresponding foreign variables), we consider the following well-known long-run relationships: (*i*) relative Purchasing Power Parity (PPP), which states that the real exchange rate is stationary (at least when the same baskets of goods are used in the construction of price indices), (*ii*) output convergence, which implies that domestic and foreign output cointegrates, (*iii*) stationarity of trade balance[22], and (*iv*) relaxation of relative PPP hypothesis by taking into account possible Balassa-Samuelson effect. Assuming export and import prices (expressed in the same numeraire) cointegrates, stationarity of nominal trade balance would imply that the export volumes and import volumes cointegrate as well. We note that the rejection of the cointegration between export and import volumes does not necessary imply that the nominal trade balance is not stationary. Regarding the Balassa-Samuelson effect, the relaxation of PPP would be necessary only if output convergence did not hold.

In addition, we consider two possibilities for the trade equations. The traditional export and

[20] For a discussion of the unit root properties of the variables in the model we refer to the working paper version of this article (see p. 21 in Bussière, Chudik and Sestieri, 2009).

[21] See Garratt et al. (2006) for a comprehensive review of long- and short-run identification methods in the macroeconometric literature.

[22] Stationarity of the trade balance implies that export and import *values* cointegrate with each other, whereas we consider here export and import *volumes* (i.e., in real terms). Accordingly, while we considered the possibility that real exports and imports cointegrate with each other with coefficients [1,-1], our empirical results suggest that this is not the case for most countries.

import volume long-run equations in the literature feature only demand and relative price terms. However, due to fragmentation of production, imports could be part of the export cointegrating relations (this is the case when some of the imports constitute inputs for the manufacturing process of exported goods) or, on the other hand, exports could be part of the import volume long-run relation (this would be the case when part of the manufacturing process is outsourced abroad). We therefore introduce "enhanced" trade equations, where the possibility of cointegration between exports and imports is also taken into account. All long run relations considered in this paper are summarized in the table below.

Theoretical Long-run Relations

Purchasing Power Parity	$rer_{it} \sim I(0)$
Output Convergence	$y_{it} - y^*_{it} \sim I(0)$
Balassa-Samuelson Effect	$rer_{it} - \omega_i (y_{it} - y^*_{it}) \sim I(0)$
Stationarity of Real Trade Balance	$ex_{it} - im_{it} \sim I(0)$
Traditional trade equations:	
Export	$ex_{it} - \delta_{i1} rer_{it} - \delta_{i2} y^*_{it} \sim I(0)$
Import	$m_{it} - \gamma_{i1} rer_{it} - \gamma_{i2} y_{it} \sim I(0)$
"Enhanced" trade equations:	
Export	$ex_{it} - \delta_{i1} rer_{it} - \delta_{i2} y^*_{it} - \delta_{i3} im_{it} \sim I(0)$
Import	$im_{it} - \gamma_{i1} rer_{it} - \gamma_{i2} y_{it} - \gamma_{i2} ex_{it} \sim I(0)$

It is important to stress that a possible misspecification of the cointegrating relationships can have a severe impact on the constructed GVAR model, with implications for the stability of the GVAR, the behavior of the impulse response functions and the shape of the persistence profiles. For all these reasons, we pay particular attention to testing for the number of cointegrating vectors and to their identification. We start with the traditional system approach, treating all 9 country-specific variables in one VARX* model and then we conduct sensitivity tests to different choices of the lags for domestic and foreign variables. With the exception of few countries, we found that no conclusive inference about the number of long-run relations could be made. This seems to be related to the dimensionality problem, because treating all 9 variables in one system requires lots of coefficients to be estimated, even when foreign variables are treated as weakly exogenous. We conduct Monte Carlo experiments to investigate this issue further, and found out that indeed the performance of cointegrating tests is not very good for the dimension of our systems. Motivated by these findings, we conduct also a parsimonious approach, where only selected subsets of country-specific variables are jointly estimated in one system at the same time. Estimating smaller dimensional VARs for subsets of country-specific variables gives us additional pieces of evidence to consider. Testing the stationarity of real exchange rate, which is a trivial example of system with one variable only, is a valid test for the relative PPP hypothesis. Similarly, treating the difference between domestic and country-specific foreign output and the real effective exchange rate in a bivariate VAR and testing for cointegration is a valid test for the Balassa-Samuelson relation.[23]

3.4.1 The chosen long-run cointegrating relationships

How to put various pieces of evidence together is not straightforward since the evidence from the cointegration tests often depend on the number of lags, leading to contradictory results. Following the results from our parsimonious approach, we chose not to impose PPP, output convergence, stationarity of the trade balance or the Balassa-Samuelson relationship for any country.

Regarding the trade equations, we follow a simple rule. A cointegrating vector is imposed only if we have evidence from smaller-scale (3- or 4-variable) models and only in the case in which the elements of the cointegrating vector satisfy the signs suggested by the economic theory. The final choice for the number of cointegrating vectors and their estimates are reported in Table 2. These cointegrating vectors were then imposed in the full country-specific VARX* models, where we also test for the validity of the implied overidentifying restrictions in a full system approach. These restrictions are tested using the log-likelihood ratio statistic at the 1% confidence level. The last column of Table 2 shows the critical values of this test, which have been computed by bootstrapping from the solution of the GVAR model[24]; none of the imposed overidentifying restrictions has been rejected, which is reassuring.

Two countries were treated differently: the Netherlands and China. The Netherlands is the only country for which unit root tests reject the null of non-stationarity for both the export and import series, which is in line with later finding of stationarity of the real trade balance. Since the Netherlands is a small open economy where a large share of imports is re-exported, we do impose a cointegrating relationship featuring imports and exports for this country. In the case of China, any attempt to identify the long-run relationships ended up to be unsuccessful, resulting in instability of the GVAR model and/or unreasonable persistence profiles. For this reason, China is the only country for which we impose 3 exactly identified cointegrating vectors, as suggested by the cointegration test conducted on the VARX* model.

The bootstrap means of the persistence profiles showing the effect of system wide shocks to the cointegrating relationships are reported in Figure 1.[25] Persistence profiles make it possible to examine the speed at which the long-run relations converge to their equilibrium states. All persistence profiles in Figure 1 are well behaved, which is again reassuring for our choice of the long-run overidentifying

[23] For a detailed description of our estimation and testing procedure and the results of the Monte Carlo experiments, see the appendix of the working paper (see Bussière, Chudik and Sestieri, 2009).

[24] See the appendix of Dées et al. (2007b) for a detailed description of the GVAR bootstrapping procedure and of the log-likelihood ratio statistic for testing over-identifying restrictions on the cointegrating relations.

[25] Persistence profiles were introduced by Pesaran and Shin (1996) to examine the effect of system-wide shocks on the dynamics of the long-run relations. See also Dées et al. (2007b) for a theoretical exposition of persistence profiles in the context of GVAR. Persistence profiles have a value of unity at the time of impact and should converge to zero as the time horizon reaches infinity.

relations.[26]

3.5 Robustness Tests and Further Results

One important issue that may arise in the present estimation framework is the potential instability of the parameters over time. For example, Hooper, Johnson and Marquez (2000) report extensive stability tests for trade equations among the G7 countries (based on Chow tests, they conclude that the equations are stable overall, but they also find some instability for the European countries, especially Germany in the wake of the reunification). Partly, we have preempted the problem by using time dummies for specific events such as the German reunification and currency crises. Nevertheless, to check whether our parameters are stable over time, we performed a battery of structural break tests: PK_{sup} and PK_{msq} are based on the cumulative sums of OLS residuals, R is the Nyblom test for time-varying parameters and QLR, MW and APW are the sequential Wald statistics for a single break at an unknown change point.

The results, reported in Table 3, show that there is broad evidence in favour of the stability of the parameters. The main reason for the rejections seems to be breaks in the error variances as opposed to breaks in the parameter coefficients. Once breaks in error variances are allowed for by performing the heteroskedasticity-robust version of the tests, parameters seem to be reasonably stable. In the simulation exercises, the possibility of breaks in variance is dealt with by using bootstrapped means and confidence intervals in the persistence profiles and in the generalized impulse responses analysis.

