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How much does aggregate demand travel across the Atlantic?

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How much does aggregate demand travel across the Atlantic?

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Abstract

We identify the spill-over of demand shocks between the world's two largest advanced economies; the US and the euro area. We estimate a Bayesian VAR with sign restrictions, using standard restrictions for the domestic impact of the shock but a novel approach to identify the geographic location of the shocks and rule out common shocks. For the latter, we use the relative performance of small open economies that are neighbors of the US and the euro area, respectively Canada and Sweden, in addition to restricting the relative effects on the US, the euro area and the rest of the world. We find that demand spill-overs of US and euro area demand shocks become smaller on average when imposing relative restrictions, while they become larger in periods which are well-known to be specific to the US (global financial crisis) or the euro area (euro area sovereign debt crisis). Our results are confirmed by running a 'placebo test' where we replace the euro area with a small euro area economy, which should not have an independent effect on the US economy due to its small size.

Keywords: International spillovers, open economy, Bayesian VAR, sign restrictions.

JEL codes: C5, F41, F44.

0 Non-technical summary

We estimate the international spill-over of aggregate demand shocks between the US and the euro area. The emphasis on demand shocks is justified by the fact that they are (i) probably highly relevant for the business cycle and (ii) they are also the ones where the spill-overs may be expected to be larger as well as (iii) the risk of common shocks (which complicate the estimates) more serious, compared for example to supply shocks, at least at business cycle frequency. Understanding spill-overs between the US and the euro area is obviously important for policy setting in the two economies, including for the question of whether policies should be coordinated. At the same time, the usual small open economy assumptions are clearly not applicable, therefore the question is more challenging from an econometric point of view.

We build on a simple set of VAR models that include variables for both the euro area and the US, and possibly other relevant countries, where we identify *domestic* demand shocks using standard sign restrictions.

We start from a simple specification and derive the associated spill-over elasticity, i.e. how much a domestic demand shock in the US (euro area) moves economic activity (proxied by industrial production) in the euro area (US). We then evaluate whether imposing additional plausible assumptions on the *geography of spill-overs*, which are also consistent with most open economy DSGE models, changes our view of the size and direction of spill-overs.

In particular, the additional assumptions or requirements are four: (i) we restrict the impact effect on output to be larger in the spill-over sending economy than in the spill-over receiving country; (ii) we impose that output of the spill-over sending country as a share of global output should rise following a positive demand shock; (iii) a novel restriction introduced in this paper applies to close 'neighbours', or so-called "satellite economies", to the euro area and the US. In particular, we impose that a shock in one of the two large economies should have a significantly larger impact on countries that are close neighbours in terms of geography, trade and financial ties – these satellite economies act like the "miner's canary" for shocks happening in the large neighbouring economy. (iv) Finally, we confirm our set up with a "placebo test" in which we substitute the major economy with a small, closely linked open economy, and follow the same identification approach. The placebo test should show that the small open economy only has a small to insignificant impact on

the large economy. Again, this is an assumption that is easily verified in DSGE models, especially the small open economy version that just assumes this to be the case (i.e., the small open economy has no impact on the large economy).

The econometric exercise in this paper uncovers four main results. First, our estimates point to much larger spill-overs of aggregate demand shocks across both sides of the Atlantic than documented by DSGE models. We find that more than 80 percent of the reaction in US industrial production following a US aggregate demand shock is transmitted to its euro area counterpart, while aggregate demand shocks in the euro area transmit for about 50 percent to their equivalent in the US. Second, imposing additional restrictions to better control for the country origin of the shock does not alter the spill-over estimates in a significant way, generally seen. (However, we do find that spill-overs between the US and the euro area tend to become somewhat smaller, if anything, when imposing additional sign restrictions on the relative reactions.) At the same time, they become larger during specific episodes that are well-known to be specific to either the US (such as the global financial crisis) or the euro area. Moreover, the uncertainty surrounding the estimates narrows as a result of imposing more restrictions in the identification. Finally, the placebo tests provide additional support for the choice of the restrictions used to identify aggregate demand shocks in the set of models employed in this paper.

1 Introduction

Understanding spill-overs between large economies is important from both an academic and a policy point of view. Although there is a very large literature on spill-overs, the identification of spill-overs between large and major economies remains challenging. Ideally, one would want to have both a structural identification of well-specified shocks at the domestic level (say, distinguish demand and supply shocks) as well as a geographical identification of the source of the shock, without which it is difficult to speak about spill-overs. The fact that macroeconomic variables and business cycles are typically positively correlated internationally (see Kose et al. (2008)) does not necessarily facilitate the task of the researcher, since it is in principle not known if the correlation stems from strong spill-overs of domestic shocks or rather from an important role of common shocks. Finally, even a model achieving a strong identification of both domestic and cross border effects has to be based on assumptions that are not too arbitrary, but at the same time it is difficult to achieve a meaningful identification with relatively agnostic assumptions.

In this paper, we focus on the spill-overs of demand shocks between the world's two largest economies, the US and the euro area.[1] The focus on demand shocks is justified by the fact that they are probably highly relevant for the business cycle and they are also the ones where the spill-overs may be expected to be larger as well as the risk of common shocks (which complicate the estimates) more serious, compared for example to supply shocks, at least at business cycle frequency. Understanding spill-overs between the US and the euro area is obviously important for policy setting in the two economies, including for the question of whether policies should be coordinated (see Claessens et al. (2016)). At the same time, the usual small open economy assumptions are clearly not applicable.