4 Empirical Results

In this section we present a selection of results, which correspond to different applications of our GVAR model of trade.[27]

In particular, we use the model to simulate the effects that shocks to selected variables of our system may have on the other variables over time. To this aim, given the difficulty in identifying the structural shocks in the GVAR framework, we make use of the generalized impulse response function (GIRF) approach.[28] Then, we present a forecasting exercise that aims at addressing the following question: is the sharp contraction in trade experienced by the world economy in the last quarter of 2008 and first quarter of 2009 consistent with the observed fall in real output and the observed real exchange rate configuration? To answer this question we use our GVAR model to compute the forecast of real exports and imports for the 21 countries in our model for these two quarters conditioning on the observed values of real outputs and real exchange rates. Finally, we

[26] Eigenvalues of the solved GVAR model provide another way of checking the dynamics of the system. The largest eigenvalue of the constructed GVAR model is equal to one in absolute value. There are exactly 58 eigenvalues that are equal to one (in absolute value), which is equal to the number of variables minus the number of cointegrating relations (85-27), and therefore it matches the number of overall stochastic trends.

[27] Given the space constraint, we present only selected results for each application.

[28] This approach has been proposed by Koop, Pesaran and Potter (1996) and further developed in Pesaran and Shin (1998).

briefly review and discuss the empirical literature on US trade elasticities in the light of the results of our model.[29]

4.1 Simulation Results

Our GVAR model contains 85 variables (4 variables per country plus the price of oil). Hence, this is also the total number of possible simulations we can run to assess the effects of a shock to one of the variables in our system on all the others. Given the strong interest that academics and policy-makers have shown on the possible factors that may reduce the US current account deficit, we first present the results for two simulations that have been generally studied in the literature: a shock to US domestic output, and a shock to the US real exchange rate. The other two simulations for which we present the results are a shock to German real output (which proxies an expansionary shock in Europe) and a shock to Chinese real imports (which proxies an expansionary shock in Non-Japan Asia).

In the absence of strong a priori information to identify the short-run dynamics of our system (with 85 variables exact identification would require 3570 restrictions, a clear overstretch of the data), we use the generalized impulse response function (GIRF) approach. Clearly, when we shock US output we will not be able to distinguish between the possible causes of the shift, but the response of the other variables in the system would still be informative about the implications of this shock for the evolution of the US current account.[30] The GIRF have also the nice property of being invariant to the ordering of the variables, which is of particular importance in big macroeconomic systems.

4.1.1 Shock to the US Variables

The first shock that we consider is a positive shock to domestic output in the US. A one-standard-deviation shock corresponds in this case to an increase of US GDP of 0.6% on impact. One noticeable result is the large effect on US imports, which increase by around 2% after one year and by around 1.3% in the long-run (after 3 years). In addition, we find that this shock would have a significant and large effect on foreign countries. Panels A and B of Figure 2 show the effects of this shock after one year on output and exports, respectively, for all the countries in the model. The red squares represent the bootstrapped mean values of the GIRF across the sample, while the 90% bootstrapped confidence intervals are represented by the thinner black lines. Unsurprisingly, a positive shock to US output would stimulate output in almost all foreign countries (Panel A). The effect is especially large in the US neighboring countries, such as Canada and Mexico. It also has a strong effect on some European countries, particularly on the smaller ones (Switzerland and the Netherlands). Surprisingly perhaps, many Asian countries are not significantly affected by the shock (a noticeable exception

[29] An additional application of the model, which consists of the generalised forecast error variance decomposition of some variables of interest, can be found in the working paper (see Bussière, Chudik and Sestieri, 2009).

[30] Note that in the paper we use the term "shock", although we recognise that this might not be entirely appropriate in this framework, given the lack of identification of structural shocks in the system.

being Singapore, for which the effect is large). Large Asian countries appear to be relatively insulated from the shock (esp. China and Japan). The same chart also shows the effect of the same shock on geographical regions, which are constructed by grouping together the countries in these regions using GDP weights.[31]

Panel B presents the response of exports to the US output shock: exports increase significantly in almost all countries in the world, consistently with the rise in US imports. The effects of higher growth abroad will also reflect in an increase of US exports, which is found to be statistically and economically significant in the first couple of years after the shock. The ranking of countries in panel A and panel B appears to match broadly, suggesting that the geographical proximity and the trade linkages are important channels in the transmission of a US output shock to the rest of the world. For instance, it is very intuitive to find that Canada and Mexico are among the countries whose exports and output increase by the largest amounts. In the case of the reaction of exports to a rise in US output, one can note that the effect is very substantial in many countries: as our model is log-linear, this also implies that a US slow-down is generally associated with a fall in world trade.

The next shock that we consider is a positive shock to the US real effective exchange rate, which corresponds to an appreciation of roughly 2.5% on impact (see panel C and D of Figure 2). The shock has an unambiguous effect on US real exports, which fall by 1.3% in the first year. This result can be reconciled with recent evidence showing a substantial acceleration in US exports towards the end of 2007 and the start of 2008, in the wake of the marked dollar depreciation that took place previously. However, the magnitude of the effect seems quite large, compared to other results in the literature.[32] On the import side, by contrast, the appreciation fails to significantly lift up US imports, which increase by 0.7% after one year and by roughly 1% in the long-run (however, the effect on US imports becomes statistically significant only after year 2).[33] This is in line with a growing body of the literature showing that pass-through is very limited in the US (see, e.g., Marazzi et al., 2005). As a result of the low pass-through to US import prices, relative prices (the ratio of US import prices to US domestic prices) do not react significantly when the dollar fluctuates, which considerably limits the expenditure switching effect. Finally, in spite of the effect on net exports, there is no marked effect on US real output: this is not surprising given that the United States is a relatively closed economy.

The chart in panel C suggests that foreign economies are heterogeneously affected by an appreciation of the US real effective exchange rate, which triggers very different shifts in the real effective

[31] The region Europe includes the 5 largest euro-area countries, i.e. Germany, France, Italy, Spain and the Netherlands; Asia includes China, Thailand, Korea and Singapore while Latin America includes Mexico, Brazil and Argentina. Note that the confidence intervals for these regions are also computed by bootstrap.

[32] Our preliminary results imply that a 10% appreciation of the dollar would trigger a fall by more than 5% in US real exports, which appears to be large. Having said that, Pain et al. (2005) also find a high effect (5.2%), and Hooper, Johnson and Marquez (2000) an even higher effect (their elasticity is above one). However, these comparisons are not without caveats because they refer to a different definition of relative prices.

[33] This result is not shown in the paper but remains available upon request.

exchange rates of foreign countries. Emerging Asian countries, whose currencies tend to follow the dollar (sometimes through hard pegs), also tend to experience an appreciation in effective terms. The same effect is found for some Latin American countries. Among European countries, instead, the dollar appreciation tends to be associated with a *depreciation* of the currency in effective terms. However, for many European countries (the UK, Sweden, Norway, Italy, Spain) the effect is not statistically significant.

The reaction of real exports in foreign countries (panel D) basically mirrors the effect of the real dollar appreciation on foreign countries' exchange rates. Japanese exports are those that are most strongly affected by the dollar appreciation, which is in line with the result of Japan being the country that depreciates most. Europe is also significantly affected by the appreciation and registers a sizeable increase in its exports, which is however somewhat smaller than the increase resulting from a US output shock. The effect on exports in Non-Japan Asian (NJA) countries is basically zero since the currencies of these countries tend to follow the appreciation of the US real exchange rate. The effect on imports (not reported here) does not appear to be significantly different from zero in any of the foreign economies.

4.1.2 Shock to Foreign Variables

When moving to foreign - from a US perspective - economies, many possible simulations could be performed due to the large number of countries in our sample. However, to keep the paper within reasonable space limits, we show only two simulation exercises to illustrate the way the model can be used. Our choice of the foreign variables coincides with the willingness to assess how expansionary shocks in Europe and Asia would influence global real trade flows. Figure 3 show the results of a shock to German output and a shock to Chinese import on the rest of the world output and exports.

Germany being the third largest advanced economy in the world and the first economy in the Eurozone, the effect of a shock to German output is more likely to be relevant for the configuration of global trade imbalances (compared to smaller countries). A positive one-standard-deviation shock to German GDP, which corresponds to an increase by 0.8% at the time of the impact, is found to have economically and statistically significant effects on other European countries (see panel A of Figure 3). This is not surprising given the strength of the European business cycle. Interestingly, we find that the effect of a positive shock to German output on US output is not negligible, at above 0.1%. Higher output growth in Germany would also have a positive effect on foreign exports (see panel B). In particular, the effect on US exports is found to be significant and roughly stable at 0.4% for the first two years.

As far as Asia is concerned, we focus on the effects of shocks to Chinese variables given the increasing importance of this country in global trade. The results of a shock to Chinese real imports on rest of the world output and exports are shown in panel C and D of Figure 3. Differently from the US and German cases, we chose here to look at a shock to Chinese imports directly. Although for most of the countries the confidence intervals are quite large and some of the GIRF are therefore not statistically significant[34], the general picture is still informative. A one-standard-error shock to Chinese imports, which corresponds to an increase of 1.9% at the time of the impact, has an economically significant effect on other Asian countries, with Korean, Singaporean and Thai real output increasing by 0.4% after one year, and a smaller but still considerable effect on the real output of Japan and New Zealand, which increase by 0.2%. The effect on Eurozone countries and on the US are instead quite small and largely insignificant with the exception of a few countries.[35] The effect on exports in the rest of the world, shown in panel D, are basically consistent with those on output: real exports of Asian countries benefit the most from a positive shock to Chinese imports. These results clearly suggest the presence of a strong Asian business cycle and of an increased vertical specialisation in international trade among Asian economies. Many papers indeed have documented that vertical specialisation - alternatively known as international fragmentation of production - has been increasing over time (e.g., see Hummels, Ishii and Yi, 2001) and can be seen as one of the main driving force of the international transmission of business cycles (Burstein, Kurz and Tesar, 2008).

4.2 Understanding the Great Trade Collapse: a Conditional Forecasting Exercise

One of the main features of the recent financial crisis is the sharp contraction in global trade that took place at the end of 2008 and beginning of 2009. In this section we investigate these trade developments using our GVAR model, in particular we want to answer the question whether the GTC can be rationalized by the observed fall in demand and the change in relative prices. If this is the case, this suggests that the explanatory variables we are using to model trade successfully account for this dramatic evolution; otherwise, this may suggest that specific factors were at play during the crisis. To answer this question, we use our model to compute the forecasts of real export and import growth of the 21 countries in our sample conditioning on the actual values of real outputs and real effective exchange rates observed in 2008 and 2009. In addition to computing the conditional forecasts of real exports and imports, we also disentangle the contributions to the predicted values of conditioning on domestic variables (y_{it} and rer_{it} of country i) and on foreign variables (y_{jt} and rer_{jt} for $j \neq i$).

Figures 4 and 5 present the results of the forecasting exercise. Figure 4 shows the actual vs. predicted values of real export growth in 2008Q4 and 2009Q1 for all 21 countries (panels A and C, respectively).[36] These results show that model performance is satisfying, especially for advanced

[34] We believe this result may be due to data issues. In particular, the series for China are interpolated from annual data for the first part of the sample. This can partly affect the inference of the model for China leading to less precise parameter estimates.

[35] It is somehow interesting that the European country which seems to benefit the most from an expansionary shock to Chinese imports is the Netherlands, i.e., one of the most open economies in the Eurozone characterised by a large transit trade.

[36] Both the forecast values and the variable contributions are computed by bootstrapping from the solution of the

countries (noticeably the US, UK, Switzerland, Sweden, and the Netherlands). For some advanced countries the model does a very good job for one quarter, but less so for the other quarter (this is the case of France and Germany for example). Overall, also, model performance is better for advanced than emerging market economies (Mexico and Brazil stand out as with large errors). One potential explanation is that specific factors played a role for these countries; potentially, for instance, trade credit issues seem to be more pronounced for emerging market economies, although it is hard to tell in the absence of data.

The results for real import growth are shown in Figure 5 (panels A and C, respectively), and a similar pattern emerges compared to Figure 4. The model is accurate in forecasting both the direction and the size of the fall in real imports for most of the countries in both quarters, with some exceptions. In particular, the model forecasts a fall in imports for Japan in 2008Q4 (the model predicts a fall in import growth by 6.8% against a realized increase of 2.5%). It should be said, however, that the increase in imports in Japan in the last quarter of 2008 was quite surprising and definitively difficult to forecast given the economic situation in the country and abroad (Japanese GDP, for instance, decreased by 3.0% on a quarterly basis in 2008Q4). Japanese imports may have been supported by the strong yen appreciation at the end of 2008. In spite of these errors, which are inevitable when looking at a large group of countries, the model manages to keep track of real imports, against an average fall of imports in our 21 countries of 4.2% and 9.4% in 2008Q4 and 2009Q1, our model is able to explain 86% and 72% of the fall, respectively.[37]

Panels B and D in Figures 4 and 5 present the contributions of foreign and domestic variables in explaining the forecast values of export and import growths discussed above. Results for the export decomposition show that domestic variables seem to be the main factors responsible for the drop in real exports in most of the large developed economies, e.g., the US, Germany, France, Italy and (partly) Japan, while foreign variables play a dominant role in explaining the fall in exports from most of the emerging markets, such as Mexico, China, Korea, Brazil and Argentina, and from some developed small open economies, such as the Netherlands, the UK and Switzerland. Results for the import decomposition suggest that, for some countries, the fall in imports experienced during the GTC was mainly caused by the external economic situation (captured by the foreign variables) and less from domestic developments (as we would expect to be given the typically large elasticity of imports to domestic demand). In particular, this is true for Mexico, Argentina and Thailand among the emerging economies and for the Netherlands, Spain and Australia among the developed ones.

GVAR and correspond to median values.

[37] These numbers are computed as weigthed averages of real import growth in the 21 countries in our sample, where the weights are the average import share of each country in 2000-2006. These results are noteworthy in light of the difficulty that most empirical models have in tracking trade flows during the GTC, as reviewed for instance in IMF (2010) and in Bussière et al. (2011), and bearing in mind that our model does not consider several factors that have been highlighted in the literature, such as the composition of trade flows and trade credit constraints. It may suggest that taking into account the global dimension of the GTC, as we do in a GVAR model, goes a long way in explaining trade flows during a global crisis.

Overall, the forecasting exercise shows that the explanatory variables of our model are able to correctly predict the direction of trade developments during the GTC for most of the countries in our sample. The forecasting performance of the model is pretty good, especially for advanced economies. Although on average the model forecasts better import than export growth, it also explains relatively well the fall in exports for the United States and most of the other industrialized countries; it is less accurate for the exports of emerging market economies. Future research may turn to the experience of this latter group of countries, but given the difficulty to deal with crisis times, we find the overall results very encouraging.

4.3 US Trade Elasticities: A Comparison with the Literature

There is a large body of literature in international economics that focuses on the estimation of trade elasticities, given its relevance in trade-related policy debates. Estimation of price and income elasticities is indeed crucial to assess, for instance, which factors would play a decisive role in the process of global trade rebalancing, as well as to gauge the effects of exchange rate and relative demand movements on trade flows. The study of income trade elasticities is instead linked to the so-called "elasticity puzzle", or Houthakker-Magee (1969) puzzle, i.e. the well-known empirical regularity for the United States (but also for other countries) that finds that the demand elasticity is significantly higher on the import side (where it is commonly estimated to be above one) than on the export side (where it is generally equal to one).[38]

A comparison of our results with other empirical works on trade elasticities is difficult; existing papers model differently exports and imports equations, featuring different measures for domestic and foreign demand and for relative prices. Moreover, most of the papers do not test for cointegration between exports and imports[39], and others *impose* a long-run import demand elasticity of one to address the "elasticity puzzle".[40]

Before discussing the results, one final point on the methodology is in order. This point does not specifically relates to the GVAR literature, but more broadly to studies aiming to estimate elasticities within a VECM framework in general. Indeed, standard practice consists in interpreting the coefficients of the cointegrating relations as long-run elasticities (e.g., see Hooper, Johnson and Marquez (2000), Chinn (2004) and Crane, Crowley and Quayyum (2007), among others). However, this disregards the full dynamics of the system (see Johansen, 2005, and Lütkepohl, 1994, for a discussion of the interpretation of cointegrating coefficients in the cointegrated vector autoregressive

[38] This represents a puzzle because it implies that, to prevent the trade balance from permanently moving towards a deficit, the exchange rate should permanently depreciate (this is also under the condition that foreign and domestic output grow at similar rates). Another puzzling implication of having a demand elasticity above one is that output should be completely imported in the long-run, barring a permanent depreciating trend.

[39] One exception is the article of Cardarelli and Rebucci (see IMF, 2007) that in one specification for the import equation includes exports of key intermediate products to correct for vertical integration. Results for this specification show a much lower income elasticity and a higher price elasticity than the benchmark model.