In this paper we focus on a simple set of VAR models that include variables for both the euro area and the US, and possibly other relevant countries, where we identify *domestic* demand shocks using standard sign restrictions. We start from a simple specification and derive the associated spill-over elasticity, i.e. how much a domestic demand shock in the US (euro area) moves economic activity (proxied by industrial production) in the euro area (US). We then evaluate whether imposing additional plausible assumptions on the *geography of spill-overs*, which are also consistent with most open economy DSGE models, changes our view of the size and direction of spill-overs. In particular, the additional assumptions

[1] Giannone and Reichlin (2006) focus on the co-movement between the US and the euro area specifically.

or requirements are four. First, we restrict the impact effect on output to be larger in the spill-over sending economy than in the spill-over receiving country. This is an assumption shared by most models and which seems plausible when discussing spill-overs between large advanced countries (it may be different when considering spill-overs between advanced and emerging countries with more volatile business cycles). Second, we impose that output of the spill-over sending country as a share of global output should rise following a positive demand shock, which comes down restricting the domestic output reaction to be larger in magnitude than the effect on output in the rest of the world. Third, a novel restriction introduced in this paper is to add a restriction on close 'neighbours', or so-called "satellite economies", to the euro area and the US. In particular, we impose that a shock in one of the two large economies should have a significantly larger impact on countries that are close neighbours in terms of geography, trade and financial ties – these satellite economies act like the "miner's canary" for shocks happening in the large neighbouring economy. For example, a sudden contraction in Canada with no apparent domestic reason may signal that there is a negative shock in the United States and suggest that the shock is not a global one but rather US-specific. Finally, we confirm our set up with a "placebo test" in which we substitute the major economy with a small, closely linked open economy, and follow the same identification approach. The placebo test should show that the small open economy only has a small to insignificant impact on the large economy. Again, this is an assumption that is easily verified in DSGE models, especially the small open economy version that just assumes this to be the case (i.e., the small open economy has no impact on the large economy).

In the absence of knowing the 'true' magnitude of spill-overs between the US and the euro area, we validate our estimates by contrasting the contribution of the US and euro area demand shock in driving the global output decline following specific events such as the 2008 financial crisis, looking for a (much) larger initial contribution of US demand given that the global financial crisis was triggered there, and the euro area sovereign debt crisis.[2] More generally, the way in which the estimated results change when imposing the additional restrictions will provide us with a sense of whether imposing them are useful and changes our view of international spill-overs.

Several interesting results emerge from our analysis. First, our estimates point to much larger spill-overs of aggregate demand shocks across both sides of the Atlantic than documented by DSGE models. We find that more than 80 percent of reaction in US industrial

[2]We are also working at including these ex ante as narrative restrictions in the spirit of Antolín-Díaz and Rubio-Ramírez (2018).

production following a US aggregate demand shock is transmitted to euro area industrial production, while aggregate demand shocks in the euro area transmit for about 50 percent to their equivalent in the US. Second, imposing additional restrictions to better control for the country origin of the shock does not alter the spill-over estimates in a significant way, generally seen. However, we do find that spill-overs between the US and the euro area tend to become somewhat smaller, if anything, when imposing additional sign restrictions on the relative reactions. At the same time, they become larger during specific episodes that are well-known to be specific to either the US (such as the global financial crisis) or the euro area. Also, the uncertainty surrounding the estimates narrows as a result of imposing more restrictions in the identification. Finally, the placebo tests provide additional support for the choice of the restrictions used to identify aggregate demand shocks in the set of models employed in this paper.

The paper is organised as follows. Section 2 reviews the relevant literature. Section 3 presents the empirical model. Results are in Section 4. Section 5 contains some robustness analysis and validation of the results. Secttion 6 concludes.

2 Related literature

We relate to a strand of literature applying two-country DSGE models to the US and euro area, notably Lubik and Schorfheide (2005), de Walque and Wouters (2008), Banerjee et al. (2016) and Kollmann et al. (2016). The last of this paper is in particular a useful reference point for us as the authors estimate a three region DSGE model of the US, the euro area and the rest of the world. While the focus of Kollmann et al. is mainly to explain the post crisis slump in the euro area, it is of interest for us because it reports results of spill-over of shocks between the euro area and the US. Specifically, they show the effects of TFP and government purchase shocks, and we will compare the results of our identification in particular with the latter shocks. Dieppe et al. (2018) is a semi-structural general equilibrium model of the world economy also featuring the euro area, the US and other economies, and will also use it as a reference point to evaluate our results. Corsetti et al. (2014) also use VAR with sign restrictions imposed on relative variables (US vs. an aggregate of other advanced countries) and look at the international dimension of productivity and demand shocks in the US economy. For demand shocks, which are closer to our work, they find that US demand shocks lead to a dollar appreciation but have

limited effects on the trade balance. This literature is certainly interesting as a benchmark against which to evaluate our results, but we also argue that any substantial deviation from results in the DSGE literature is not necessarily to be seen as a problem for the empirical model, as it is well known that DSGE models have a hard time explaining international co-movement (see Justiniano and Preston (2010)).

Our paper is also related to a number of papers imposing sign restrictions on relative variables in SVAR models, for example Farrant and Peersman (2006), Peersman (2011), Enders et al. (2011), Bobeica and Jarociński (2017), Hanisch (2017) and Forbes et al. (2018). Other papers have used Global VAR (GVAR) models to understand international spill-overs, for example Georgiadis (2016). Finally, there are papers looking at spill-overs from a more methodological angle, such as Georgiadis (2017), who argues that it may be misleading to use bilateral models to understand spill-overs if the data are generated by a multilateral model, and the bias is stronger if direct bilateral spill-over channels are not dominant, and if the indirect channels through third countries are stronger. Montinari and Stracca (2016) look at the role of trade and financial integration in driving international spill-overs of business cycles, using both reduced form estimates and a small two country DSGE model.

In Table 1 we summarise the spill-over of demand shocks that can be derived from existing recent DSGE models of the euro area and the US. reports estimates of the spill-over of euro area or US specific demand shocks on the other economy.[3] Overall, the existing DSGE models point to very limited spill-overs of demand shocks. Spill-overs are somewhat larger in the semi-structural model of Dieppe et al. (2018), but this is not surprising since this model has been designed precisely to study international spill-overs and provide realistic spill-over estimates.

3 Empirical model

The empirical strategy goes as follows. First, we propose a relatively small-scale Bayesian two-country structural VAR model which uniquely separates out US and euro area aggregate demand shocks using sign restrictions, which we will refer to as the "benchmark model". In a second step, we further restrict this benchmark model in order to

[3]Gunter (2019) also estimates a DSGE model of the US and the euro area, but does not show impulse responses of demand shocks, which are our main focus here.