[40] This is for instance the case of Pain et al. (2005) in one of their specifications. In this paper, we do not impose restrictions on parameters and demand elasticities are freely estimated for each country.

model). Consistently with this latter interpretation, in the paper we base our simulation results on the generalized impulse response functions, focusing on the shocks we are interested in (this approach is also that of Boyd et al., 2001). However, as many of the authors who estimated trade elasticities only report the cointegrating vectors and not the impulse responses, and since the comparison is already made difficult by the different modeling choices listed above, we comment on the results from our cointegrating vectors, as presented in Table 2.

The table below is taken from Crane, Crowley and Quayyum (2007) and summarises the results for the US trade elasticities of some recent papers on this topic. We add a few lines to the table; two of them report the results from the IMF (2007) import specification that corrects for vertical integration and from the specification that includes the real effective exchange rate, respectively, and the last line reports our results. The table shows the estimated export and import income and price elasticities. For the price elasticities, it distinguishes between specifications in which relative trade prices are included (RMP and RXP, respectively) and specifications that feature the real effective exchange rate ($REER$).[41]

US Trade Elasticities

	Imports			*Exports*			
	Income	*RMP*	*REER*	*Income*	*RXP*	*REER*	*Sample*
Houthakker and Magee	1.51	-0.54		0.99	-1.51		1951-66
Hooper, Johnson and Marquez	1.79	-0.31		0.83	-1.47		1961-94, imp. 1976-94, exp.
Chinn	2.29		-0.12	1.62		-0.73	1975-2003
IMF	2.03	-0.69		1.85	0.02		1973-2006
	2.46		-0.37	1.82		-0.49	1973-2006
(*correcting for VE*)	0.64	-1.48		1.85	0.02		1973-2006
Crane, Crowley and Quayyum	1.93	-0.63		2.34	-0.61		1960-06, imp. 1981-06, exp.
Bussière, Chudik and Sestieri	1.24		-1.04	1.52		-1.10	1980-2007

In our results, we do not find support for the Houthakker-Magee asymmetry. Our import income elasticity of 1.24 is on the low side compared to the literature but consistent with the finding of the IMF (2007) that, once exports are included in the import equation (to take into account the vertical integration process that characterises the US economy, i.e., the fact that a large part of its production

[41] One important caveat is that, by including the REER instead of the relative price of exports and imports in the trade equations, the elasticities with respect to the real exchange rate take implicitely into account the degree of pass-through from exchange rates to relative prices without the need to model it.

is outsourced abroad), the value of the elasticity reduces substantially. Our value, however, is not directly comparable with that of the IMF authors since we use slightly different variables from them.

We find price elasticities for the US to be relatively high, equal to -1.04 for imports[42] and -1.1 for exports, so that we place ourselves in the optimistic side of the literature. A direct comparison with the literature is again difficult. In the IMF import specification that corrects for vertical integration, the price elasticity of imports is also high, but it refers to a different measure of relative prices.[43] In studies that use the REER, such as Chinn (2004) and IMF (2007), this elasticity is much lower, but these specifications do not include exports in the import cointegrating vector. The estimates of export price elasticities also vary a lot in the literature, ranging from basically zero (IMF, 2007) to about -1.5 (Hooper, Johnson and Marquez, 2000); our estimate of -1.1 is on the optimistic side but not much different from other papers that used similar specifications (e.g., Chinn, 2004).

Interestingly, we find evidence of exports entering the import cointegrating vectors for most of the other G-7 countries (the only exceptions are France, for which no cointegrating vector is found, and the UK) and for Canada, Germany and Japan we do not find the Houthakker-Magee asymmetry to hold. Price elasticities vary for each country but, in general, we find the price elasticity of exports to be bigger than that of imports (see Table 2 for a comparison across countries).

5 Conclusion

This paper has presented results from a GVAR model applied to the issue of global trade imbalances and global trade flows. The approach proposed in the present paper distinguishes itself from previous contributions on the subject in two main ways. First, the use of a GVAR model, which is specifically designed to account for international linkages, is particularly well suited to tackle the issue of trade imbalances given their dispersion among many different countries and regions. Second, while most empirical trade papers model real exports and imports separately, we show that there is value added in jointly modeling them, in particular because of the internationalisation of production chains across the world. The aim of the paper was not to carry out a structural exercise, but to assess what variables are typically associated with trade adjustments.

The model can be used to gauge the effect on trade flows of various scenarios, such shocks to US and foreign variables. The main results show, first, that a shock to US output significantly affects exports from other countries, in particular Canada and Mexico, small open Asian economies, but also several European countries. Second, a US real exchange rate appreciation would significantly stimulate exports from foreign economies, but to a lower extent than a positive shock to US output.

[42] Notice that, to make an easier comparison between the two different import specifications (the one that includes the RMP and the one that includes the REER), an increase of the REER corresponds here to a domestic depreciation.

[43] The IMF authors explain the difference between the import price elasticity in the specification that corrects for vertical integration and the same elasticity in the benchmark specification (-1.48 vs. -0.69) with the fact that the former is the sum of two components, the "true" elasticity of imports and the effect of the exchange rate on US exports of intermediate products.

This result is in particular in line with the fact that the adjustment in global imbalances observed in the wake of the 2008 financial crisis was not associated with a sharp depreciation of the dollar (contrary to what many observers had expected). The large effect of a US output shocks on exports from other countries may also explain the importance of the trade channel in the transmission of shocks across countries. Third, shocks to foreign variables (focusing on Germany and China) also have the expected effects on the rest of the world. For each of these shocks, the paper has provided a ranking of the countries, from most to least affected.

In addition, we also explored the factors behind the noticeable contraction in world trade that took place in the wake of the 2008 financial crisis. In a different application of the model we aimed to compare the growth rates of exports and imports among our 21 countries with the model's conditional prediction for the last quarter of 2008 and first quarter of 2009 (conditioning on the observed real output and real exchange rate developments). The objective was to assess whether the actual configuration of global output and real exchange rates was able to account alone for the collapse in world trade over that period. What makes this second exercise particularly interesting is that the collapse in world trade was particularly large, sudden (world exports contracted by more than 6% in the last quarter of 2008 only), and synchronized across countries. Results indicate that the model successfully accounts for the direction of trade adjustments for most of the countries in our sample and that the goodness of fit is pretty good overall, in spite of some exceptions that we highlighted and leave for future research to investigate. Finally, compared to other papers that estimated long-run trade elasticities for the US, we find larger estimates for the long-run trade price elasticities of imports and exports and lower long-run demand elasticities on the import side, much closer to one than previous studies have found.

Overall, the model we have outlined in this paper lends itself to a variety of simulation and forecasting/monitoring exercises. Looking forward, we hope that the tool developed in this paper will be used to explore a variety of policy and research questions related to global imbalances and global trade

Table 1: Data sources

Country	rer_{it}	y_{it}	x_{it}	m_{it}	max time span
Argentina	BCS	GI	GI	GI	1980Q1-2007Q4
Australia	BIS	OECD	OECD	OECD	1979Q1-2007Q4
Brazil	BCS	Pes+BIS	IFS	IFS	1979Q4-2007Q4
Canada	IFS	OECD	OECD	OECD	1979Q1-2007Q4
China	IFS	IFS+WEO$^{(1)}$	GI$^{(1)}$	GI$^{(1)}$	1980Q1-2007Q4
France	BIS	OECD	OECD	OECD	1979Q1-2007Q4
Germany	IMF	OECD	OECD	OECD	1979Q1-2007Q4
Italy	BIS	OECD	OECD	OECD	1979Q1-2007Q4
Japan	BIS	OECD	OECD	OECD	1979Q1-2007Q4
Korea	BIS	OECD	OECD	OECD	1979Q1-2007Q4
Mexico	BIS	OECD	OECD	OECD	1979Q1-2007Q4
Netherlands	IMF	OECD	OECD	OECD	1979Q1-2007Q4
New Zealand	IMF	OECD	OECD	OECD	1979Q1-2007Q4
Norway	IMF	OECD	OECD	OECD	1979Q1-2007Q4
Singapore	IMF	GI	IMF	IMF	1980Q1-2007Q4
Spain	IMF	OECD	OECD	OECD	1979Q1-2007Q4
Sweden	IMF	OECD	OECD	OECD	1979Q1-2007Q4
Switzerland	IMF	OECD	OECD	OECD	1979Q1-2007Q4
Thailand	BCS	GI+Pes	IMF	IMF	1979Q1-2007Q4
UK	IMF	OECD	OECD	OECD	1979Q1-2007Q4
US	BIS	OECD	OECD	OECD	1979Q1-2007Q4

Notes: (^{1}) Interpolated from annual data. We have used data from the following sources:

(I) The OECD: we used real exports, imports and output from the OECD Economic Outlook quarterly database, with codes XGSV, MGSV and GDPV, respectively.