Table 1: Estimates of the *relative* peak-to-peak spill-over of a euro area or US demand shock on the activity variable

	Model description	**EA to US shock**	**US to EA shock**	**Type of demand shock**
Kollmann et al. (2016)	Estimated three-region (EA, US and ROW) DSGE	Close to zero (real GDP)	Close to zero (real GDP)	Government purchase shock
Lubik and Schorfheide (2005)	Estimated two-country DSGE of the US and the euro area	Around 0.05 (Output)	Close to zero (Output)	Government purchase shock
de Walque and Wouters (2008)	Estimated two country New Keynesian model of the euro area and the US with sticky local currency pricing		Around -0.1	Risk premium shock
Dieppe et al. (2018)	Calibrated semi-structural global model	0.36	0.25	Demand shock

arguably better control for the geographical origin of the aggregate demand shock, relying on additional sign restrictions drawn from the open-economy DSGE literature. This is to validate the empirical approach by testing whether these modifications alter the spill-over results in a significant way, i.e. whether the simple benchmark model can be assumed to reliably estimate spill-overs between the US and the euro area.

All model specifications will include the six following endogenous variables that are needed to disentangle US from euro area aggregate demand shocks: US industrial production, US CPI, euro area industrial production, euro area CPI, the bilateral nominal USD/EUR exchange rate and oil prices. Depending on the type of relative restriction we impose in addition, we add additional endogenous variables to the 6-variable model as outlined below. We use monthly data over the period January 1999 to July 2017. All endogenous variables are specified in log levels and we include three lags of the endogenous variables. The structural shocks in the VAR models are identified using sign restrictions, as outlined in Table 2. A Bayesian approach is used for estimation and inference, employing Normal-Wishart prior and posterior distributions for the reduced form VAR. A total of 1,000 'successful' draws from the posterior are used to construct the median and the confidence bounds.

Table 2: Sign restriction identification

		(1) **Benchmark VAR – no relative restrictions**		(2) **6 VAR – relative US-EA restriction**		(3) **7 VAR – rest of the world restriction**		(4) **8 VAR - satellite restriction**		(5) **9 VAR – all relative restrictions**	
		US	euro area	US	euro area	US	euro area	US	euro area	US	euro area
Panel A: no relative restrictions	US ind. production	≥ 0		≥ 0		≥ 0		≥ 0		≥ 0	
	US CPI	≥ 0		≥ 0		≥ 0		≥ 0		≥ 0	
	euro area ind. production		≥ 0		≥ 0		≥ 0		≥ 0		≥ 0
	euro area CPI		≥ 0		≥ 0		≥ 0		≥ 0		≥ 0
	USD/EUR	≤ 0	≥ 0	≤ 0	≥ 0	≤ 0	≥ 0	≤ 0	≥ 0	≤ 0	≥ 0
	oil price	≥ 0	≥ 0	≥ 0	≥ 0	≥ 0	≥ 0	≥ 0	≥ 0	≥ 0	≥ 0
Additional endogenous variables	*Canada ind. production*							x	x	x	x
	Sweden ind. production							x	x	x	x
	RoW ind. produc					x	x			x	x
Panel B: additional relative restrictions	US *minus* RoW ind. prod					≥ 0				≥ 0	
	euro area *minus* RoW ind. prod						≥ 0				≥ 0
	US *minus* euro area ind. prod			≥ 0	≤ 0					≥ 0	≤ 0
	Canada *minus* Sweden ind. prod							≥ 0	≤ 0	≥ 0	≤ 0

Notes: An 'x' denotes that a specific variable is included as an endogenous variable in the VAR model. An increase in the USD/EUR is an appreciation of the euro exchange rate.

3.1 The benchmark structural VAR model

Sign restrictions are used to uniquely separate out US and euro area aggregate demand shocks. In the 6-variable benchmark model, a positive US aggregate demand shock is assumed to increase US industrial production and CPI, lead to an appreciation of the US dollar against the euro and cause oil prices to rise. These restrictions are standard and consistent with most, if not all micro-founded structural models. To identify the euro area aggregate demand shock, a symmetric identification scheme is imposed for the euro area shock as shown in Panel A of Table 2. Key in separating out the US and euro area demand shock is imposing that both shocks affect the oil price similarly (i.e. with the same sign), while sending the bilateral exchange rate in the opposite direction. As the spill-overs between the different economies is of key interest to this paper, the responses of the euro area to the US shock are left unrestricted, and vice-versa. The restrictions are imposed for one year following the shock.

Figure 1 shows the estimated spill-overs of an aggregate demand shock originating in the US and the euro area, respectively, to the other large economy. The impulse response

functions are normalised to increase industrial production in the spill-over sending economy with 1 % on impact for ease of comparability, and the confidence bounds represent the 68th percentile interval around the median effect. The US aggregate demand shock is found to spill over almost entirely to the euro area, lifting euro area industrial production with about the same magnitude as domestic industrial production over the impulse response horizon. In comparison, the spill-overs of the aggregate euro area demand shock are somewhat smaller (while still large in absolute terms) with about 60% of the increase in euro area industrial production spilling over to the US economy. These estimated spill-over magnitudes of aggregate demand shock between the US and euro area - while being in line with other empirical studies for other types of shocks - are much larger than what is put forward by the DSGE literature, as argued earlier. The asymmetry between US and euro area is also consistent with previous studies, for example for monetary policy shocks.

3.2 Imposing additional relative restrictions

In order to counter possible criticism that the 6-variable model is not sufficiently rich in coverage or structure to properly control for common shocks, we augment the model with additional restrictions on the impulse response functions to arguably better account for the geographical origin of the shock. While this can be done in several ways, this paper focuses on empirically testing whether imposing restrictions on the *relative* magnitudes of the variable responses helps in better identifying country-specific shocks. Four different sets of relative restrictions are analysed. The restrictions are consistent with open economy DSGE models and therefore should be uncontroversial in our view, yet should potentially be informative to better pin down the geographical origin of the impulse. In this, we follow the intuition put forward by Corsetti et al. (2014) to restrict the relative responses of country-specific variables to better account for the origin of the shock.

Relative response of the US versus euro area. First, we explore the magnitude of aggregate demand spill-overs in a model that restricts the impact effect on industrial production to be larger in the spill-over sending economy than in the spill-over receiving country. Apart from this assumption, the set of sign restrictions remains unchanged from the benchmark VAR model, see the second column in Table 2. That is, an aggregate US demand shock is assumed to increase US industrial production and CPI, appreciate the

US dollar against the euro exchange rate, lead to higher oil prices and lift US industrial production more strongly than that in the euro area during the first month after the shock.[4] The relative variables are constructed as the difference in the absolute value of the loglevel response of industrial production in the US and the euro area, with the absolute value being taken in order to not take an ex-ante stance on the sign of the spill-over effects.