(II) The IMF: for real exports, imports and GDP we used IFS lines 72, 73 and 99.v; for the real effective exchange rate we used IFS line REC.

(III) The BIS: for real GDP we used the code 9.9B.BVP; for the real effective exchange rate we used BIS code QTGA. National sources through Global Insight/World Market Monitor (GI).

(IV) Some of the variables compiled by Prof. Pesaran and his coauthors, available on-line on his website (Pes): http://www.econ.cam.ac.uk/faculty/pesaran/.

(V) For the exchange rate we also completed missing observations from raw data, i.e. from bilateral exchange rates and price indices provided by the IMF/IFS (BCS).

(VI) For a few series/countries we were missing some of the data at a quarterly frequency; in this case we interpolated the annual data from the IMF World Economic Outlook (WEO)

(VII) For oil prices in dollar, we used the OECD series OEO.Q.WLD.WPBRENT.

Table 2: Over-identified long-run relationships

The table reports the estimates of the cointegrating vectors in the country-specific VECMs, where theory-based over-identifying restrictions have been imposed to all countries (but China). The table also reports, for each VARX* country-specific model, the number of cointegrating relations imposed and the log-likelihood ratio statistic for testing these long-run relations (number of over-identifying restrictions in brackets). The bootstrapped upper one percent critical value of the LR statistics is provided in the last columns. Standard errors are in parenthesis. Sample 1980Q1-2007Q4.

Country	Exports	Imports	#CV	LLR(df)	99%CV
Argentina		$\underset{}{im_t} - \underset{(0.1350)}{2.90}y_t - \underset{(0.0635)}{0.72}rer_t$	1	10.61(7)	36.49
Australia		$im_t - \underset{(0.0304)}{2.15}y_t - \underset{(0.0607)}{0.47}rer_t$	1	31.43(7)	39.12
Brazil		$im_t - \underset{(0.1124)}{1.09}y_t - \underset{(0.1203)}{0.01}rer_t$	1	43.08(7)	45.20
Canada	$ex_t - \underset{(0.0334)}{1.58}y^*_t + \underset{(0.0809)}{0.64}rer_t$	$im_t - \underset{(0.0363)}{0.61}ex_t - 1.00y_t - \underset{(0.1574)}{0.42}rer_t$	2	48.52(12)	84.93
China			3	-	-
France			0	-	-
Germany	$ex_t - \underset{(0.1929)}{1.58}y^*_t + \underset{(0.8695)}{3.69}rer_t$	$im_t - \underset{(0.0446)}{0.62}ex_t - \underset{(0.1086)}{1.02}y_t - \underset{(0.1181)}{0.14}rer_t$	2	53.92(11)	64.95
Italy	$ex_t - \underset{(0.1036)}{1.17}y^*_t + \underset{(0.3416)}{1.29}rer_t$	$im_t - \underset{(0.1423)}{0.14}ex_t - \underset{(0.3025)}{2.00}y_t - \underset{(0.1367)}{0.10}rer_t$	2	67.90(11)	75.88
Japan	$ex_t - \underset{(0.0174)}{0.86}y^*_t + \underset{(0.0478)}{0.55}rer_t$	$im_t - \underset{(0.1127)}{0.62}ex_t - \underset{(0.2505)}{0.75}y_t - \underset{(0.1487)}{0.54}rer_t$	2	60.56(12)	68.08
Korea		$im_t - \underset{(0.1542)}{1.53}y_t - \underset{(0.6221)}{0.97}rer_t$	1	25.74(7)	50.99
Mexico		$im_t - \underset{(0.3366)}{0.16}ex_t - \underset{(1.2419)}{2.86}y_t - \underset{(0.3482)}{0.67}rer_t$	1	20.30(6)	43.18
Netherlands	$ex_t - im_t$	$im_t - \underset{(0.0427)}{2.21}y_t - \underset{(0.1211)}{0.28}rer_t$	2	54.15(14)	63.47
New Zealand	$ex_t - \underset{(0.0976)}{0.30}im_t - \underset{(0.1306)}{0.79}y^*_t + \underset{(0.0683)}{0.30}rer_t$		1	36.03(6)	53.21
Norway			0	-	-
Singapore		$im_t - \underset{(0.0333)}{1.22}y_t - \underset{(0.1718)}{0.37}rer_t$	1	33.06(7)	49.55
Spain	$ex_t - \underset{(0.0765)}{2.78}y^*_t + \underset{(0.2338)}{1.74}rer_t$		1	53.93(7)	58.74
Sweden		$im_t - \underset{(0.2233)}{2.86}y_t - \underset{(0.3996)}{2.54}rer_t$	1	23.66(7)	41.10
Switzerland		$im_t - \underset{(0.1731)}{2.32}y_t - \underset{(0.3379)}{0.56}rer_t$	1	29.71(7)	50.00
Thailand		$im_t - \underset{(0.0894)}{1.65}y_t - \underset{(0.2856)}{0.97}rer_t$	1	34.98(7)	47.78
U.K.		$im_t - \underset{(0.0427)}{2.12}y_t - \underset{(0.0905)}{0.39}rer_t$	1	11.25(7)	38.06
U.S.	$x_t - \underset{(0.0610)}{1.52}y^*_t + \underset{(0.1993)}{1.10}rer_t$	$im_t - \underset{(0.1196)}{0.58}ex_t - \underset{(0.2356)}{1.24}y_t - \underset{(0.1191)}{1.04}rer_t$	2	52.98(11)	73.65

Table 3: Stability tests

The table shows the number (percentage) of rejections of the null of parameter stability per variable across the country-specific models at 5% level. Different tests for structural breaks are considered: PK_{sup} and PK_{msq} are based on the cumulative sums of OLS residuals, R is the Nyblom test for time-varying parameters and QLR, MW and APW are the sequential Wald statistics for a single break at an unknown change point. Statistics with the prefix "r" denote the heteroskedasticity-robust version of the tests. The critical values of the tests, computed under the null of parameter stability, are calculated by bootstrap.

Tests	**Domestic variables**					**Numbers(%)**
	ex_{it}	im_{it}	y_{it}	rer_{it}	p_t^{oil}	
PK_{sup}	0(0)	1(4.8)	3(14.3)	1(4.8)	0(0)	5(5.9)
PK_{msq}	0(0)	0(0)	3(14.3)	1(4.8)	0(0)	4(4.7)
R	2(9.5)	3(14.3)	6(28.6)	5(23.8)	0(0)	16(18.8)
r-R	2(9.5)	1(4.8)	2(9.5)	4(19)	0(0)	9(10.6)
QLR	5(23.8)	6(28.6)	9(42.9)	8(38.1)	0(0)	28(32.9)
r-QLR	2(9.5)	1(4.8)	6(28.6)	1(4.8)	0(0)	10(11.8)
MW	3(14.3)	4(19)	7(33.3)	7(33.3)	0(0)	21(24.7)
r-MW	1(4.8)	1(4.8)	4(19)	1(4.8)	0(0)	7(8.2)
APW	5(23.8)	6(28.6)	9(42.9)	8(38.1)	0(0)	28(32.9)
r-APW	2(9.5)	1(4.8)	6(28.6)	1(4.8)	0(0)	10(11.8)

Figure 1: Bootstrap means of the persistence profiles

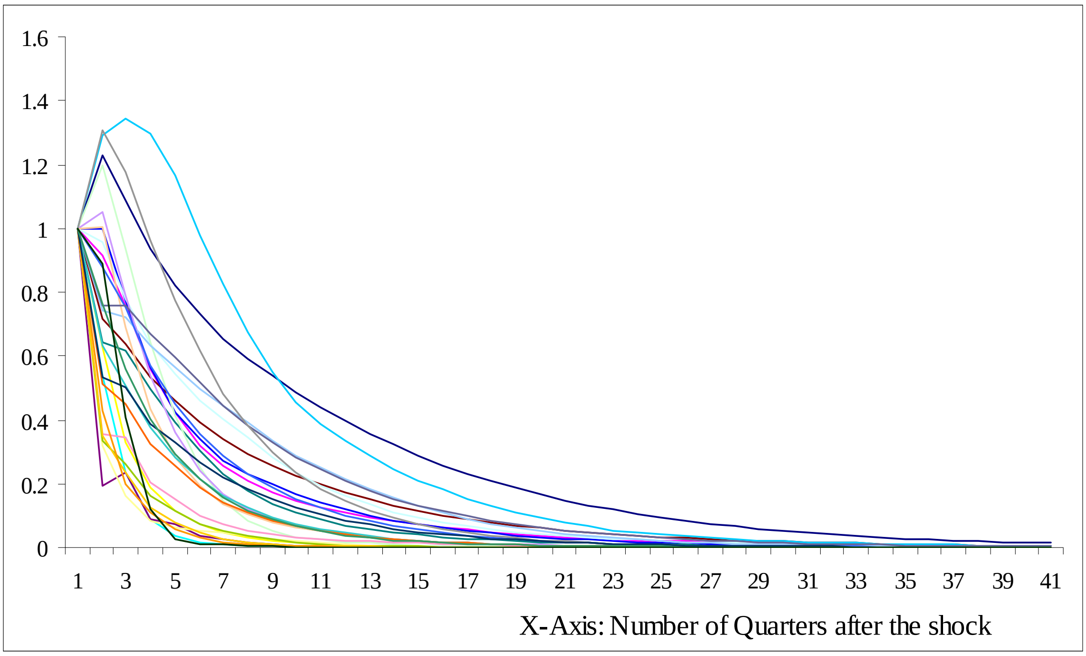
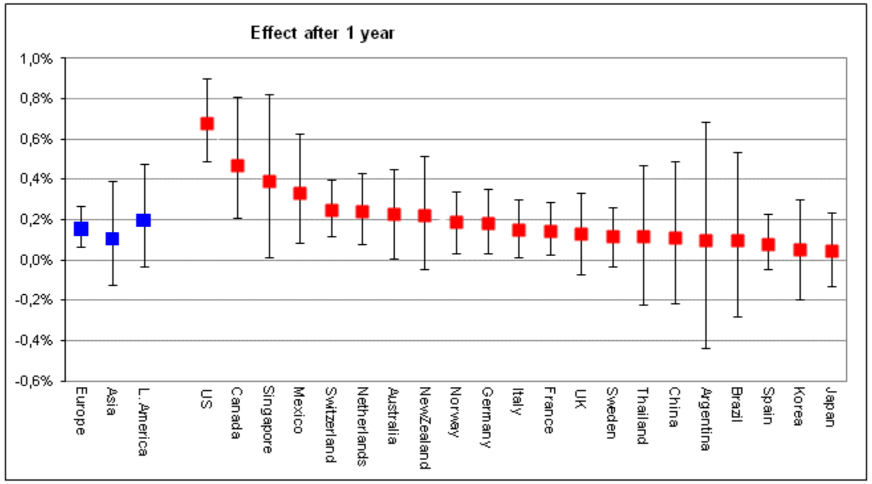
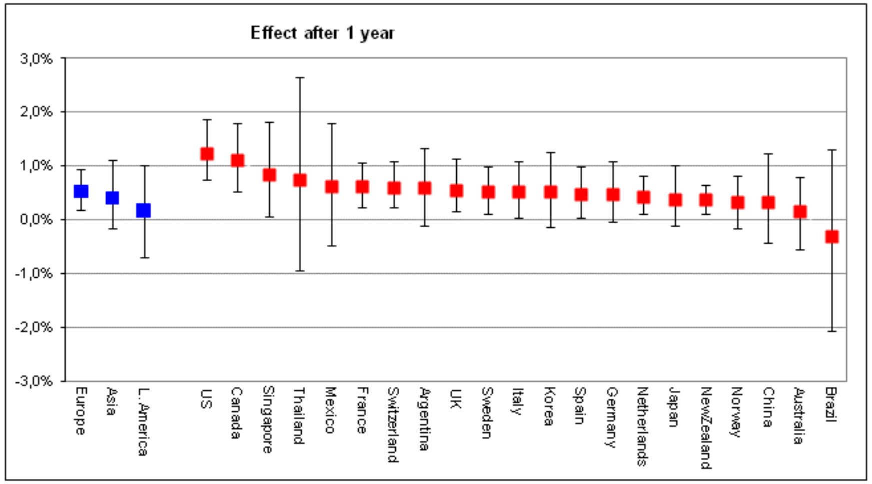


Figure 2: Shocks to US variables

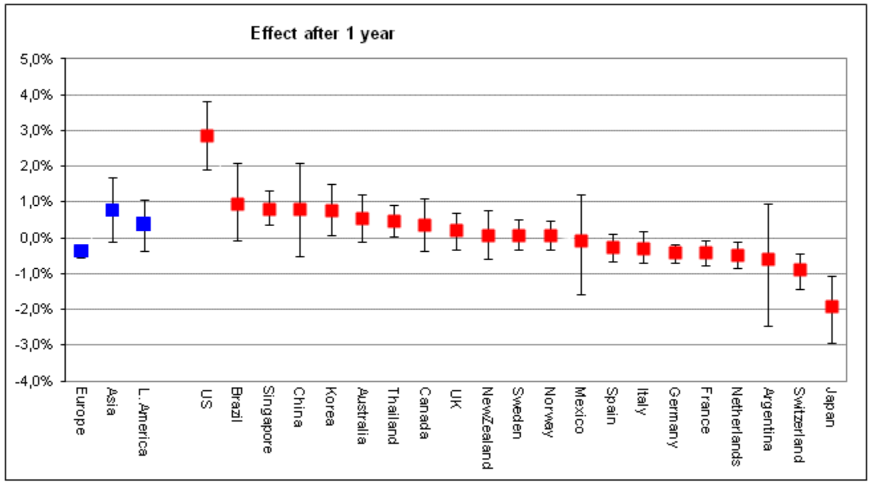
Panel A: Shock to US output (+0.6%), effect on output



Panel B: Shock to US output (+0.6%), effect on exports



Panel C: Shock to US REER (+2.6%), effect on REER



Panel D: Shock to US REER (+2.6%), effect on exports

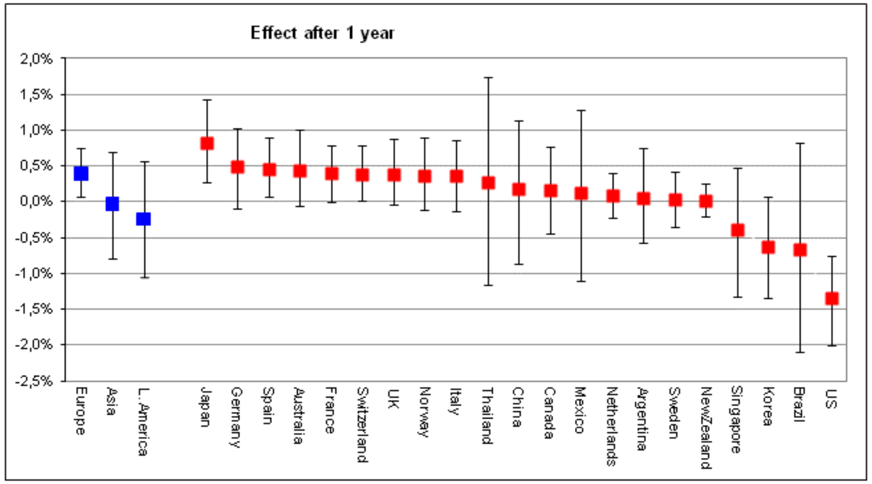
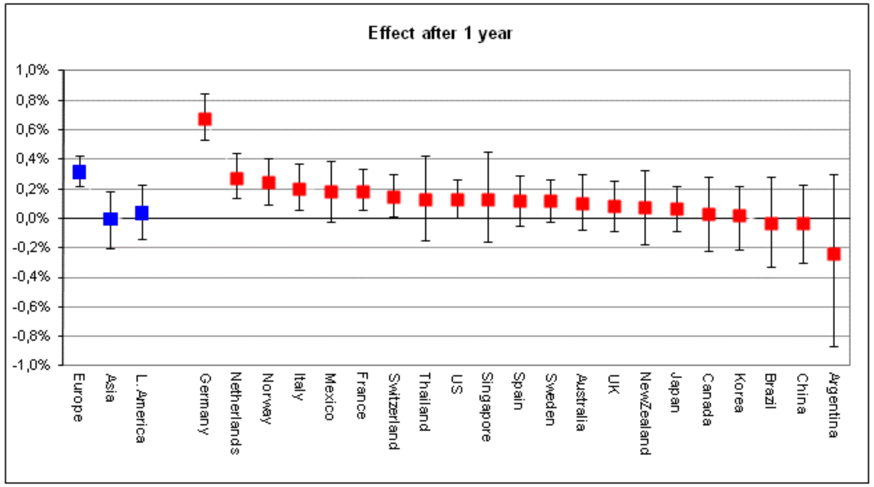
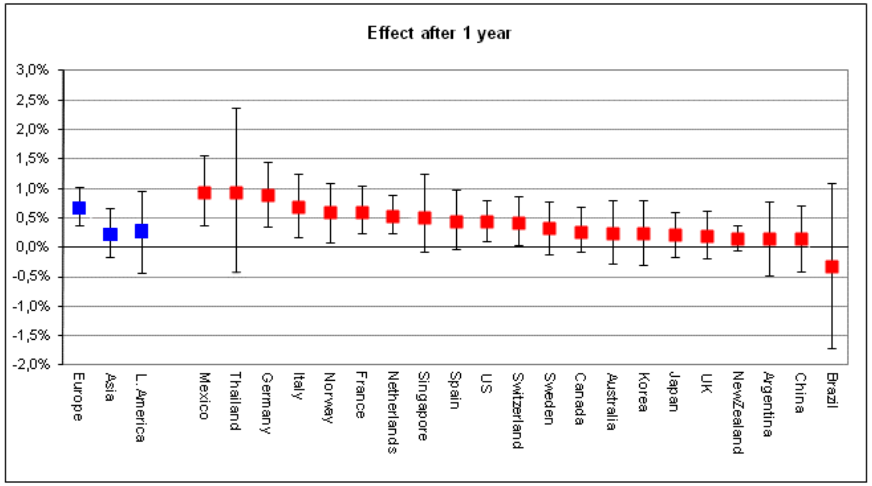