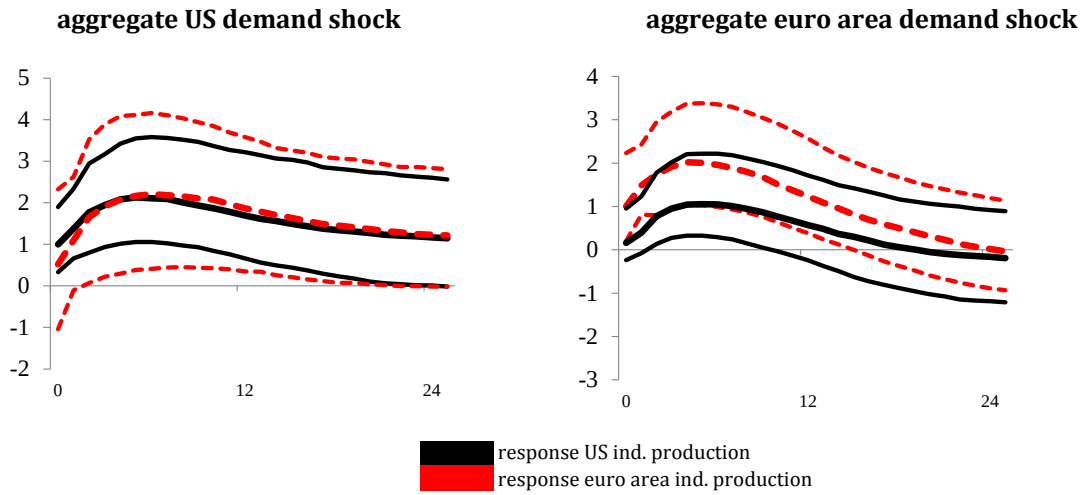
Relative response of the US and euro area versus the rest-of-the-world. A second relative restriction we test is imposing the impact effect on industrial production to be larger in the spill-over sending economy than in the rest of the world, as in Bobeica and Jarociński (2017) and Eickmeier and Kühnlenz (2018) among others. This restriction should better filter domestic shocks from a common global component through imposing that industrial production of the spill-over sending economy as a share of industrial production in the rest-of-the-world should increase on impact. A shock originating in another part of the world would do the opposite. In order to be able to impose this restriction, we construct a rest-of-the-world aggregate and add this as an additional endogenous variable to the model.[5] The sign restriction identification for this 7-variable VAR is given in the third column of Table 2.

Relative response of 'satellite' economies. Third, a novel idea presented in this paper is to add restrictions on the reaction of close 'neighbours' - or 'satellite economies' - following aggregate demand shocks in the US and the euro area. The idea is that a demand shock in one of the two large economies should have a significantly larger impact on the country which is a close neighbour in terms of geography, trade and financial ties. Should this is not be the case, then the shock is more likely to be a common one. For this, we need countries that have very close trade and financial links with the US and the euro area, which ideally are closely interlinked with one of the large economies but have weak ties with the other one. At the same time, the satellites should have similar economic structures that would make them broadly equally responsive to common shocks, such as countries with a similar GDP per capita. Based on these arguments, we select Sweden as the satellite economy for the euro area and Canada as the satellite for the US. As the table above shows, both satellite economies are indeed strongly tilted towards their large neighbour in terms of trade and financial linkages. Their GDP per capita is not too dissimilar and both

[4]In contrast to the sign restriction set in the benchmark 6-variable model, which is imposed for 12 months following the shocks, we choose to only impose the relative restriction on impact in order to not excessively constrain the magnitudes of the spill-overs.

[5]The rest of the world industrial production aggregate excludes the US and the euro area, covers 19 other advanced and emerging economies including China, and is constructed as a trade-weighted average

Figure 1: Aggregate demand spill-overs between the US and the euro area



Notes: impulse response functions are normalised to increase industrial production in the spillover-sending country with 1 % on impact, units are in percentages and horizon is in months

Table 3: Canada and Sweden's asymmetric ties with the US and euro area

	Exports to the euro area	Exports to the US	euro area financial assets	US financial assets	Real GDP per capita in PPP	Correlation world real GDP growth
Sweden	57,114	10,200	200,190	153,847	46,662	0.60
Canada	15,360	297,589	138,961	793,370	43,087	0.59

economies are equally strongly correlated with world real GDP growth. More specifically, Canada's international trade is about 15 times more titled towards the US than the euro area, and the opposite holds for Sweden for which the ratio is about 6. In the model, we add industrial production of both satellite economies as endogenous variables and restrict the aggregate US demand shock to have a stronger impact on industrial production in Canada than in Sweden on impact. Similarly, euro area demand shocks are assumed to affect Swedish industrial production more than Canadian industrial production on impact. Observe, however, that even when not restricting the relative strength of the responses of the satellite economies, the US demand shock significantly increases industrial production in Canada while having no impact on Sweden, while the opposite is true for euro area demand shocks, suggesting that this relative restriction therefore seems to be supported by the data. The rest of the sign restrictions remains unchanged relative to the benchmark model, see the fourth column of Table 2.

Imposing all relative restrictions. Finally, we estimate the magnitude of the demand spill-overs between the US and the euro area when jointly imposing all relative restrictions described above. This expands the model to include 9 endogenous variables. The sign restriction scheme for this model is given in the fifth column of Table 2.

4 Results

We summarise the results of the different structural VAR specifications using 'spill-over ratios', which measure the ratio between the maximum impact of industrial production in the spill-over sending economy and the maximum impact of the industrial production measure in the spill-over receiving economy, taken over the impulse response function horizon. Differently put, it measures the percentage share of the increase in domestic industrial production that spills over to the foreign economy. This ratio is generated for each successful sign restriction draw, allowing us to calculate the 68th percentile posterior ranges of the spill-over ratio that we can compare across the different model specifications in order to evaluate whether adding relative restrictions significantly alters the estimated magnitude of demand spill-overs as put forward by the benchmark model.

Figure 2 shows the estimated spill-over ratios of an aggregate US demand shocks to euro area industrial production (Panel A) and of an aggregate euro area demand shocks to US industrial production (Panel B) for the different versions of the structural VAR

models outlined above. Consistent with Figure 1, the spill-over ratios as estimated by the benchmark 6-variable model indicate that the increase in euro area industrial production following an aggregate US demand shock is of about the same magnitude than the rise in US industrial production, while about 60 percent of the aggregate euro area demand shock spills over to the US (see the first column in Panel A and B in Figure 2, respectively).

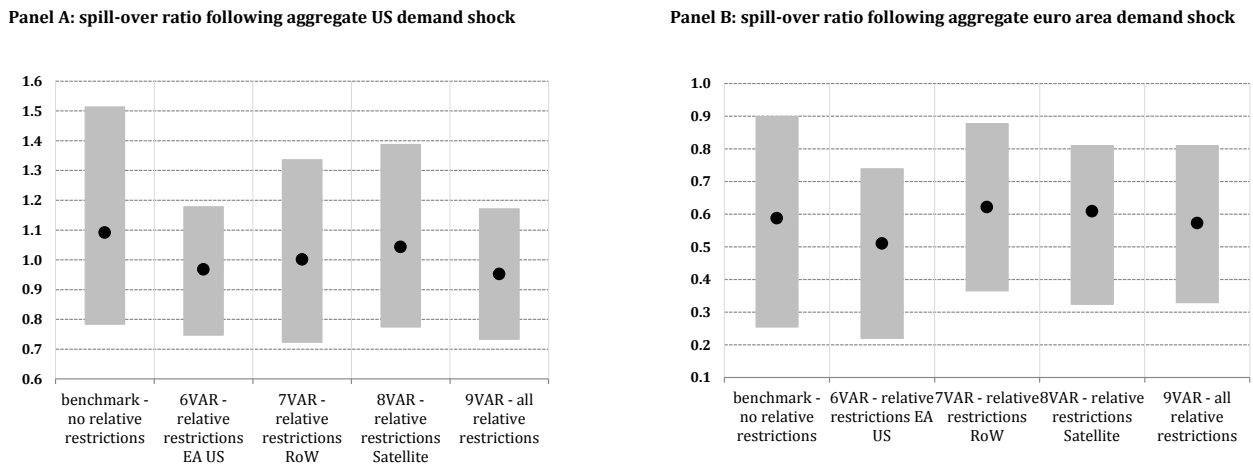
Interestingly, when imposing relative restrictions and adding more control variables to better account for the geographical origin of the aggregate demand shock, the spill-over ratios do not change in a significant way (see Figure 2). At the same time, the estimated confidence bounds become more narrow when imposing relative restrictions, indicating that imposing them helps in more accurately pinning down the range of possible spill-over effects. The estimated *median* spill-over ratios are nevertheless broadly similar across specifications, fluctuating around 100 percent for the US demand spill-over to the euro area and around 60 percent for the euro area demand spill-over to US industrial production. The benchmark 6-variable model therefore seems to perform fairly well in controlling for the country origin of the shock, despite its limited set of endogenous variables and imposed restrictions. In sum, even when imposing more stringent restrictions on the empirical model and bringing these closer in spirit to the assumptions often made in the DSGE literature, the estimated aggregate demand spill-overs remain much larger than the estimates put forward by theoretical models.

5 Validation of the model and empirical approach

5.1 Looking at selected historic country-specific events

It could be argued that the relative restrictions might add too little additional information to allow the spill-over ratios to deviate in a meaningful way from those estimated by the benchmark model. One way of testing whether the relative restrictions help in better controlling for the geographical origin of the shock - and the exercise above has informative value - is to look at specific historic events that clearly originated in one of the two large economies, and evaluate based on the historical decomposition whether the relative restrictions help in better identifying these events. This exercise is similar in spirit to the 'narrative' identification approach (see Antolín-Díaz and Rubio-Ramírez (2018)). We focus on three events that clearly originated in either the US or the euro area, likely spilled over

Figure 2: Spill-over ratios following US and euro area aggregate demand shocks



Notes: The bar charts represent the estimated median spill-over ratio (black dots), measured as the ratio between the maximum response of industrial production in the spill-over receiving country over the spill-over sending country over the impulse response horizon, together with the 68th percentile confidence bands (grey shaded areas). The model specifications are explained in more detail in Table 2.

significantly to the other large economy, and during which aggregate demand shocks played an important role: the 2001 US recession, the 2008 global financial crisis and the 2011 euro area sovereign debt crisis.

Figures 3-5 compare to what extent industrial production was driven by aggregate demand shocks in the euro area and the US, respectively, and how this changes when imposing the different types of relative restrictions as outlined above. For the 2001 US recession, the historical decomposition results show that when imposing relative restrictions, the relevance of US demand shocks in explaining the 2001 decline in US industrial production generally becomes larger. Also the spill-overs from negative US demand shocks to the euro area are estimated to become more pronounced, see Figure 3. At the same time, aggregate euro area demand shocks are estimated to have been more supportive for US and euro area industrial production over this period. Given that the 2001 recession was US specific, the results indicate that imposing the relative variable restrictions have information value for better tracking the origin of the shock. This is also the case for the 2008 global financial crisis that originated in the US, see Figure 4. Negative aggregate US demand shocks are estimated to become more important in dragging down US industrial production, while adverse euro area demand shocks become less dominant. Finally, imposing relative re-

strictions also helps in better capturing the 2011 euro area sovereign debt crisis event. Figure 6 shows that negative euro area demand shocks become much more prominent in explaining the fall in euro area industrial production at that time, in contrast to the estimated historical decomposition of the benchmark model without relative restrictions that only attributes a limited role to euro area demand shocks. Also the estimated spill-overs from euro area-specific shocks to US industrial production become larger. In contrast, US demand shocks are found to have been more supportive than what the model without relative restrictions would suggest. Overall, these results indicate that restricting the relative magnitudes of the responses has informational value in better controlling for the origin of the shock. During the US-specific events, the aggregate US demand shocks are found to become more dominant, while during the euro area-specific event, the euro area demand shocks gain in importance - as would be expected a priori.