Figure 3: Shocks to foreign variables

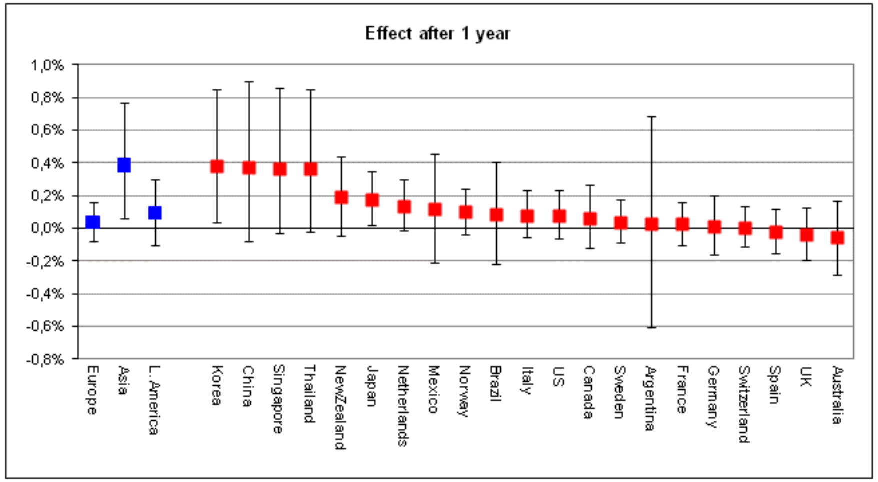
Panel A: Shock to German output (+0.8%), effect on output



Panel B: Shock to German output (+0.8%), effect on exports



Panel C: Shock to Chinese imports (+1.9%), effect on output



Panel D: Shock to Chinese imports (+1.9%), effect on exports

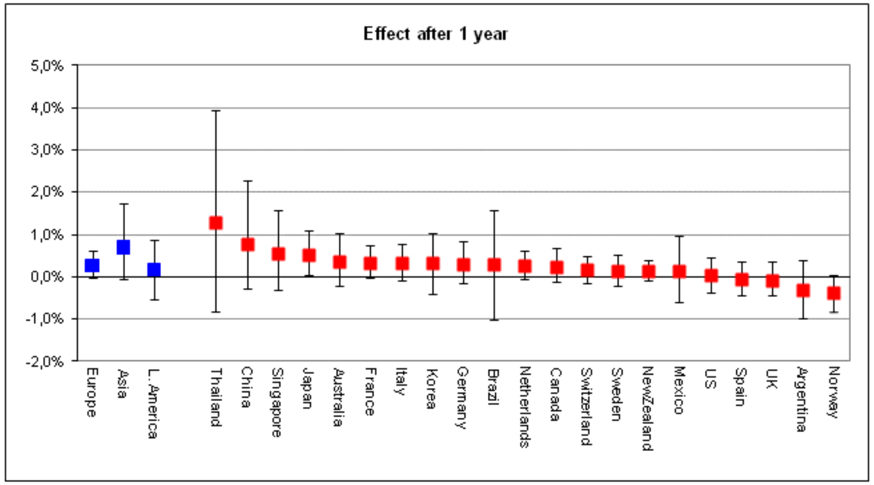
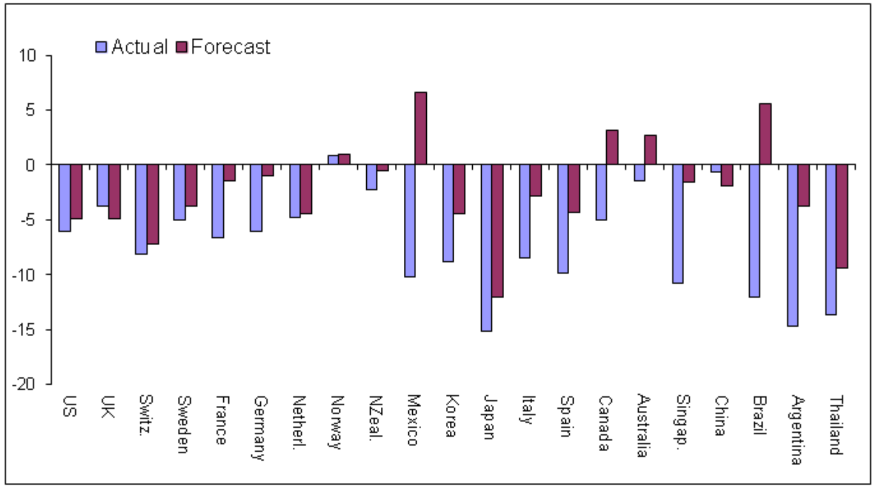
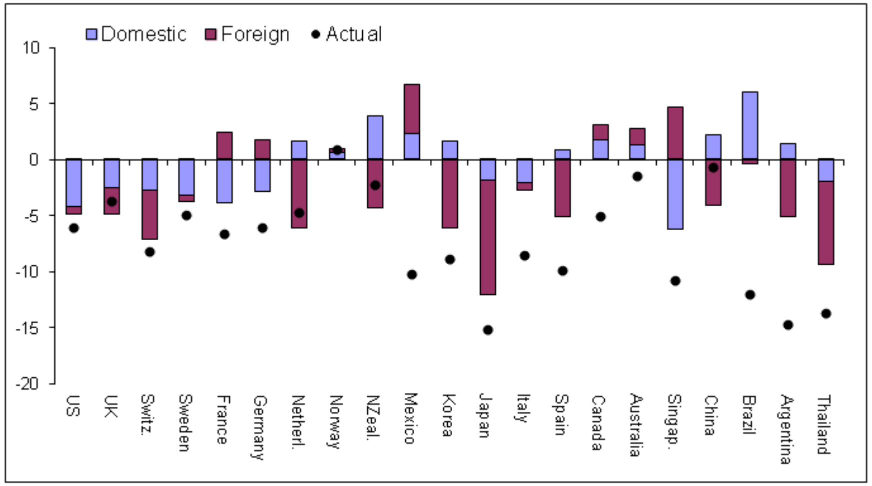


Figure 4: Actual vs. forecast values of real export growth during the GTC

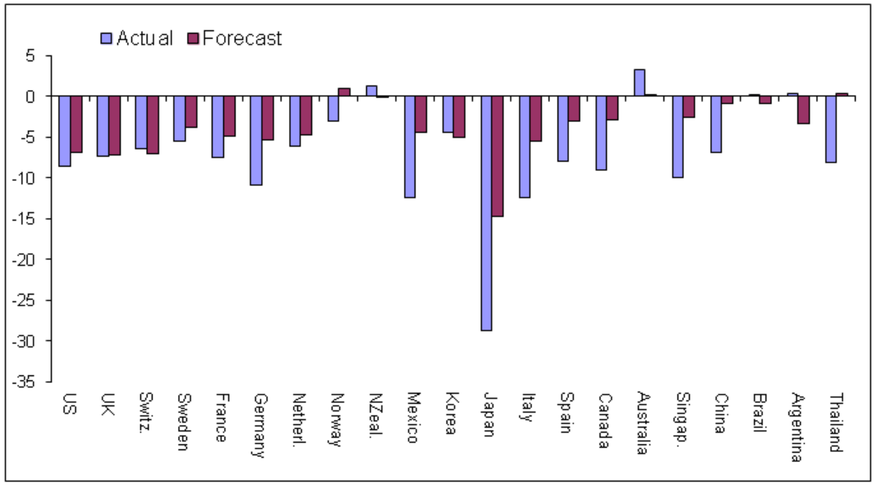
Panel A: Actual vs. forecast real export growth in 2008Q4



Panel B: Domestic and foreign variables contribution



Panel C: Actual vs. forecast real export growth in 2009Q1



Panel D: Domestic and foreign variables contribution

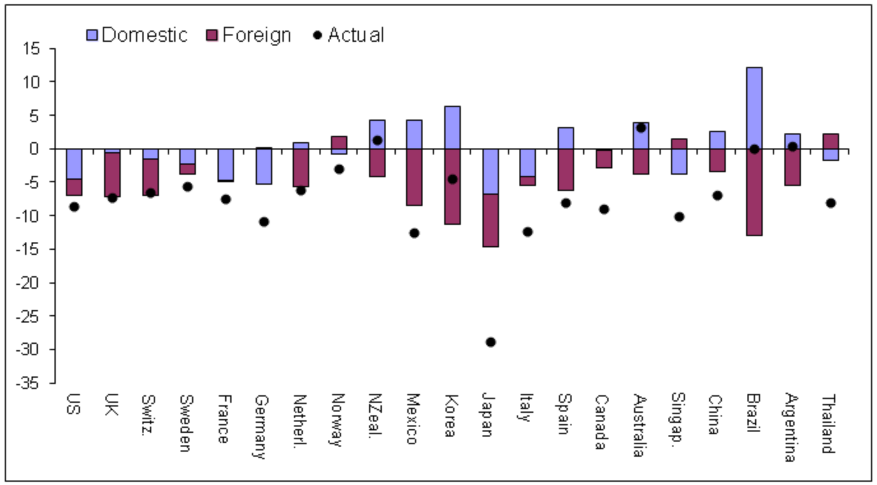
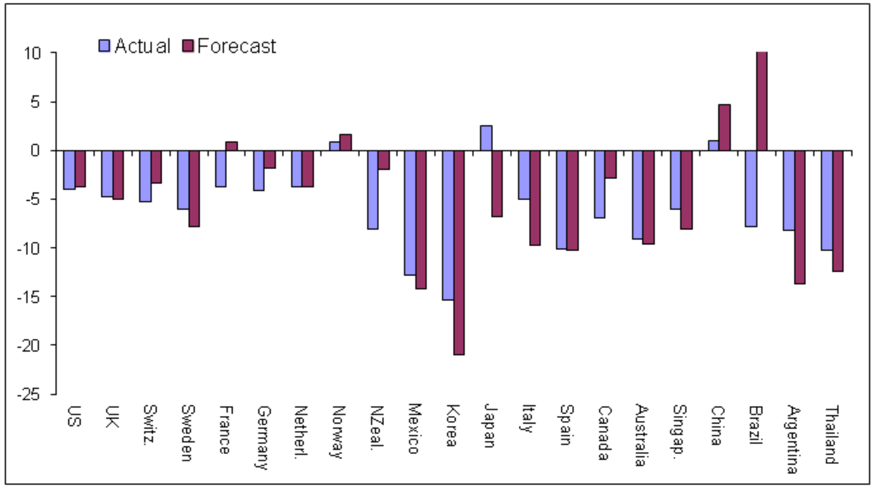
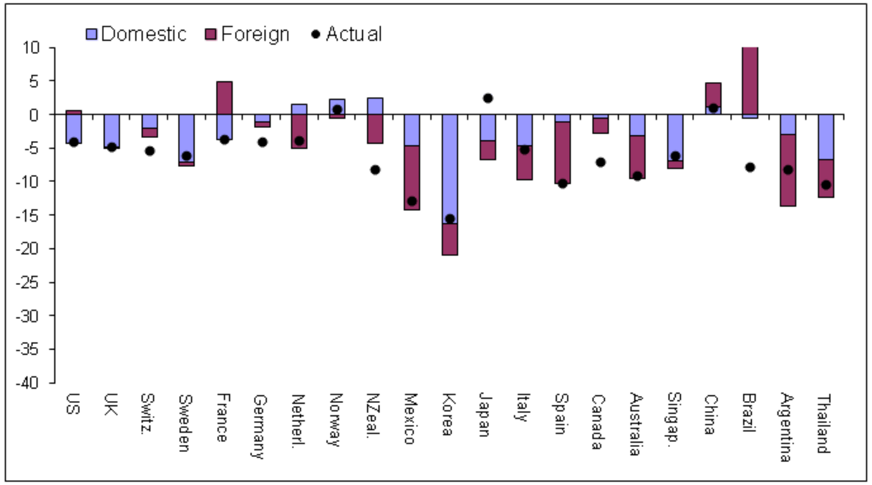


Figure 5: Actual vs. forecast values of real import growth during the GTC

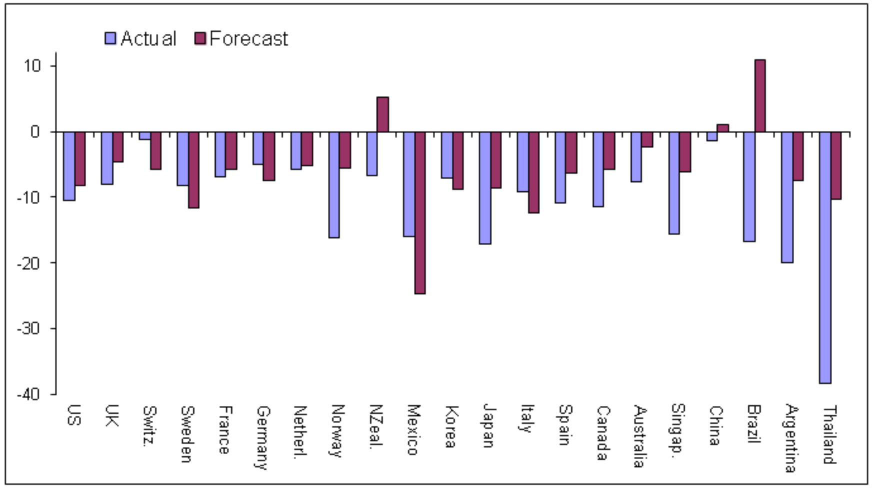
Panel A: Actual vs. forecast real import growth in 2008Q4



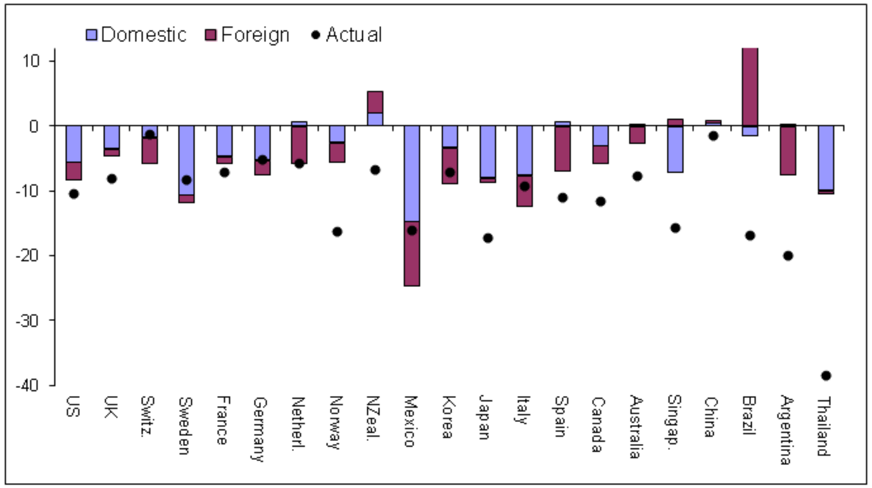
Panel B: Domestic and foreign variables contribution



Panel C: Actual vs. forecast real import growth in 2009Q1



Panel D: Domestic and foreign variables contribution



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