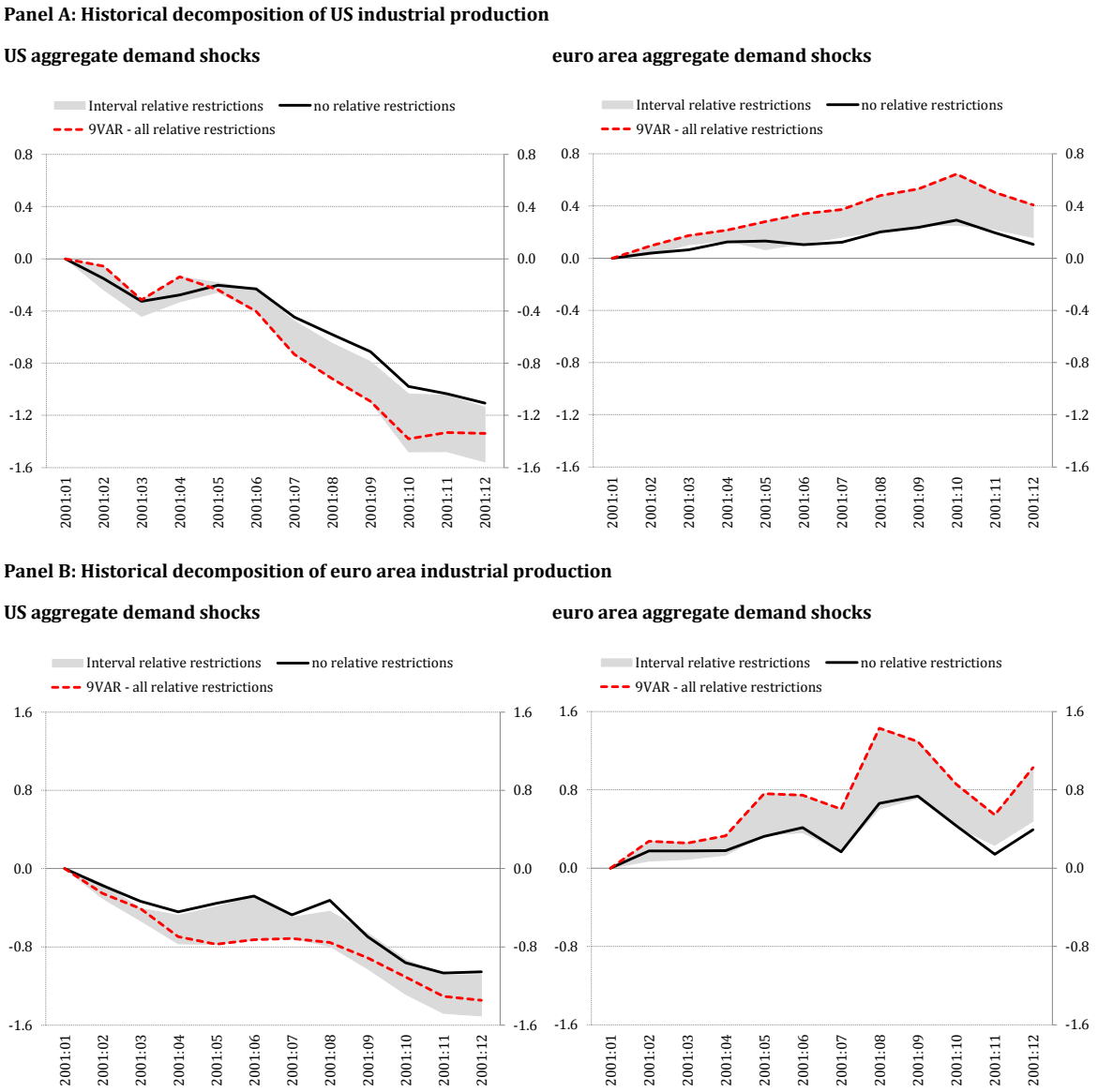
In sum, while imposing relative restrictions does not significantly alter the *average* estimated spill-overs of US and euro area demand shocks (cfr. section above), they provide valuable information in order to better uncover the geographical origin of the shock when dealing with two large, closely interlinked economies. This exercise therefore lends credence to the spill-over estimates put forward by the tested models, and the empirical approach pursued in this paper to evaluate whether a simple, small-scale structural VAR model is able to adequately capture spill-overs between the US and the euro area.

5.2 Placebo test

A second test to validate our empirical approach is to subject the models to a "placebo test". In comparison to the validation exercise above, this test is meant more to evaluate whether the model framework is able to separate shocks originating in large from those arising in smaller economies. It could be argued, for example, that the estimated spill-over ratios as estimated in this simple framework would be large for any set of countries - also between a small and large economy - for the reason that an insufficient amount of control variables is included. Finding large spill-overs between two countries that are not closely interlinked could occur in the case that both countries are tightly linked to another economy which is not properly accounted for in the model set-up (on this potential problem see Georgiadis (2017)).

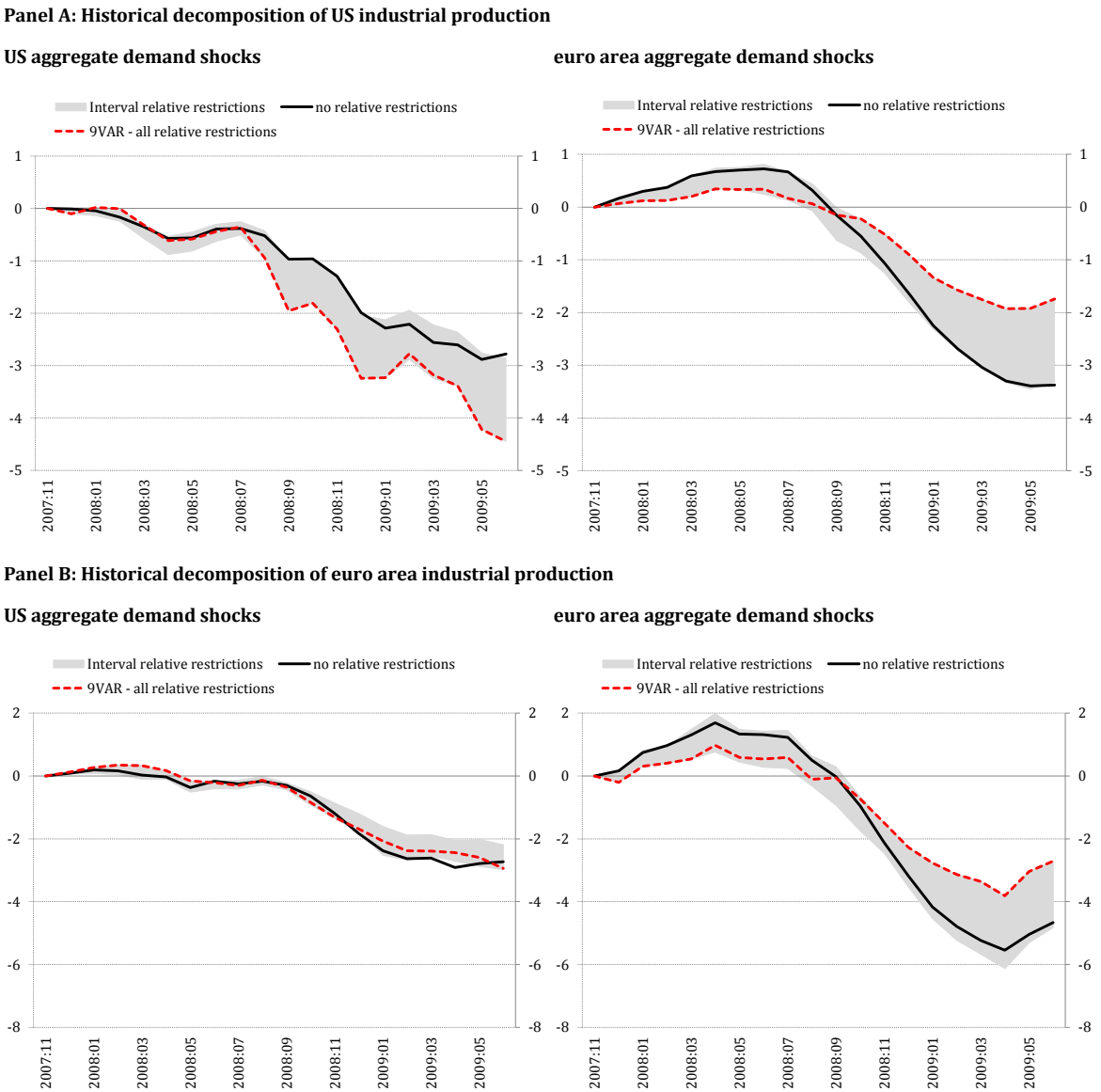
We test this in the following way. In all model specifications, we replace the euro area economy by one of its small, open member states, notably Finland. If the model framework

Figure 3: Comparison historical decomposition; 2001 US recession



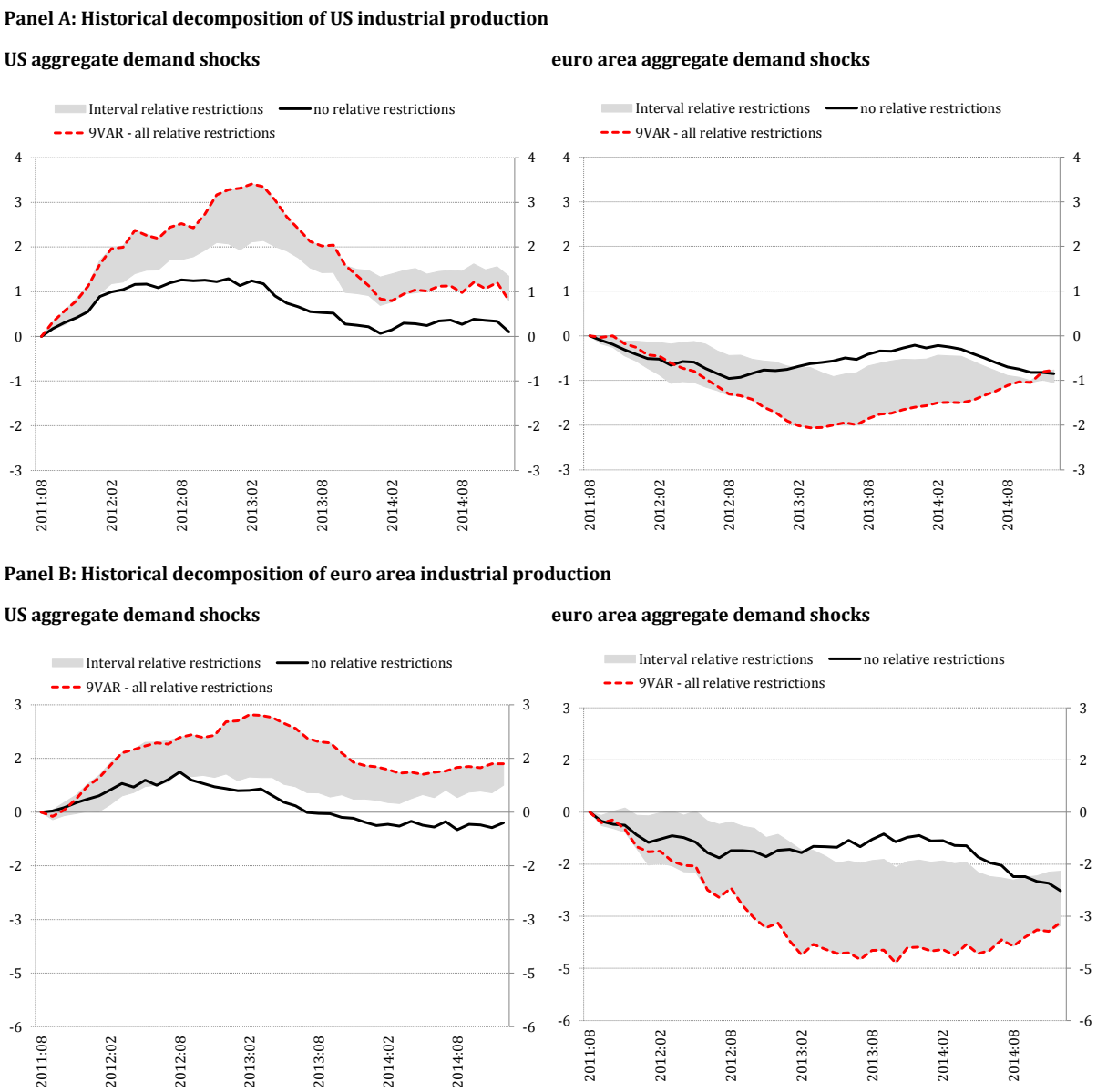
Notes: The chart compares the change in the estimated historical contributions of US and euro area aggregate demand shocks to US and euro area industrial production at a selected event for the different model specifications as outlined in Table 2. The historical contribution based on the benchmark model is represented by the black line, the contributions of the models that also restrict relative magnitudes by the grey interval, and the 9-variable VAR model that imposes all relative restrictions by the red dotted line.

Figure 4: Comparison historical decomposition; global financial crisis



Notes: The chart compares the change in the estimated historical contributions of US and euro area aggregate demand shocks to US and euro area industrial production at a selected event for the different model specifications as outlined in Table 2. The historical contribution based on the benchmark model is represented by the black line, the contributions of the models that also restrict relative magnitudes by the grey interval, and the 9-variable VAR model that imposes all relative restrictions by the red dotted line.

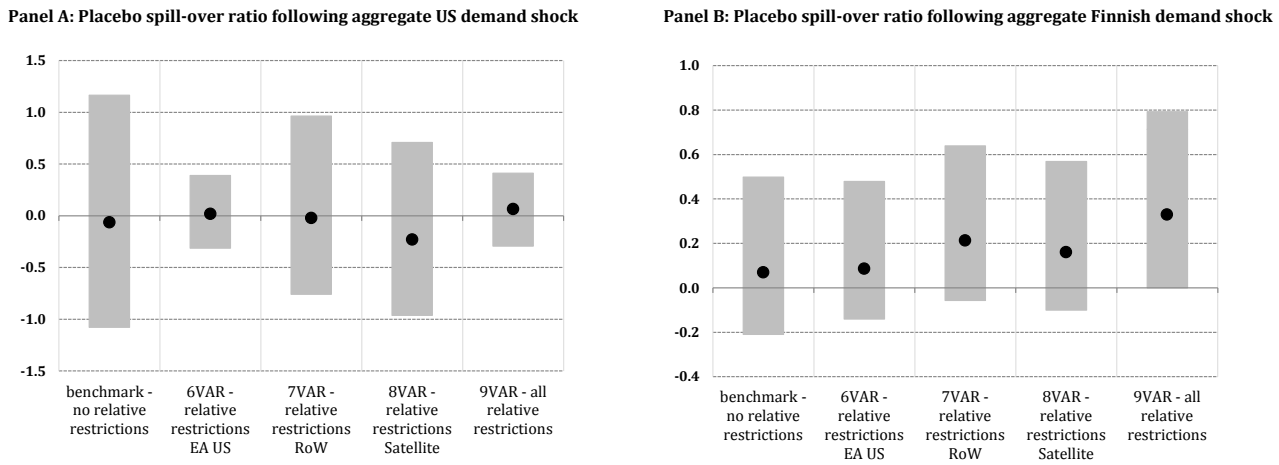
Figure 5: Comparison historical decomposition; euro area sovereign debt crisis



Notes: The chart compares the change in the estimated historical contributions of US and euro area aggregate demand shocks to US and euro area industrial production at a selected event for the different model specifications as outlined in Table 2. The historical contribution based on the benchmark model is represented by the black line, the contributions of the models that also restrict relative magnitudes by the grey interval, and the 9-variable VAR model that imposes all relative restrictions by the red dotted line.

is able to sufficiently account for the "true" inter-linkages, the results should show that the aggregate demand shocks originating in Finland do not significantly spill over to the US economy. On the choice of the placebo country, it seems natural to use a euro area member state that is small enough so that its country-specific shocks do not significantly affect US industrial production, yet is sufficiently open so that its country-specific developments are potentially confused with those of the euro area. In addition, the fact that Finland uses the euro exchange rate should make the placebo test more difficult to pass. In practical terms, the test is performed by re-estimating the models in the same set-up as outlined in Table 2, but then replacing euro area industrial production and consumer prices by their Finnish counterparts.

Figure 6: Placebo test: spill-over ratios following Finnish demand shock



Notes: The bar charts represent the estimated median spill-over ratio (black dots), measured as the ratio between the maximum response of industrial production in the spill-over receiving country over the spill-over sending country over the impulse response horizon, together with the 68th percentile confidence bands (grey shaded areas). The model specifications are explained in more detail in Table 2.

Figure 6 shows that all model specifications pass the placebo test. The aggregate demand shock in Finland does not significantly affect industrial production in the US, with the posterior estimated spill-over ranges including zero in all cases. Also the US demand shocks are found to not significantly spill over to Finnish industrial production, despite their large spill-overs to the euro area economy in the aggregate. This implies that the general model set-up is able to separate shocks originating in small countries versus those coming from - or being transmitted though - large and open economies. Again, this lends

support to the general set-up of the empirical framework employed in this paper to estimate the demand spill-overs between the US and the euro area.

6 Conclusions

Estimating the magnitude of demand spill-overs between large, highly interlinked advanced economies such as the US and the euro area is not straightforward: they share broadly similar economic structures and tend to co-move upon major shocks originating in each of the two economies because of their deep trade and financial integration with each other, and with the rest of the world. As is often done in the literature when evaluating spill-overs, a small open economy assumption cannot reasonably be assumed in this case. That is, for the US and the euro area, characterising one country as small enough to not influence the large country but open enough to be affected by it, and imposing this in the structure of the model to identify the country-specific shocks, seems implausible.

This paper proposes a simple, small-scale structural VAR model to estimate the magnitude of spill-overs of aggregate demand shocks between the US and the euro area using sign restrictions. The results indicate that about the full reaction of US industrial production following an aggregate US demand shock is transmitted to the euro area, whereas spill-overs from euro area aggregate demand shocks to US industrial production are in comparison more limited, yet still large and significant. This finding continues to hold when adding more sign restrictions to the structural VAR model in the form of relative restrictions to better control for the geographical origin of the shock. While these relative restrictions are informative, the estimated aggregate demand spill-overs between the US and the euro area remain little changed and large in magnitude. This stands in stark contrast to the estimates put forward by the DSGE literature, which typically finds spill-overs to be small, if significant at all. We validate our model choice and the empirical set-up, first, by showing that imposing the relative restrictions helps in uncovering the origin of the shock, and second, by showing that the models pass a 'Placebo test' in which they are expected not to confuse the demand spill-overs from a small open euro area member country for that from the euro area itself. These tests underpin the general set-up of the empirical framework employed and confirm that both US and euro area aggregate demand shocks spill over significantly to the other side of the Atlantic.

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